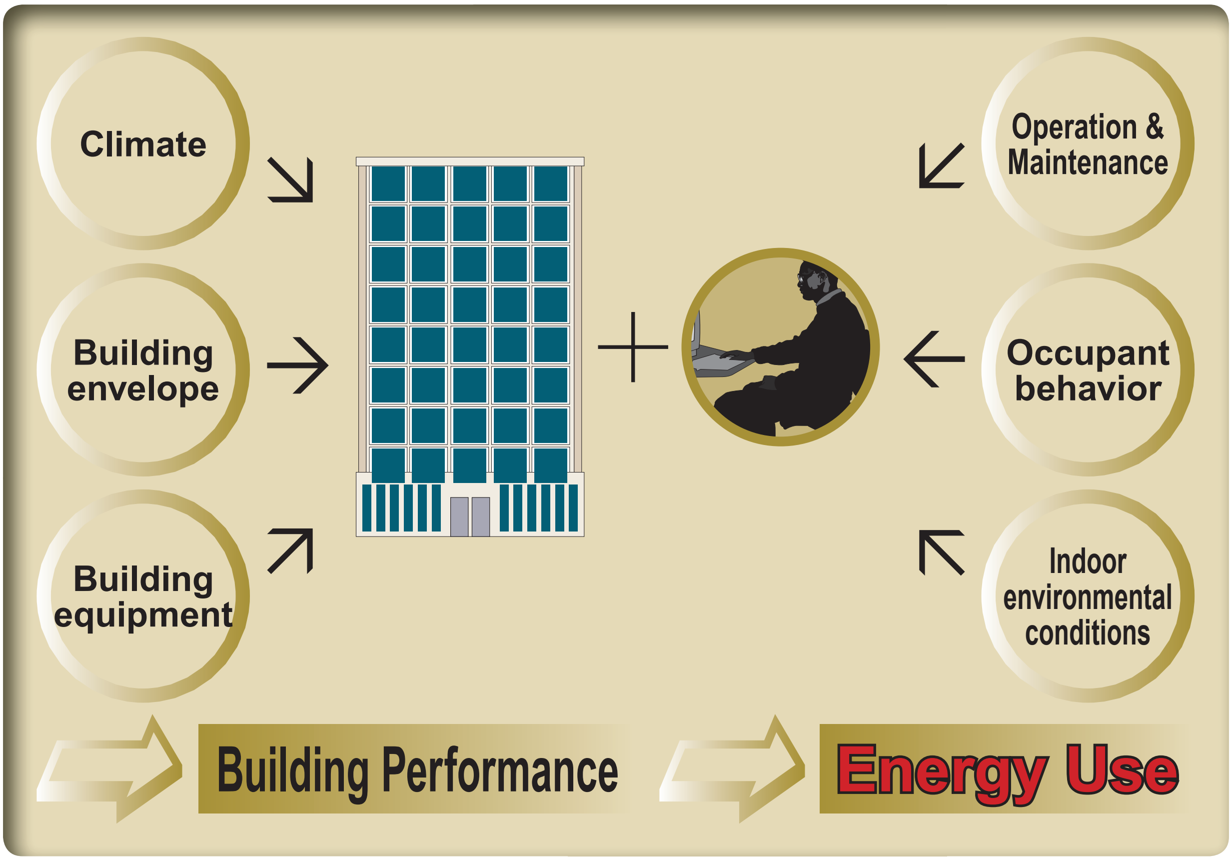
International Energy Agency
Programme on
Energy in Buildings and Communities

Total energy use in buildings

Analysis and evaluation methods



Final Report Annex 53

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Operating Agent: Emeritus Professor Hiroshi Yoshino
Graduate School of Engineering, Tohoku University
Sendai, Japan

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Preface

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organization for Economic Co-operation and Development (OECD) to implement an international energy program. A basic aim of the IEA is to foster international co-operation and to increase energy security through energy research, development and demonstration in the field of technology for energy efficiency and renewable energy sources (RD&D).

The Energy in Buildings and Communities Programme

The IEA co-ordinates research and development in a number of areas related to energy. The mission of the EBC - Energy in Buildings and Communities Programme, is to develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission and sustainable buildings and communities, through innovation and research. (Until March 2013, the EBC Programme was known as the Energy in Buildings and Community Systems Programme, ECBCS.)

The research and development strategies of the EBC Programme are derived from research drivers, national programs within IEA countries, and the IEA Future Buildings Forum Think Tank Workshops. The R&D strategies of EBC aim to exploit technological opportunities to save energy in the building sector, and to remove technical obstacles to market penetration of new energy efficiency technologies. The R&D strategies apply to residential, commercial, office buildings and community systems, and will impact the building industry in five focus areas of R&D activities:

- Integrated planning and building design
- Building energy systems
- Building envelope
- Community scale methods
- Real building energy use

The Executive Committee

Overall control of the program is maintained by an Executive Committee, which not only monitors existing projects but also identifies new strategic areas where collaborative effort may be beneficial. Actually the following projects have been initiated by the Executive Committee on Energy in Buildings and Communities (completed projects are identified 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: Inhabitant Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)

Annex 10: Building HEVAC Systems Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)
Annex 15: Energy Efficiency in Schools (*)
Annex 16: Building Energy Management Systems - User Interfaces and System Integration (*)
Annex 17: Building Energy Management Systems - Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilating Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Environmental Performance of Buildings (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multizone Air Flow Modelling (*)
Annex 24: Heat, Air and Moisture Transport in Insulated Envelope Parts (*)
Annex 25: Real Time HEVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Control Strategies for Hybrid Ventilation in New and Retrofitted Office Buildings (HybVent) (*)
Annex 36: Retrofitting in Educational Buildings - Energy Concept Adviser for Technical Retrofit Measures (*)
Annex 37: Low Exergy Systems for Heating and Cooling (*)
Annex 38: Solar Sustainable Housing (*)
Annex 39: High Performance Thermal Insulation (HiPTI) (*)
Annex 40: Commissioning of Building HVAC Systems for Improved Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-EN) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (COGEN-SIM) (*)
Annex 43: Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy-Efficient Future Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost Effective Commissioning of Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)

Annex 51: Energy Efficient Communities (*)
Annex 52: Towards Net Zero Energy Solar Buildings (*)
Annex 53: Total Energy Use in Buildings: Analysis & Evaluation Methods (*)
Annex 54: Analysis of Micro-Generation & Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance & Cost (RAP-RETRO)
Annex 56: Cost-Effective Energy & CO2 Emissions Optimization in Building Renovation
Annex 57: Evaluation of Embodied Energy & Carbon Dioxide Emissions for Building Construction
Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements
Annex 59: High Temperature Cooling and Low Temperature Heating in Buildings
Annex 60: New Generation Computational Tools for Building & Community Energy Systems Based on the Modelica & Functional Mockup Unit Standards
Annex 61: Development & Demonstration of Financial & Technical Concepts for Deep Energy Retrofits of Government / Public Buildings & Building Clusters
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-Insulation in Building Components and Systems
Annex 66: Definition and Simulation of Occupant Behavior in 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 (*)

(*) – Completed

As the program is based on a contract with the IEA, the projects are legally Annexes to their implementing agreements.

0. Abstract

Background

One of the most significant barriers for substantially improving the energy efficiency of buildings is the lack of knowledge about the factors determining the energy use. There is often a **significant discrepancy between the designed and real total energy use in buildings**. The reasons for this divergence are generally poorly understood and often have more to do with the role of human behavior than the building design. This discrepancy leads to misunderstanding and miscommunication between the parties involved in the topic of energy savings in buildings.

In fact, **building energy consumption is mainly influenced by six factors: (1) climate, (2) building envelope, (3) building services and energy systems, (4) building operation and maintenance, (5) occupant activities and behavior and (6) indoor environmental quality provided**. The latter three factors, related to human behavior, can have an influence as great as or greater than the former three. The user related aspects and behavior effects can be seen from the large spread in energy use for similar or identical buildings, but a distinction between the building-related and the user-related energy consumption cannot be established. **It is necessary to investigate all six factors together to understand building energy consumption data**. Detailed comparative analysis on building energy data, concerning the six factors mentioned above, would provide essential guidance to identify opportunities to save energy.

Key findings

1) **Developed uniform definitions of building energy use items, including energy boundary, conversion factors, building end use, and energy performance indicators**, which provide uniform language for building energy use comparison and benchmarking, as well as three different levels of data collection typologies, that can help in the analysis of energy performance and influencing factors.
2) **Presented international office building and residential building typologies in the form of case studies**. Basic information for twelve office case study buildings including category, data level, location, gross floor area, number of floors, construction years, air conditioning system, cooling and heating sources were outlined. Basic information for twelve residential case buildings including category, number of floors, floor area, construction year, and data level were described.
3) **Reviewed state-of-the-art online data collection systems and technologies, which included five online systems from Finland, China, Japan, Germany, and Spain**. These systems were analyzed to identify the main features and characteristics of various measurement strategies for online data collection and monitoring systems designed for building energy systems and indoor air quality.
4) **Highlighted suitable statistical models to apply for energy use analysis: recommendations about the proper application of the different models as a function of the goal of the analysis are offered**. The potential to use these statistical models is very high for both individual buildings and large building stocks, but it is important to clearly define the goal of the analysis in advance and the availability of suitable data where the influencing factors required for the analysis are collected.
5) **Developed and applied specific methodologies to analyze energy consumption in buildings, in order to get the maximum benefit from the use of simulation models**. These methodologies used specific concepts like sensitivity analysis, uncertainty analysis, and highlighted the importance of model calibration when analyzing an existing building.

0.1 Goal and objectives

The ultimate approach/goal of this annex was to better understand and strengthen knowledge regarding the robust prediction of total energy usage in buildings, thus enabling the assessment of energy-saving measures, policies and techniques. This annex studies how occupant behavior influences building energy consumption in order to bring occupant behavior into the building energy field so as to develop building energy research, practice, policy, etc. more closely aligned with the real world. The research was performed on two building types: residential buildings (detached houses and multi-family apartments) and office buildings (large scale high rise offices and small scale offices).

The main objectives of the annex were to develop and demonstrate the items shown below:

- Definitions of terms related to energy use and the influencing factors of building energy use
- An approach to describing occupant behavior quantitatively and to setting up a model for occupant behavior
- Database of energy use and influencing factors for existing typical buildings in different countries
- Methodologies and techniques for monitoring total energy use in buildings including hardware and software platforms
- A statistical model for national or regional building energy data including the influence of occupant behavior
- Methodologies to predict total energy use in buildings and to assess/evaluate the impacts of energy saving policies and techniques

0.2 Receptors and Benefits

The beneficiaries of the annex results and deliverables will be policy decision makers, property developers, energy contracting companies, financers and manufacturers, and designers of energy saving technology. The outcome of the annex contributes to the further improvement of instruments used for energy ranking and labeling. It will lead to a better understanding of these instruments among all building users, with the following benefits:

- Substantially improved understanding of effective energy data on real, long term performance of buildings and building systems in the context of evaluating and developing new energy saving measures and technologies;
- Knowledge about the main determining factors of total energy use in buildings and about the specific interactions between them in order to develop new energy saving strategies, technologies, methodologies, and policies;
- Opportunities for the development of energy saving technologies that take into consideration building related as well as user related energy use, and the prediction of both expected energy use in new and renovated buildings and the cost-benefit relationship of energy saving measures to increase implementation of energy contracting and management,
- Support for standardization and benchmarking of total energy use in buildings, so as to establish indicators for energy use in buildings that take occupant related factors into consideration, to achieve better acceptance of energy labeling systems among the public, and to improve the ability to communicate to the public the behavior that influences energy use in buildings; and,

- The findings of this work demonstrated the tremendous complexity that is related to user behavior. Consequent to this the IEA-EBC Executive Committee decided to further investigate upon Occupant Behavior in Annex 66.

0.3 Subtask structure and flow chart (see also Chapter 8)

0.3.1 Subtask structure

Subtask A: Definition and reporting
A1: State-of-the-art review;
A2: Definition of energy boundaries, building energy use terms (energy consumption for different end users, et al), and conversion factors; and
A3: Definition of influencing factors and energy performance indicators, and formatting the report.

Subtask B: Case Studies and Data Collection
B1: Collection, review and selection of case studies for analysis;
B2: Documentation and analysis of case studies and collected data;
B3: Reviewing and development of measurement techniques; and
B4: Development of a central database, which includes an information model (database).

Subtask C: Statistical Analysis
C1: Review of statistical studies and analyses;
C2: Development of statistical analyses for global, national, and regional total energy use in buildings;
C3: Development of statistical analysis for total energy use in individual buildings; and
C4: Development of prediction methods and identification of relevant factors of total energy use in buildings.

Subtask D: Energy Performance Evaluation
D1: Analysis of the effects of building and occupant related factors on building total energy use;
D2: Evaluation of existing and new performance indicators on total energy use considering the influencing factors; and
D3: Demonstration of knowledge and methods developed in this annex to predict the effect of energy saving technologies and occupant behavior and lifestyle on building energy use.

Task force: Occupant behavior
Understanding occupant behavior is essential to evaluating total energy use in buildings. As the subject is common through the subtasks, a task force group was established to assist the work of subtasks in the first year of the working phase

0.3.2 Flow chart and relationship between subtasks

Flow chart for showing the relationship between subtasks is indicated below. Deliverables are also included in the chart. The relationship between subtasks and reports is shown on the final page.

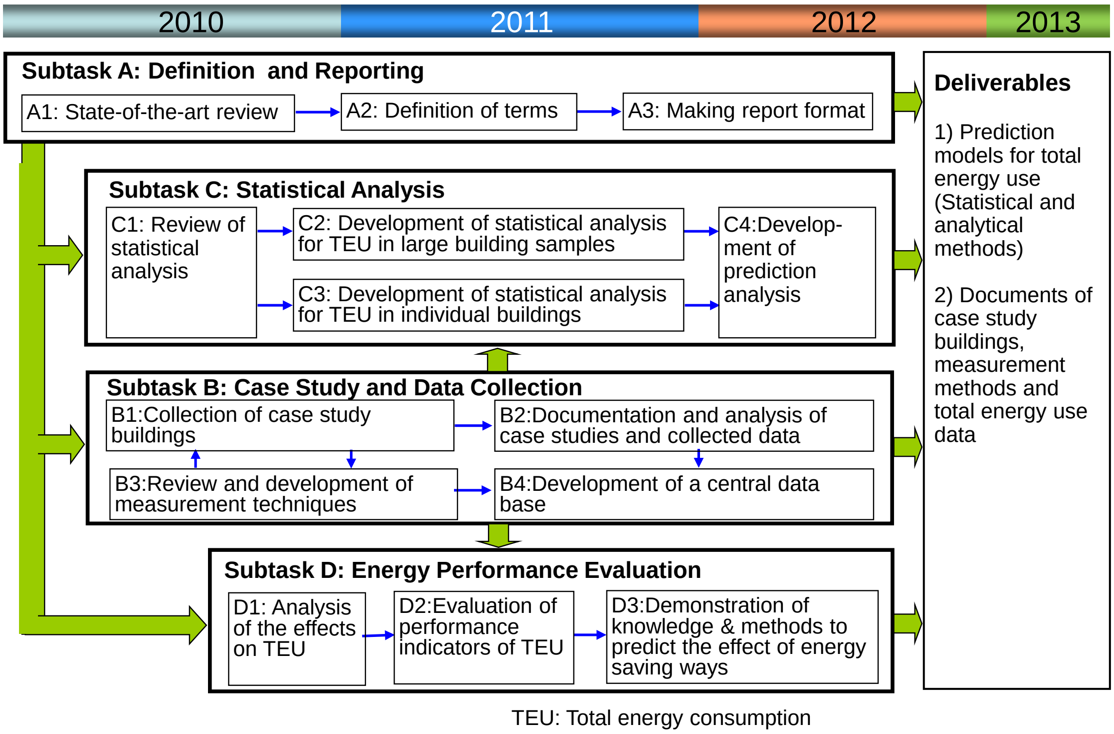


Figure 0.1. Flow chart of subtasks and deliverables for Annex 53.

1. Definition of terms relating to energy use and influencing factors

Summary

What is covered

Subtask A provides definitions of terms to describe total energy use in buildings. The work of the subtask resulted in the definition of energy boundaries for reporting whole building energy performance. The work also defined a variety of key building energy use terms to improve the comparability of datasets and expressions of building energy performance. The work also sets out three different typologies for the collection and reporting of energy use data and influencing factors: one for large scale datasets, a second for more detailed case studies, and a third, complex data typology for building simulations or detailed diagnostics. The conceptual framework for assessing factors that influence energy use in buildings involves considering them in six distinct categories. Most importantly, the subtask is dedicated to removing ambiguity in reporting energy use data that renders some work difficult if not impossible to interpret: understanding what is included when energy performance is expressed in "kWh/m^2".

Why is it important

There is often confusion about the relative performance of total energy use in buildings between different economies, and sometimes even within a country or region. Sometimes building performance is reported as "whole building delivered energy," including all end uses within the building, and other times certain loads, especially "plug loads" (appliances plugged into electric outlets in the building, but not part of the permanent building infrastructure), are excluded. As such, what energy use is being reported is unclear or unknowable and comparison of different datasets or even individual building case studies can be extremely difficult unless complete details are provided about what is and is not included.

Most critically for comparison, when energy use is expressed in kWh/m^2, the term must be clarified to note whether the building is all-electric (in which case the term is unambiguous), or what other fuels are included. It should also always be noted that the kWh (or MJ)/m^2 refers to the quantity of energy consumed in one year, and if the different forms of energy are combined into one common unit of kWh/m^2, that the electricity from fossil fuel reflects the conversion losses in electricity generation. In order to consistently measure and report impacts of energy efficiency policies, common and consistent definitions and a reporting format related to building energy use are needed to know if one is comparing "apples to apples" between different indicators.

Another significant barrier preventing the improvement of building energy efficiency is a lack of knowledge about the actual factors that determine total energy use. The well-known factors that have a direct influence include climate, building envelope, and building equipment, but energy use also depends on operation and maintenance, occupant behavior and indoor environmental conditions which have little existing research on their influences. In addition, different research purposes usually adopt different influencing factors for the analysis, and one common format cannot serve different needs. Therefore, it is helpful to develop different levels of data collection typologies for statistical analysis, case studies, and simulation/detailed diagnostics, which can allow better consistency of datasets between various projects and countries, and provide the reference to select influencing factors for the three kinds of analyses.

Key points learned

- It is essential that the ambiguity in the meaning of kWh/m^2 for a building whose energy needs are served by both electricity and fossil fuels be removed by reporting electricity and the different fuel forms separately. (For such buildings, it is often useful to also report results in kWh/m^2. In this case, conversion of all fuels to kWh needs to reflect a factor for fuel conversion losses in the generation of electricity; this (these) factor(s) need to be reported.)
- A set of definitions of key terms related to building energy use, such as building energy boundary, conversion factors, building end use, and energy performance indicators, have to be established, in order to provide a uniform language to allow better understanding, benchmarking and comparability of different energy use in buildings datasets. When we mention energy use, it is very important to point out what kind of energy boundary the energy use belongs to.
- It is clear that different reporting serves different needs, and one common format is not realistic. Through the Subtask, three different levels of data collection typologies have been defined for statistical analysis, case studies, and simulation/detailed diagnostics. These typologies allow better consistency of datasets between various projects and countries.

Conclusions

There is on-going related work in developing standard definitions and boundary conditions for whole building energy performance, including ISO TC 163 (developing an ISO Standard on “Energy performance of buildings - Presentation of real energy use of buildings”). It is challenging to come up with a single definition for total energy use in a building that fits all applications, but the Subtask A working group has developed uniform definitions of building energy use items, including energy boundary, conversion factors, building end use, and energy performance indicators, which provide a uniform language for building energy use comparison and benchmarking, as well as three different levels of data collection typologies, which can help analysis of energy performance and influencing factors.

1.1 **Purpose**

Annex 53 focuses on the factors that influence building energy use and total building energy use analysis and evaluation methods. Building energy consumption is mainly influenced by *the factors of six categories shown in Fig 6.1* (1) climate, (2) building envelope and other characteristics, (3) building equipment, (4) operation and maintenance, (5) occupant behavior and (6) indoor environmental conditions. In order to undertake a comprehensive analysis of these factors, it is important that clear and precise definitions of key terms are presented and agreed upon. It is a lack of clarity that has given rise to many misunderstandings—and at times basic errors—in the interpretation of building energy use data. The ambiguity of many terms has been a formidable obstacle for much of the research on energy use and factors influencing energy use in buildings. The main objective of Subtask A is to establish consistent definitions. This effort is of particular value in the context of Annex 53 that includes researchers from countries that in many cases follow different conventions and use different definitions from each other. The definitions described in this report provide a common platform toward achieving a complete understanding of energy use in buildings and an ability to more accurately compare building energy performance.

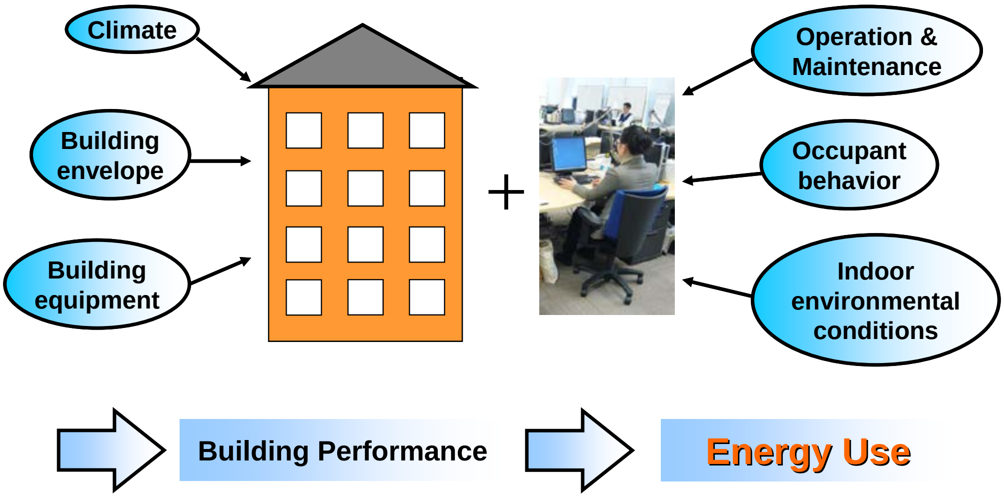


Figure 1.1. Six factors influencing total energy use in buildings.

1.2 Objectives and contents

The items defined in Subtask A are shown in Figure 1.2. In addition to the six influencing factors, the figure includes other items that will be defined, such as energy boundary, conversion factors, end uses, and energy performance indicators.

Annex 53 deals with office buildings and residential buildings. Office buildings are appropriately divided into large and small buildings, as the magnitude of the factors influencing energy use in these two building types are often different from one another. Residential buildings include single detached houses and multi-family apartment buildings. Key terms describing building characteristics will vary among the four building types.

The detail of the data collected and analyzed can vary significantly, depending on the number of buildings in a sample. For statistical analysis of large numbers of buildings, only a few parameters are collected while for case studies and simulations, data for a detailed analysis is desired and many more parameters are needed. There are cases in between, for which more data are available for large samples of buildings or less for individual case studies. Thus, three levels of definitions have been developed (simple, intermediate, and complex) in order to serve different analytical purposes.

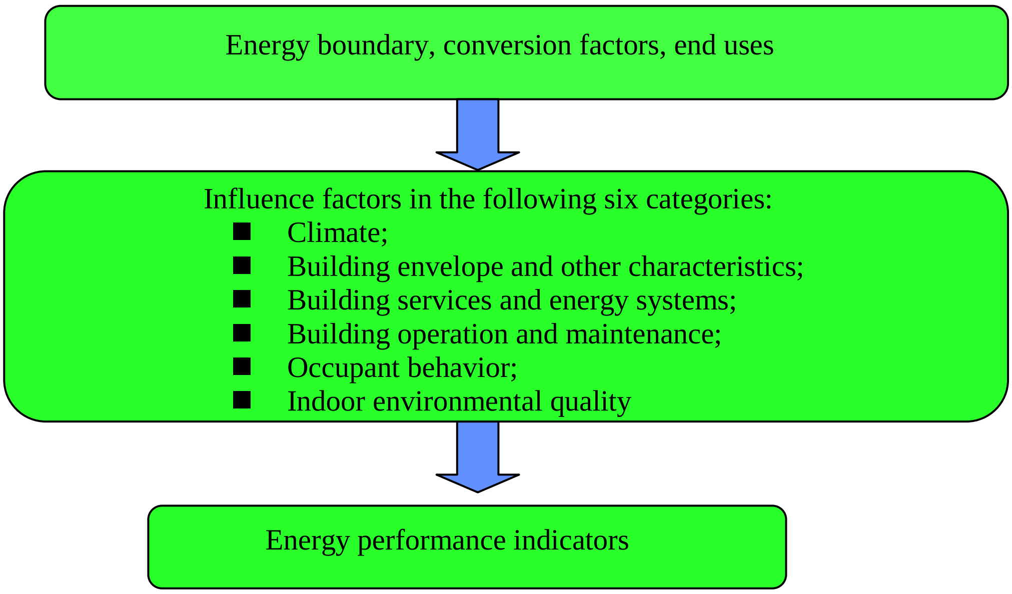


Figure 1.2. Items to define

Table 1.1 lists the typologies for the sets of definitions and categories that we believe to be useful in characterizing each of the factors that influence building energy use.

Each level serves for different research purposes and covers different categories of influencing factors. For example, as shown in the table, the Level A typology definitions include categories of influencing factors one through three and are used for the statistics with large scale datasets. Level B typology definitions serve for case studies. Moving from Level A to Level C increases the quantity and specificity of the data and generally goes from large samples of buildings (often thousands) to small numbers (typically one to the low tens). Levels B and C typically include data on indoor environment and occupant behavior, with the more extensive set of definitions in Level C. In addition to the six influencing factors, some indirect factors (i.e., family information, energy-related attitude of occupants, thermal environmental satisfaction of occupants, socio-economic data, etc.) could be taken into account in any of the three levels for the residential buildings, taken as the optional influencing factors for the analysis. Also, the frequency of measurements varies depending on the data level:

- Level A – Monthly (preferred) or annual (acceptable) energy consumption
- Level B – Daily (preferred) or monthly (acceptable) energy consumption
- Level C – Daily/hourly energy consumption

Table 1.1 Three level typology definitions

Typology	Energy use data	Categories of influencing factors			
		I	II	III	+(Optional)
Level A (Simple; for statistics with large scale datasets) Datasets with small number of data points per building	Annually or monthly	IF1. Climate IF2. Building envelope and other characteristics IF3. Building service and energy system	IF4. Building Operation		IF7. Indirect factors (for residential buildings)
Level B (Intermediate; for case studies)	Monthly or daily	Same categories as Level A, more detail	IF4. IF5. Indoor environmental quality	IF6. Occupant behavior	IF7. Indirect factors (for residential buildings)
Level C: (Complex; simulations or detailed diagnostics)	Daily or hourly				

Levels B and C include the same categories of data; although Level C has more parameters to describe each of the six factors plus optional factors. The acceptable minimum level depends on the goal and on the subject of the analysis, but typically:

- For analyses of very large samples of buildings, especially a statistical sample of buildings, Level A is acceptable.
- For analysis of a moderate number of buildings, Level B is a typical level. This is a minimal level for case studies on individual buildings or groups of buildings.
- For very detailed analysis of individual buildings, including detailed diagnostics, Level C is the appropriate level.

1.3 Definitions for basic items related to building energy use

It is first necessary to define several basic items, including the energy boundary, conversion factors, energy performance indicators, and end uses for office buildings and residential buildings.

Defining the energy boundary is the first step for energy analysis. Energy used to meet only the cooling load is different from the energy used in air conditioning systems for cooling, as the latter includes the energy lost in air conditioning systems. By defining the energy boundary, it is possible to compare the energy data within the same boundary.

Three energy regions with two boundaries are shown in Figure 1.3. This is best understood by considering these three regions from right to left.

Region III is called "Eb" represents the energy actually required (namely net energy need, or energy demand) within the building space for space heating, cooling, and domestic hot water in a building, considered from the energy demand side. This is the theoretical energy required to meet needs of the building occupants. It is difficult to estimate this number, as its value will depend on assumptions about thermal comfort, usage, and other factors. It is useful however for assessing the theoretical maximum potential for energy savings.

Region II encompasses all energy delivered to all the technical systems in the buildings, called "Et", usually considered from the energy supply side. Here the efficiencies of converting the delivered energy to meet the basic needs in Region III are specified. Also, the usage of the equipment, their capacity, and any energy-related characteristics of the equipment need to be described. These efficiencies are one of the six influencing factors of energy use in a building but are not part of the more aggregated description of whole building energy use.

"Ed" in Region I specifically aims to capture the energy use of space heating, cooling and hot water in district heating and cooling systems. The energy delivered to the central plant such as boilers, chillers or CHPs for district heating or cooling or DHW is Ed. The energy for running the auxiliary equipment such as pumps and fans in the plant is also considered in Ed.

In fact, the definition of energy boundary in this report is a combination of the work of ISO 16346, ISO 12655, and the system boundary definition for nearly net zero energy buildings. In the ISO 12655, three energy boundaries of Eb, Et, and Ed are defined, where Eb is the net heat and cold need of HAVC system and domestic hot water system, and Ed is the energy input for the district heating and cooling system. In ISO 16346 and the energy calculation framework and system boundaries for nearly net zero energy buildings, energy flow and energy balances among two system boundaries are defined.

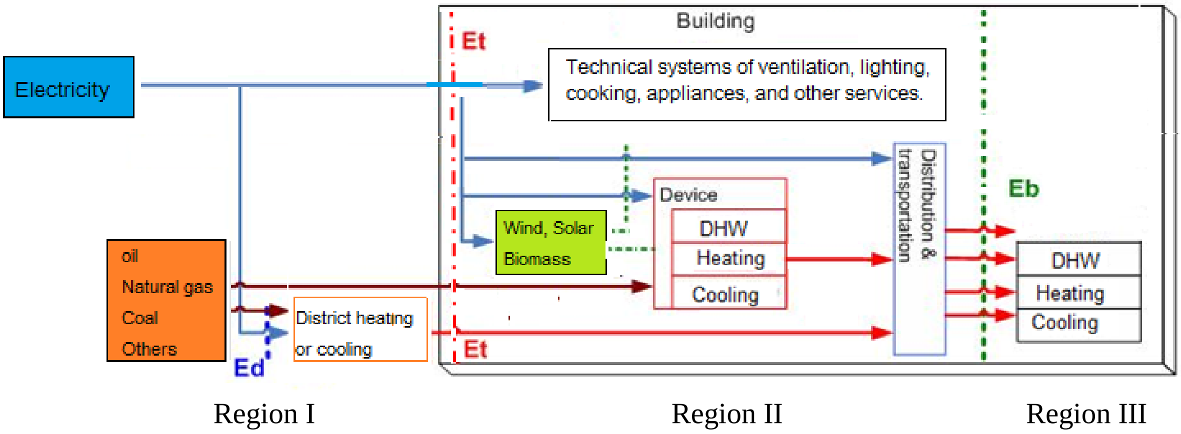


Figure 1.3 Energy boundaries

Converting electricity into a common unit (primary energy) will involve different factors depending on the source of the electricity, the conventions used in different countries, and the purpose for which the results will be used (e.g., as contributors to greenhouse gas emissions, for comparing buildings, as contributors to total energy use of a region or country).

It is thus not feasible or even desirable to have one system for converting electricity to primary energy. What is essential is that assumptions, conventions, and parameters used for this conversion are made explicit in research reports.

Table 1.2 lists the definition of end uses for residential buildings and office buildings. It is recommended that any end use data specify to which energy boundary this end use corresponds.

Table 1.2 End uses for residential buildings and office buildings

End Use	Ed	Et	Eb	Residential building	Office building
1) Energy for space heating	Energy delivered to the central plant for space heating	Energy delivered to the heating system of the building for space heating	Heat delivered into the building space	X	X
2) Energy for space cooling	Energy delivered to the central plant for space cooling	Energy delivered to the cooling system of the building for space cooling	Cooling energy delivered into the building space	X	X
3) Energy for ventilation	Not Applcable (N/A)	Energy for ventilation	N/A	X	X
4) Energy for lighting	N/A	Energy for lighting	N/A	X	X
5) Energy for domestic or office appliances	N/A	Energy for domestic/office appliances	N/A	X	X
6) Energy for domestic hot water	Energy delivered to the central plant for domestic hot water	Energy delivered to the heating system of the building for domestic hot water	Heat delivered to domestic hot water	X	N/A
7) Energy for other appliances	N/A	Energy for other appliances, such as elevators/escalators, security monitors, etc.		X	N/A
8) Energy for other appliances	N/A	Energy for other appliances, such as cooking, domestic hot water, elevators, security monitors, etc.		N/A	X

For the detailed definitions, please see Appendix I-1.

1.4 The definition of three level typologies for residential buildings

The main purpose of the definitions of three-level typologies for residential buildings is to define the influencing factors of energy use for residential buildings. Hence, as a first step, it is important to determine the influencing factors of each end use for residential buildings and what kinds of parameters should be used to describe and quantify these influencing factors. Great efforts have been made in Subtask A to realize this target of identifying and defining the influencing factors of energy use in residential buildings, which are as follows:

1) Reviewing the contents and analytical methodologies in some well-known national or regional investigations, such as Residential Energy Consumption Survey (RECS) in the U.S. The results provided references and enlightenments for the exploration of the important influencing factors of residential buildings and related parameters to describe these factors;
2) Reviewing all of the data in the case studies of residential buildings in Subtask B to determine what parameters are used in the analyses and diagnostics of these cases studies;
3) Reviewing all of the parameters in the statistical research collected in Subtask C to determine the kinds of parameters used in the statistical analyses of the effect of energy use in residential buildings; and
4) Reviewing the simulation models for residential buildings and the outcome from the simulations in Subtask D to collect the parameters used in the simulation models and those proven to affect energy use of residential buildings by simulation.

Based on these contributions, the influencing factors of each end use in residential buildings are identified, and these factors can be classified into the six categories listed in Figure 1.1. The tree diagrams (see Figure 1.3 and 1.4) show examples of the main factors influencing space cooling and ventilation in residential buildings, and the parameters used to define these influencing factors (The tree diagram for heating is very similar to that for space cooling). As shown in Figure 1.4, the influencing factors of space cooling include the climate, building envelope and other characteristics, building services and energy systems, building operations, occupant behavior, and indoor environment. The weather data with the HDD (heating degree day) and CDD (cooling degree day) can be used to quantify the climate and to analyze the influence of climate on space cooling energy use. The thermal performance of the envelope, airtightness, and floor areas are used to define the properties of building characteristics. The number of air conditioners and their performance parameters can be used to describe the influence of building appliances on space cooling energy use. Similarly, the schedule, control and set point of air conditioners, and the schedules and controls of window opening and shading are the key parameters to describe and quantify the building operation and occupant behavior. These parameters are used to analyze the influences of building operation and occupant behavior on space cooling energy use. Finally, thermal environment is also an important factor.

In the three level typologies definitions for residential buildings, all of the influencing factors of the end uses for residential buildings are classified into the six categories, and each level covers its corresponding categories (see Table 1.1). In addition, since single-family houses and apartment buildings have different energy use characteristics and influencing factors, the three level typologies definitions are developed for each kind of residential building. There are six sets of classifications that provide different definitions for single-family houses and apartment buildings for the three levels.

As clarified above, the simple level serves for the statistical analyses with large datasets. It therefore includes the smallest number of parameters. The intermediate level is used for case studies, and therefore there are more items defined in this level than the simple level. The complex level has the most comprehensive and most complicated item definitions, as is serves for simulation and detailed diagnosis. When statistical analyses, research for case studies, or simulations are conducted, some of or all of the items in the corresponding level can be selected and used in the analysis. For each level, all of the defined influencing factors and items are indicated as being of primary importance or secondary importance. The items with the primary importance have a larger influence on energy use or are the more basic factors in this kind of analysis, and hence they should be prioritized for analysis. In the complex level, the parameters needed for the simulation models or those which are embodied in the simulation tools are also indicated, which means that these parameters can be used in simulation and their values should be collected for simulations.

Tables 1.3 to Table 1.9 list the items defined in the three level typologies for residential buildings. For the detailed definitions, see Appendix I-2.

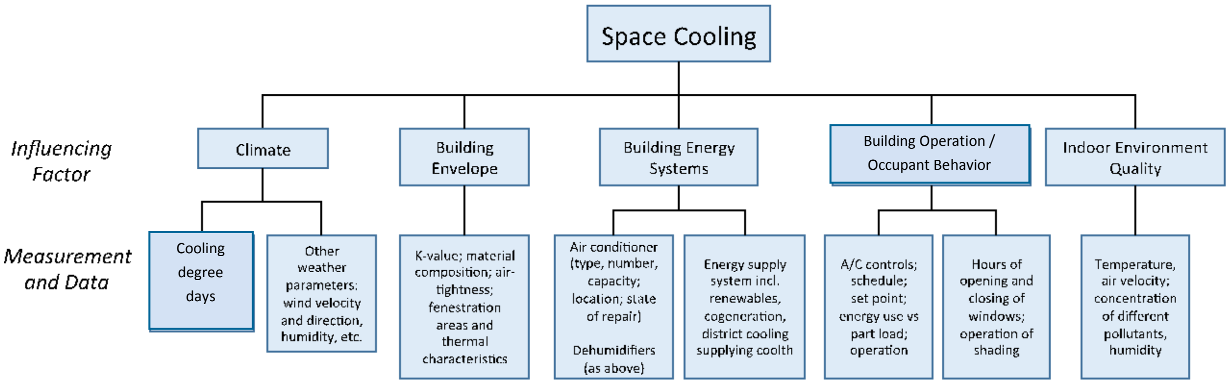


Figure 1.4 Influencing factors related to space cooling

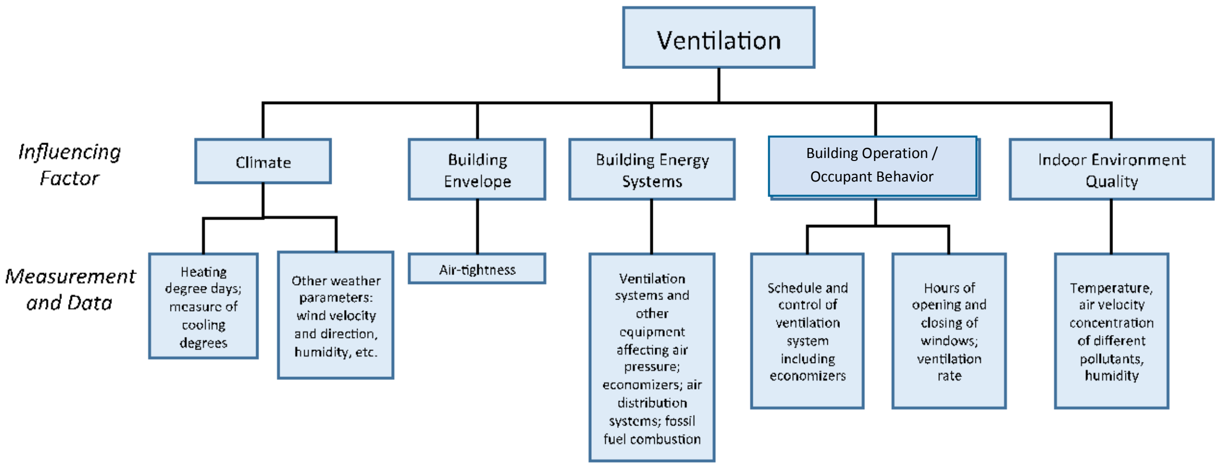


Figure 1.5 Categories of influencing factors related to ventilation

Table 1.3 Items defined in the category of climate

Name of parameter	Simple level	Intermediate level	Complex level
a) Degree day	Annual CDD and HDD	Yearly/monthly	Yearly/monthly
b) Weather data	Annual	Monthly/daily	Daily/hourly
c) Indoor temperature	N/A	Daily indoor temperature of typical days on weekdays/weekends in each season	Daily/hourly
d) Indoor humidity	N/A	The same as above, but for humidity rather than for temperature	Daily/hourly
E) Ventilation rate	N/A	N/A	Daily or daily mean value of typical days on weekdays/weekends in each season
F) Indoor illumination	N/A	N/A	The same as above but for lighting parameters (lumens per m^2, lux, lumens/watt)
G) Indoor pollutant concentrations (e.g., formaldehyde, benzene, CO_2, total volatile organic compounds (TVOC), etc.)	N/A	N/A	The same as above, but for individual pollutant concentrations

Table 1.4 Items defined in the category of whole building characteristics

Level	Simple level	Intermediate level	Complex level
Indices	a) Year built b) Number of floors c) Conditioned/ heated floor area d) Gross floor area e) Number of occupants f) Gross floor area of each unit g) Type of building h) Building activity areas i) Number of unit Note: Items f) - i) are just for apartment buildings.	a–i) The same as in the simple level j) Gross floor area occupied by each activity	a)-j) The same as in the intermediate level plus. k) Building geographical position l) Curtains/blinds m) Planar graph n) Ownership o) Orientation

Table 1.5 Items defined for building envelope

	Simple level	Intermediate level	Complex level
Indices	a) Material of the building envelope b) U-value c) Window to wall ratio	a– c) the same as in the simple level d) Comprehensive shading e) Coefficient of the windows f) Solar heat gain coefficient	a)-e) the same as in the intermediate level f) Material thickness g) Area of the components h) Shading system i) Shape factor j) Curtain/blinds k) Air tightness

Table 1.6 Items defined for building services and energy systems

		Simple level	Intermediate level	Complex level
Classification of end uses	Building technical systems: space heating, air conditioning, ventilation, domestic hot water	Centralized or decentralized	Classified by different types of heat and cold resources	List all the subsystems: such as water system, air system, etc. List all the appliances in each subsystem
	(1) Lighting (2) Cooking (3) Domestic appliances (4) Others	Each category: further classified by different appliances types	Each category: further classified by different appliances types	Each category: further classified by different appliances types
Performance		a) Fuel type, b) Total power c) Capacities of heating, cooling and hot water supply	a)-c) the same as in the simple level d) Number of each type of the appliances e) A few other important parameters	a)-d) The same as in the intermediate level e) Detailed performance parameters for each type of appliances, such as the pump lift, input air/water volume for fan and pump, etc.

Table 1.7 Building operation and human behavior

	Items	Simple level	Intermediate level	Complex level
Appliances	Space and time mode	Full/part space, full/part time	Full/part space, full/part time	Full/part space
	Schedule	Number of hours/weeks	1) # of weeks used in summer and winter; when used, # of hours at night/daytime on weekday/weekend, separately. 2) Number of times used on weekday/weekend; minutes per use. Portion of appliances running. 3) Range of running hours	Different subschemas for each kind of appliances in each subsystem of each end use.
	Set point	N/A	a) 1) Set point of AC and space heating; 2) Range of set points; 3) If possible, indicate set points when occupied and unoccupied. b) Set point of ventilation: power level used c) Set point of DHW: temperature at which hot water is maintained.	Different subschemas for each kind of appliances in each subsystem of each end use.
	Control	N/A		Different subschemas for each kind of appliances in each subsystem of each end use.
Occupancy	Space and time mode	N/A	Full/part space, full/part time	Full/part space
	Schedule	N/A	Fraction of the nominal occupancy (value between 0 and 1) for each hour of weekday/weekend.	Different subschemas
Opening windows; Shading and curtains	Schedule	N/A	1) Times of use per day and minutes per use; 2) Hours open during day/night and week/weekend.	Different subschemas
	Control	N/A	N/A	Different subschemas

Table 1.8 Input into energy performance indicators

	Simple level	Intermediate level	Complex level
Step 1: Energy carrier	Monthly (preferred) or annual (acceptable)	Daily or monthly	Hourly or monthly plus daily for typical weeks in each season
Step 2: Aggregation of energy			
Step 3: Factors relating to energy performance indicators			

Table 1.9 Items defined for social and economic category

	Simple level	Intermediate level	Complex level
Indices	a) Family-related factors b) Energy- related attitude of occupants c) Thermal environmental-related attitude of occupants	The same as in the simple level	The same as in the simple level

1.5 The definition of the three level typologies for office buildings

The typologies and influencing factors for office buildings are similar to those for residential buildings, although the relative importance of the influencing factors is often very different for the two building types. For example, the influencing factors of climate, building envelope and other characteristics, indoor environment, and the associated measurement and data are similar for office buildings and residential buildings. Heating, cooling, and ventilation equipment are very different for residential and commercial buildings, as there are usually central systems and these systems are more complex for office buildings. However, both central systems and individual systems need definition for both residential buildings and office buildings and at that level the influencing factors such as associated measurement and data are discussed—e.g., for "performance, efficiency", the parameters for the two building types are very similar. As for building operation and human behavior, the definitions for occupant behavior are generally the same for the two kinds of buildings, while office buildings still need the definition of building managers' control of service systems. As a result, the discussion for residential buildings above is generally applicable for commercial buildings, except for some characteristics specific to office buildings.

More detailed definitions of the terms for office buildings are provided in Appendix I-3.

1.6 References

[1] ISO 12655 Energy performance of buildings, *Presentation of real energy use of buildings*

[2] ISO 16343 Energy performance of buildings, *Methods for expressing energy performance and for energy certification of buildings*

[3] ISO 16346 Energy performance of buildings, *Assessment of overall energy performance*

[4] ISO TR 16344, Energy Performance of Buildings, *Definitions and general procedures for energy performance rating and certification — Terms, definitions and symbols*

[5] ISO/Draft International Standard 16346: *Energy performance of buildings - Assessment of overall* energy performance

[6] Jarek Kurnitski, Francis Allard, Derrick Braham, et al. How to define nearly net zero energy buildings nZEB. REHVA Journal. 2011, May, 6-12

[7] M.D. Lyberg. *Source Book for Energy Auditors*. ECBCS. Annex XI. Energy Auditing, International Energy Agency, 1987, 4.

[8] K. Engelund Thomsen, K.B. Wittchen, O.M. Jensen, S. Aggerholm, Danish Building Research Institute, SBi. *Applying the EPBD to improve the Energy Performance Requirements to Existing Buildings – ENPER-EXIST,* Final report of WP3, Building stock knowledge. 2007, 6.

[9] Alan Meier, et al. *Indicators of energy efficiency in cold climate buildings.* Results from a BCS Expert Working Group, 1999, 2.

[10] Final report of IEA-ECBCS Annex XV, *Energy Efficiency in Schools*. International Energy Agency, 1991, 7.

[11] Commercial Buildings Energy Consumption Survey in U.S.A. http://www.eia.doe.gov/emeu/cbecs/

[12] Itron, Inc. California Commercial End-Use Survey, *Consultant Report. The California Energy Commission,* March 2006

[13] Itron, Inc. California Commercial End-Use Survey, *Appendices A-J. Consultant Report. The California Energy Commission,* March 2006

[14] Residential Energy Consumption Survey in U.S.A. http://www.eia.gov/consumption/residential/

[15] Survey in U.S.A. http://www.eia.gov/consumption/residential/

Appendix Document list of definitions
Appendix I-1: Definitions for basic items related to building energy use: Energy boundary
Appendix I-2: Three level data typologies for residential buildings
Appendix I-3: Three level data typologies for office buildings

2. Definitions of energy-related occupant behavior and modeling

Summary

What is covered

Energy use in residential and office buildings is influenced by the behavior of occupants in various ways. In order to achieve better understanding of total energy use in buildings, the identification of the relevant driving factors of energy-related occupant behavior and a quantitative approach to modeling energy-related occupant behavior and energy use are required. Energy-related occupant behavior, as meant here, refers to observable actions or reactions of a person in response to external or internal stimuli, or actions or reactions of a person to adapt to ambient environmental conditions. These actions may be triggered by various driving forces. These driving forces of behavior have been identified. Quantitative modeling approaches for describing energy-related occupant behavior and energy use were also investigated.

Why is it important

To realistically predict total energy use in buildings it is necessary to better understand how occupant behavior influences building energy consumption. The development of an approach to describe occupant behavior and factors influencing this behavior is needed to achieve this objective. Beyond the calculation of energy consumption, models of occupant behavior and energy use are assumed to have several practical implications: the match or mismatch between building operation and occupant behavior, occupant behavior as a basis for building optimization, occupant behavior as a basis for interventions (e.g. supplying information on control actions and energy use in relation to occupant behavior), etc.

Key points learned

The influence of occupant behavior on energy use in buildings has been investigated in various domains: natural sciences and social sciences as well as economics. The literature review resulted in an overview and classification of driving forces that may trigger energy-related occupant behavior. The various classes can be distinguished into biological, psychological, and social contexts, time, building/installation properties, and physical environment. Generally, the two purposes for modeling occupant behavior are (1) to understand driving forces for the behavior itself, and (2) to reveal the relationship between energy demand and usage, as well as the driving forces for variations. Within the framework of this Annex, the focus is on the second purpose. The different reasons for modeling occupant behavior with respect to total energy use in buildings are design (conceptual, preliminary, and final), commissioning (initial and ongoing), and operation (control). Based on the aforementioned reasons, model types for the various purposes are defined. The selection of a model type is strongly dependent on the number of buildings, the user profile, and the time scale. The different model types which are discussed here are psychological models, average value models, deterministic models, probabilistic models, and agent based models combined with action based models.

Conclusions

Various driving forces of occupant behavior have a significant influence on energy use. These driving forces can provide a quantitative understanding and allow modeling of energy-related occupant behavior and energy use. However, knowledge of some types of energy-related behavior and

corresponding driving forces along with interactions between driving forces is limited and needs further research. Also, future work is needed to validate existing models.

2.1 Introduction

The physical characteristics related to the energy consumption of a building, such as the building envelope, building installations and climate are well understood. However, in practice there is often a significant discrepancy between a building's designed and real total energy use.

The comparison of heating energy use for identical houses showed that households using the most heating energy used three times more heating energy than households using the least. For electricity use, an even larger variation was found: households using the most electricity used five times more than households using the least. Such variations in energy use were shown to be due to the occupant behavior.

Energy-related occupant behavior, as defined in this annex, is related to building control actions (in order to control the indoor environmental quality) as well as household or other activities. With respect to the energy-related issues of this report, the term 'behavior' is meant as the following: observable actions or reactions of a person in response to external or internal stimuli, or actions or reactions of a person to adapt to ambient environmental conditions such as temperature or indoor air quality or sunlight. In this definition, attitudes and motivations of a person which lead to a specific action are not included. With respect to the complexity of this issue, besides the models dealing with the simulation of energy performance, some psychological models are presented, which show different approaches to explain behavior as a result of decisions, attitudes and habits. Different energy-related behavior patterns based on different environmental attitudes may play a role in the context of decision making concerning technical building systems or intervention strategies for households.

These actions and activities may be driven by various factors. The influence of occupant behavior on energy use in buildings has been investigated in various domains: natural sciences and social sciences as well as economics. Many investigations in the natural science literature focus on (statistical) relations between energy-related behavior and mainly physical factors influencing this behavior, such as outdoor temperature, indoor temperature and solar radiation, see e.g. Refs. [1], [2]. (Figure 2.1)

However, there is no well-defined relation between physical parameters and actions of control, e.g. outdoor temperature and window opening. In reality, the occupant decides to open or close a window. This decision is based on a number of influencing factors that can be divided into physical, biological and psychological factors. (Figure *2.2*)

Figure 2.1 Occupant behavior related to physical factors.

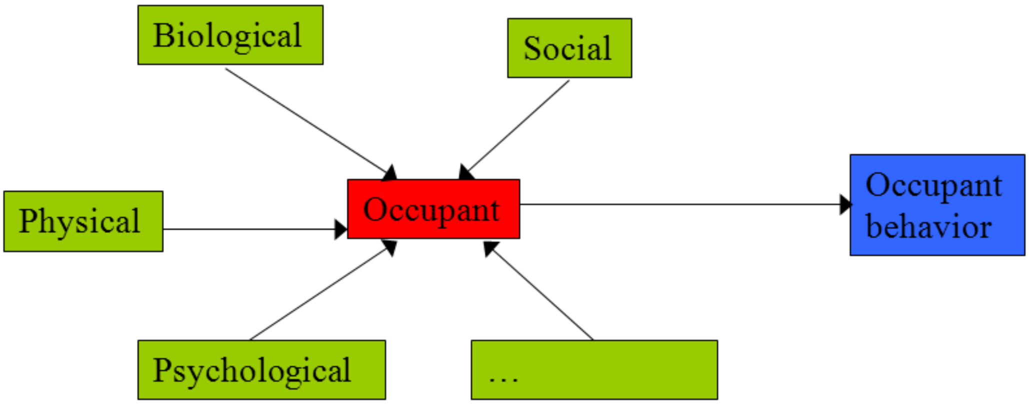


Figure 2.2 *Factors influencing occupant behavior*

Driving forces categories mentioned above have been identified based on a literature review and are discussed in more detail in Volume II.1 of Annex 53 "*Driving forces of energy-related behavior in residential buildings*" and Volume II.3 of Annex 53 "*Definition of occupant behavior in office buildings*" .
Quantitative modeling approaches for describing energy-related occupant behavior and energy use are discussed in Volume II.2 of Annex 53 "*Total energy use in residential buildings – the modeling of occupant behavior*".
An overview of the contents of these volumes is provided in the following sections.

2.2 Definitions of residential energy-related occupant behavior and driving forces

The complex relation between occupants and their environment is displayed in Figure 2.3. This scheme is based on the presence of the occupant at a specific time at a specific location having access to specific building controls. The occupant experiences a specific physical environment due to location, biological and psychological states and interaction with their environment.

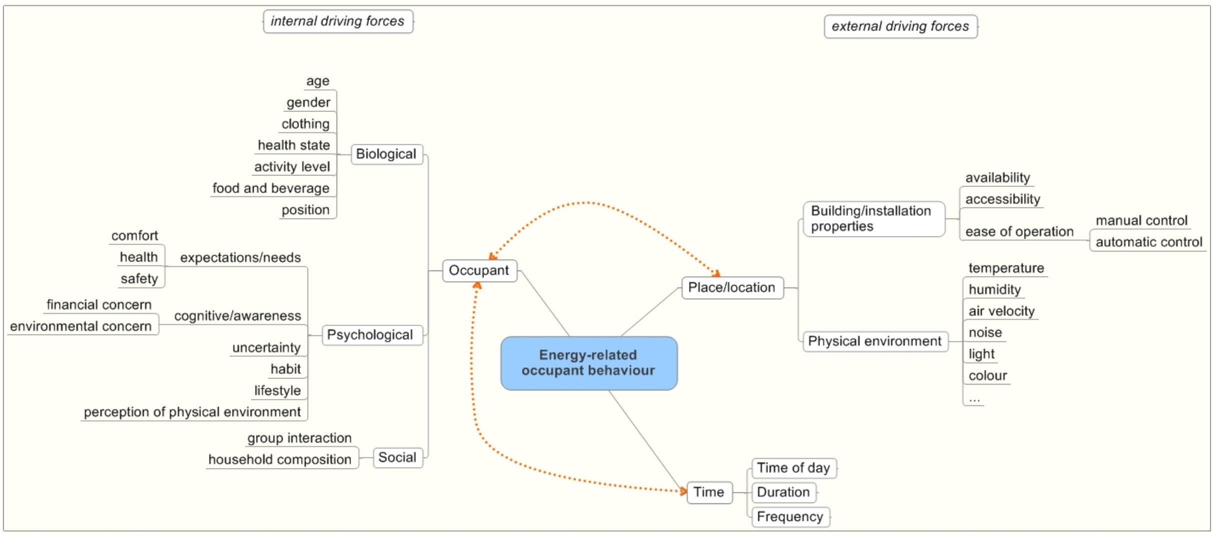


Figure 2.3 Driving forces of energy-related occupant behavior

Information on occupant presence and activities may be obtained from time-use surveys. The interaction between people and control systems of buildings and installations results from a combination of influencing parameters, from now on referred to as driving forces. These driving forces can be regarded as *internal* and *external* driving forces (see e.g. Refs. [3] and [4]). Another discussion on the relationship between humans, buildings and installations is given in Ref. [5]. The various research fields have different foci or requirements for occupant behavior. In social or physiological sciences, the focus is on how occupant behavior is formed and how behavior can be regulated. In natural (building) science more attention is paid to the quantitative description of occupant behavior based on physical (*external*) parameters.

The first three types of driving forces of energy-related behavior are *internal* driving forces (*biological, psychological, and social*) and are depicted on the left-hand side of Figure 2.3. These are investigated in the domain of social sciences, economic sciences and biology. The *external* driving forces depicted at the right-hand side of Figure 2.3 (*building/installation properties, physical environment, and time*) are investigated in natural (building) science.

There is a strong interaction between biological and psychological aspects, resulting in disciplines such as biopsychology or psychophysiology. Furthermore, a model exists that addresses health and considers biological, psychological, and social elements as a bio-psychosocial entity. Thus, it is difficult to differentiate between these driving forces.

Biological: Age, gender, health situation, clothing, activity level, eating and drinking habits are examples of driving forces within the biological context.

Psychological: Occupants tend to satisfy their needs concerning thermal comfort, visual comfort, acoustical comfort, health, safety, etc. Furthermore, occupants have certain expectations for indoor environmental quality.

Social: Social driving forces refer to the interaction between occupants. For residential buildings, this depends on the household composition.

Building/installation properties: Insulation of buildings, orientation of façades, heating system type, thermostat type (e.g. manual or programmable), etc. are examples of building/installation properties.

Physical environment: Temperature, humidity, air velocity, noise, illumination, and indoor air quality are examples of important driving forces of the physical environment.

Time: Examples of this type of driving force that affect energy-related occupant behavior are season of the year, week or weekend day, and time of the day.

Energy-related occupant behavior, influenced by these driving forces, can be usage-related, purchase-related, and maintenance-related. The types of energy-related occupant behavior concern actions related to:

Heating:
The activities of occupants are more important within buildings with lower energy consumption. Studies have shown that user behavior and lifestyle can affect energy consumption by up to a factor of three, see Ref. [6]. Occupant behavior related to heating concerns the temperature set point, number of heated rooms, heating duration, as well as gender, age, expectations, knowledge of control functions, and meteorological conditions.

Cooling:
Depending on the type of system, occupant behavior has a significant influence on the use of cooling. This includes the choice of cooling system, the duration and frequency of usage, the choice of set-point temperatures, and the frequency of maintenance.

Ventilation and window operation:
Investigations of window opening behavior and natural ventilation have mainly been carried out with two aims: to find whether or not occupants are provided with an adequate fresh air supply and to determine the influence on energy consumption. The former category of studies has usually been carried out in dwellings from a health or comfort perspective, while the latter has mostly been studied in offices with a comfort and energy performance emphasis. So far, there are only a few investigations regarding residential buildings and the studies aim to implement realistic behavior patterns in simulation programs. These are based on occupant behavior in offices. No investigations regarding the driving forces of mechanical ventilation in residential buildings have been found in the literature.

Domestic hot water:
Occupant behavior can significantly influence the use of hot water in residential buildings. Examples of energy-related occupant behavior related to domestic hot water use include the frequency of taking a shower, duration and intensity of showers, frequency of taking a bath, frequency of sink use, frequency and temperature of washing machines and dishwashers, and efficiency of water using appliances.

Electric appliances / lighting:
The use of electric appliances and lighting in residences is strongly influenced by occupant behavior. When the energy consumption of appliances and lighting are considered, large variations are found. This partly relates to socio-economic parameters such as income, persons per household, age, education etc., but research regarding other ways to describe occupant behavior related to energy consumption is also ongoing, though a final and perfect model is a long way away. Another suggestion for understanding occupants comes from social science, where the practices of the occupants are used as indicators for their energy consumption. This model is suggested by Ref. [7]. It is based on practice theory where the routines, ways of thinking and actions of the occupants create the basis for different energy related behaviors varying from families with high energy consumption to families who know how to save energy and also are very good at it. Routines are influenced by norms and ethics learned in childhood, by conscious reasoning on economic or ecological aspects, by design of new technologies and by changes in social relations.

Cooking:
Many different appliances are used for cooking, such as microwave ovens, ovens, stoves, pressure cookers, kettles, etc. The type of equipment used and their corresponding energy consumption as well as the number of meals prepared will determine the energy use for cooking. Very limited information on driving forces for occupant behavior related to cooking has been found in the literature.

Interactions between behaviors:
Occupant behavior related to heating is not an isolated phenomenon, but rather a combination of driving forces that must be analyzed in relation to each other. Ref. [6] finds that in homes without mechanical ventilation, heating behavior is typically influenced by the combination of set-point temperature combined with window opening. A strong correlation was also found between window opening behavior and indoor temperature set-point during the cold season, making it difficult to ascertain which influences which behavior: indoor set-point temperature or degree of window opening. Similar to the findings in Ref. [6] that occupants have established behavioral patterns that are not coupled with environmental factors, some interviewed occupants in a low energy cooperative also opened windows due to established morning and evening routines, as opposed to opening windows as a reaction to microclimate conditions. The time of day then becomes a driving factor, see Ref. [8].
In Ref. [9] multivariate regression models have been developed for window opening, fan usage and interactions with the sun shading device, based on data from a semi-controlled climate chamber experiment in an office environment. They found that for the window opening behavior, the fan state has a significant influence as well as vice-versa (the window state influencing the fan state). The usage of the sun shading device was influenced by the state of the window, but not by that of the fan. The state of the sun shading device did not have a statistically significant influence on the other two interactions. There are several studies dealing with the use of shading systems in office environments. Nevertheless, a literature review on the use of sun shading devices in the residential environment did not reveal a substantial amount of publications regarding the topic of user behavior.

2.3 Definitions of energy-related occupant behavior in office buildings

The relationship between occupants and their environment is more complex in office buildings than in residential ones. The total energy use in an office building can be calculated using Equation (1) and Equation (2), where i refers to energy use systems or equipment and j refers to the zones in an office building as follows:

$$E = \sum_i \sum_j E(i, j) \qquad \text{Equation (1)}$$

$$E(i, j) = P(i, j) \times A(i, j) \times \tau_{eq}(i, j) \qquad \text{Equation (2)}$$

In Equation (2), $P(i, j)$ illustrates the energy use intensity of a certain item of equipment or system in a certain zone, $A(i, j)$ refers to the serving area of this certain item of equipment or system and $\tau_{eq}(i, j)$ refers to the equivalent occupied time. All occupant behaviors have effects on these three parameters: energy intensity, occupied area, and occupied time.

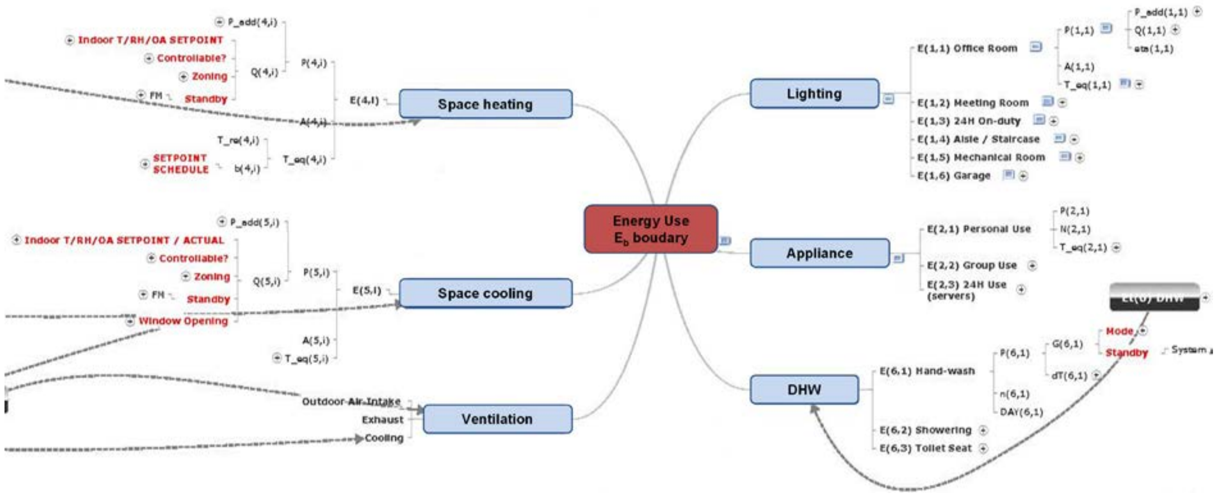


Figure 2.4 Driving forces of energy-related occupant behavior in office buildings

The driving forces of energy-related occupant behavior as shown in Figure 2.4 include the following categories: *lighting, electrical appliances, ventilation, space heating, space cooling* and *domestic hot water*. Examples of driving forces for each category are listed below.

<u>Lighting:</u> illuminance set-point, natural lighting, design of electric lighting installation including task lighting, and utilization period (manually control strategy or automatic control strategy).

<u>Appliance electrical loads:</u> job variety, functional areas (i.e. cooking area in the building or not), installation capacity of office equipment, working period on weekdays and weekends, and control strategy of public appliance (i.e. public copier, printer, etc.).

<u>Ventilation:</u> weather conditions, ventilation system type (mechanical ventilation system only, natural ventilation only or combined), outdoor air intake volume, exhaust air volume, indoor air control set-point.

<u>Space heating:</u> heating system type (district heating, boiler, individual heaters, etc.), installation capacity of heating system, indoor temperature set-point, zoning and intermittency (full-space heating or only heating occupied areas), manual or automatic control, and control pattern or strategy.

<u>Space cooling:</u> cooling system type (district cooling, individual central chiller plant, package air-conditioner, etc.), installation capacity of cooling system, indoor temperature and humidity set-point, serving floor area (full-space cooling or just cooling in the occupied area), manual or automatic control, and control pattern or strategy.

<u>Domestic hot water:</u> DHW system type (boiler or individual water heater), installation capacity, and control pattern or strategy.

Usually, information on occupant presence and activities can be obtained from individual questionnaire surveys or monitoring by zone. Thus, office buildings can be classified at three different levels from a bottom-up perspective as follows (as shown in Figure 2.5).

- Individual occupant/manager level: Occupant behavior of each occupant or building manager is defined by activities (i.e. weekday and weekend schedule, switch on/off of artificial lighting, control strategy of heater, etc.). After conducting a questionnaire survey or monitoring, occupants can be categorized into behavior modes, which is the combination of activities.

- Zone/office level: By surveying individual occupants and conducting statistical analysis, each zone or office can be classified by the percentage of different modes of occupants.

- Building level: Each zone in the office building can be classified into different zone types. A specific office building can be defined then by the percentage of different zone/zones or office types.

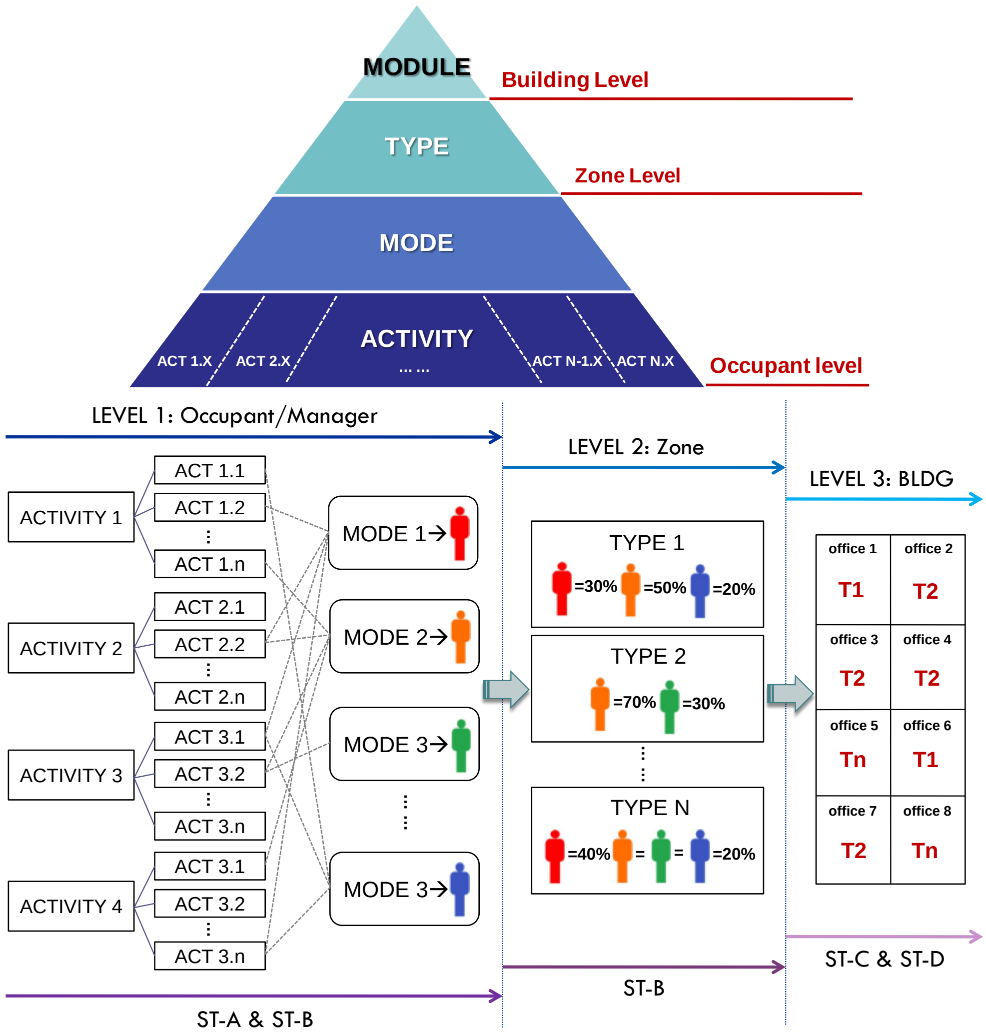


Figure 2.5 Methodology for occupant behavior definitions in office buildings

At each level, occupant behavior with respect to *lighting systems*, *appliances*, *ventilation and window operation*, and *space heating and cooling* is discussed in Volume II.3 of Annex 53 “Definition of occupant behavior in office buildings”.

Lighting system:
The use of artificial lighting in office buildings is influenced by both building design and occupant behavior. Occupant behavior refers to occupancy, lighting use patterns and control strategies. The literature review shows that there is a close link between the start of daily occupancy and switching-on lighting in large open space office building in Ref. [10] and Ref [11]. Comparing case studies from Norway, China and Belgium also shows that peak lighting hours are usually between 10 am and 6 pm (with an average lighting use percentage $\geq$ 90%) during weekdays in large open spaces of office buildings. This means occupant behavior related to lighting systems has little effect on lighting energy use because of the large internal area. On the contrary, occupant related lighting behavior has a strong affect on lighting energy use in individual offices or small open spaces in a case study building in China. Occupants can more easily use natural lighting in individual offices than in large open plan offices.

Behavior in the off-hours and on weekends also leads to huge differences among office buildings, due to the variety of energy conservation awareness programs and the control strategy of lighting systems.

Appliances:
Office appliances include computers, CRT displays, LCD displays, copiers, laser printers, and so on. Office appliances usually have to be switched on during working hours. However, the important occupant behavior for energy conservation is what occurs at night (Ref [12]). The office with higher turn-off rates during off-hours saves more energy than other offices in case buildings in China and the U.S, as shown in the Volume II.3 of Annex 53 *“Definition of occupant behavior in office buildings”*

Ventilation and window operation:
The first attempt to study occupant behavior of window operation started in the early 1990s. The discrete-time Markov process and logistic function are used to predict window opening. It is found that both the indoor and outdoor temperature have a strong relationship with the window opening proportion. Ref. [13] indicates that people with more opportunities to adapt to their environment or adapt their environment to their own requirements will be less likely to suffer from discomfort. Other references reveal a strong relationship between window opening behavior and indoor air temperature, such as Ref. [14].

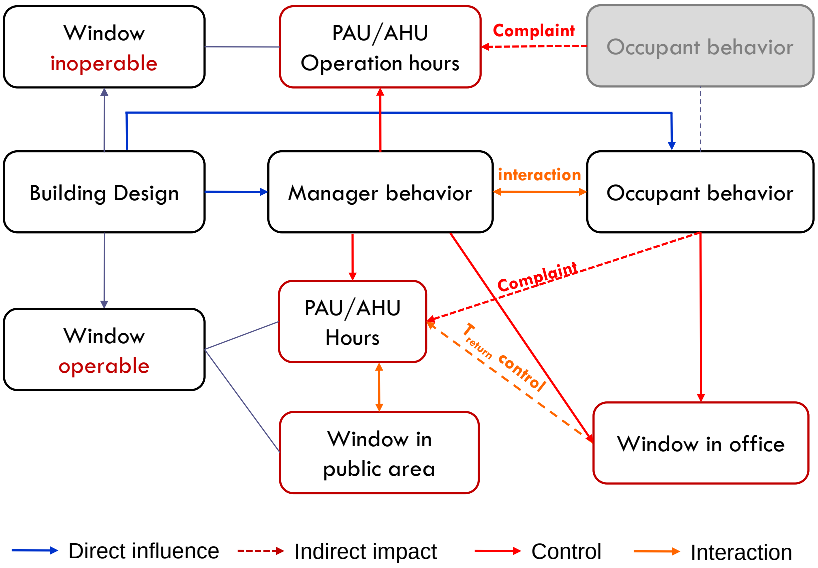


Figure 2.6 Logistical diagram of the relationship between window opening and the mechanical ventilation system

Figure 2.6 explains the relationship between window opening and the mechanical ventilation system. For buildings designed with inoperable windows, ventilation can only be realized by mechanical systems such as Air Handling Units, Primary Air Units or Fan Coil Units. For buildings designed with operable windows, the building operator/manager can control use of the mechanical ventilation system, as well as windows in public and office areas. Therefore a good feedback mechanism should be set up to balance window opening and the number of mechanical ventilation systems. For example, if many occupants open windows in the office, then the number of Primary Air Units should be decreased or shut down when necessary by the building operator to conserve energy. According to our investigation, few office buildings are designed to have special control logic connecting window status and the mechanical ventilation system. The latter is usually controlled manually by the building operator or automatically by a BMS system with fixed control logic.

Space heating and cooling:

Ref. [15] indicates that occupancy rates, use of shading devices and turning on and off of lights have a strong influence on HVAC system energy consumption. Simulation based on case studies in China (CHN-03) shows that the set-point of indoor air temperature and humidity, the amount of outdoor air intake and the operation time of Air Handling Units have significant impacts on the HVAC system energy use.

2.4 Modeling energy-related occupant behavior

As pointed out in the final report of Subtask C and in the report, "*Driving forces of energy-related behavior in residential buildings,*" occupant behavior can affect energy use by a magnitude of threefold, i.e. the highest use is three times the lowest. A wide range of driving forces of energy-related behavior was shown to influence energy use. These were grouped into biological, psychological, social, time, and physical parameters of the environment and the building. Modeling energy-related behavior demands interdisciplinary work between engineering and the social sciences. When it comes to interaction between buildings and human beings, a variety of disciplines are conducting research on energy-related comfort parameters such as room temperature or indoor air quality.

Although there are no general differences in scientific principles between natural sciences and human sciences, the integration of different perspectives and vocabulary is not trivial. Nevertheless the goals are ambitious with respect to the models that combine formalistic parameters and real life processes, especially when human behavior is taken into account. Models always reduce complexity and abstraction. At the same time, all relevant parameters must be considered, namely objective physical (environmental) parameters, personal variables and the interaction between these two. The models are translated into computer simulation as a connection between theory and experiment. This includes mathematical-logical processing, by which there might be a risk of overestimating the degree of precision and the explanatory power of results.

From the perspective of environmental psychology, computer simulation is considered a helpful method to look at complex systems and to handle practical problems, but the method is seldom applied, see Ref. [16]. Methodological determinism in the human sciences is often a basis for modeling human behavior, and requires one to make assumptions regarding adequate explanations, regularities of attitudes, intentions, and behavior. There is no guarantee that a theory is better because a computer simulation is undertaken. In addition, the successful implementation and validation of an algorithm in simulation does not show that the theory is generalizable or that it is the reason for successfully predicted cases. See Ref. [17].

Computer simulation in the field of user behavior and energy use can serve as an approach to address current circumstances and develop practical solutions by visualizing the processes in different energy-related settings. The models can be used as a basis for calculating expected energy consumption as well as verification of theoretical assumptions about the driving factors of energy-related behavior.

Beyond the calculation of energy consumption, the models could show the potential to deal with practical implications such as:

- The fit between building operation and user behavior (match or mismatch);
- Behavior as a basis for building optimization (e.g. to determine under which conditions behavior turns into counterproductive behavior);
- Behavior as a basis for interventions (e.g. information about the building concept, handling of controls as well as training for energy-related behavior).

2.4.1 Purpose of modeling

Within the framework of this Annex, the major concern is to model occupant behavior in order to reveal its relationship to energy demand and usage as well as the driving forces for variations. This is in contrast to modeling occupant behavior in order to understand driving forces for the behavior itself.

An important question is how much detail is necessary to reach the set purpose. This is strongly dependent on the number of buildings, the user profile, and the time scale. With respect to the number of buildings, a single object needs to be dealt with differently compared to multiple objects. The user profile can be created for known or unknown users and the time scale considered can be short term (daily, hourly down to fractions of seconds) or long term (season or year). The occupant behavior can be modeled through schedules or diversity profiles (Type A), stochastic models (Type B), or agent based models (Type C). Table 2.1 gives an overview of possible objectives for the simulation of occupant behavior together with typical time scales, time steps, and preferred behavior models for single buildings, and

Table 2.2 provides the same overview for a group of buildings.

Table 2.1. Objectives for the simulation of occupant behavior, time scales and preferred behavior models for a single building.

	Design			**Commissioning**		**Operation**
	Conceptual	Preliminary	Final	Initial	On-going	Control
Aim	Design concept comparison	Design optimization	System sizing/ Building code compliance	Initial commissioning	Fault detection	Model predictive control
Typical time scale	Season, year	Season, year	Season, year		Continuous	1 or 2 days ahead
Typical time step	1 hr.	1 hr.	1 hr.	1 min, 1 hr.	1 min, 1 hr.	1 min, 1 hr.
Preferred behavior model	A	A, B or C*	A (B or C*)	A, B or C*	A, B or C*	A, B or C*
* The required model depends on the sensitivity of the investigated building performance indicator to occupant behavior. This sensitivity depends on the performance indicator itself and on various building related aspects, among others, building function and user type, building/system concept and the degree to which the occupants are able to interact with the building, see Ref. [18].						

Table 2.2. Objectives for the simulation of occupant behavior, time scales and preferred behavior models for a group of buildings.

	Design			**Commissioning**		**Operation**
	Conceptual	Preliminary	Final	Initial	On-going	Control
Aim	Policy making/ solar/shading analysis	Solar/shading analysis	Design electricity grid / district storage		Fault detection of district storage	District energy storage
Typical time scale	Season, year, 30-years	Week, season, year	Week, season, year		Continuous	1 day/season ahead
Typical time step	1 hr.	1 min, 1 hr.	1 min, 1 hr.		1 hr.	1 hr.
Preferred behavior model	A	A	A		A	A

2.4.2 Model types

Basic types of models are defined in Volume II.2 of Annex 53 "*Total energy use in residential buildings – the modeling of occupant behavior*" and briefly discussed in this subsection. Examples of energy-related occupant behavior modeling can also be found in this appendix.

Psychological models:
Psychological models of occupant behavior can be grouped into those explaining the behavior itself and those related to the energy use in buildings. Examples of the first category are Theory of Planned Behavior, Ref. [19], and the MODE (Motivation and Opportunity as Determinants) model, Ref. [20]. Examples of the second category are the behavioral model of residential energy use, Ref. [21], and the NOA (Needs-Opportunities-Abilities) model, Ref.[22]

Average value models:
Average value models define the important parameters for occupant behavior that influence the total energy use of a building for a selected period (e.g. daily, weekly, or monthly basis).
Empirical studies have shown that average values are sufficient for estimating total energy use in residential buildings with many inhabitants, such as apartment buildings (Ref. [23]). The larger the building and the larger the sample set, the smaller the deviation from the average. Predicting total energy use for individual single-family homes has been shown to be more challenging. Energy use profiles for single houses can show great variance from current estimates based on average values (Ref. [13]).

Deterministic models:
Deterministic models use predefined typologies of families, which will give deterministic input values for computer simulations. Building simulation tools, on the other hand, are based on heat transfer and thermodynamic equations, which are deterministic. Typically human (control) actions are modeled based on predefined fixed schedules or predefined rules. These tools often reproduce building dynamics using numerical approximations of equations modeling only deterministic behavior. In simulation tools, occupant behavior is not specifically addressed, but only modeled by means of its effect. For example, the infiltration rate might be modeled as a fixed value that does not vary over time. However, in reality an occupant will not react in exactly the same manner every time he or she is exposed to the same condition. Consequently, occupant behavior will include elements of randomness.

Probabilistic models:
Traditional modeling approaches look at human beings as if they behave in a fully deterministic way. However, in the real world many parameters influence environmental conditions and occupant behavior (e.g. actions to control indoor environmental parameters) varies significantly and unpredictably during the building's life. The evaluation of occupant behavior will be based not only on fixed actions (e.g. opening windows if indoor temperature exceeds of a certain limit), but on coupling these repeatable interactions with building control systems with a certain probability. This approach results in a probability distribution instead of a single value for energy use.

Agent-based models:
Agent-based modeling is a bottom up approach. It focuses on individual behavior and local interactions. Simple behaviors at a micro-level will result in complex behaviors at a macro-level. The agents may vary from individual human beings to components of energy networks. Agent-based models involve modeling occupants as individuals with autonomous decisions based on rules and experiences (such as memory, self-learning, etc.). Agent-based simulation models are used to quantitatively study multi-agent systems, in which agents are autonomous but also interacting with each other and the environment.

Action based models:
Action based models define "occupant behaviors'' as actions - *movement* and *control action* - that change the state of objects (movement is the change of occupant location, while control actions are the operational state change of windows, lights, air conditioners, etc.). Proposing a uniform description for occupant movement and control actions, and classifying each action by several typical patterns that can be easily investigated and applied allows the model to evaluate the impact of occupant behaviors on building systems.

Following the description of the modeling approaches, examples for energy-related behaviors found in the literature are presented together with those developed within the framework of this Annex. A broad range of models is shown; however, few have been implemented into simulation software for energy demand prediction. Furthermore, all of these models were – if at all – validated only internally and not using external data (see Ref. [14] for such an approach to window opening behavior). Therefore no conclusion can be drawn on the quality of the developed models.

2.4.3 Conclusions

Average and deterministic models are often based on assumptions, not on data. Implementing values based on assumptions into simulation algorithms cause the outcome to be a single value for each assumed/derived type of behavior. In order to show a variety of behaviors, types of occupants, and so forth various simulations have to be run once each for each model.

Probabilistic models could be based on assumptions as well, but in practice, they are mainly based on data. They represent probabilities of a behavior. Various types of occupants can be represented either by different models or by variables related to the aspects modeled within one model. The outcome is a distribution of behaviors/energy demands and the variety is shown by results of different models or the distribution of one model.

Agent-based simulation models are used to quantitatively study multi-agent systems in which agents are autonomous and interact with each other and their environments. The agents may be very different objects varying from individual human beings to components of energy networks. The agents are in a specific state at a specific time during the simulation. Due to interactions with other agents the state may change over time. An agent-based model for simulating domestic user behavior can be used in a co-simulation with, e.g. a building model.

Action based models provide a new approach for building occupancy simulation. Compared to the "fixed schedule" method, this model considers the randomness that result in the uneven and non-synchronous change of occupancy over space and time. Compared to other random process methods, this model keeps the time and space relevance of occupancy and is more practical due to the great reduction of inputs.

The choice of model depends strongly on the objective of the simulation. Recommendations are presented in *Table 2.1* and
Table 2.2 above. The possibility to use a certain model also depends on the software used, because not all simulation tools generate all necessary variables needed for some of the models presented.

Future model developments are meaningful if they are validated on external data. This necessitates case studies being available to perform such validation. The final report of Subtask C presents the outlines of existing studies analyzing the total energy use in buildings. All of them indicate whether occupant behavioral variables are included in the database and whether others can use the database.

Suggestions for future work, such as dynamic occupant behavior models, are described in the Volume II of Annex 53.

2.5 Reference

[1] J.F. Nicol, *Characterising occupant behaviour in buildings: towards a stochastic model of occupant use of windows, lights, blinds, heaters and fans*, Proceedings of the "Seventh International IBPSA Conference", Rio de Janeiro, Brazil, 2001.

[2] C.F. Reinhart, *Lightswitch-2002: a model for manual and automated control of electric lighting and blinds*, Solar Energy 77, 15-28, 2004.

[3] M. Schweiker, M. Shukuya, *Comparison of Theoretical and Statistical Models of Air-Conditioning-Unit Usage Behaviour in a Residential Setting under Japanese Climatic Conditions,* Building and Environment 44, 2137-2149, 2009.

[4] V. Fabi, S.P. Corgnati, R.V. Andersen, M. Filippi, B.W. Olesen, *Effect of occupant behaviour related influencing factors on final energy end uses in buildings.* Proceedings of the Climamed11 Conference, Madrid, Spain, 2011.

[5] C. Peng, D. Yan, R. Wu, C. Wang, X. Zhou, Y. Jiang, *Quantitative description and simulation of human behaviour in residential buildings*, Building Simulation 5, 85-94, 2012.

[6] R.V. Andersen, *Occupant Behaviour with Regard to Control of the Indoor Environment,* in International Centre for Indoor Environment and Energy, Ph.D thesis, Technical University of Denmark, Copenhagen, Denmark, 2009.

[7] K. Gram-Hanssen, *Residential heat comfort practices: Understanding users,* Building Research and Information, 38(2), 175-186, 2010.

[8] A. Keul, R. Salzmann, A. Lehmden, *Komfort und Luftqualität im Niedrigenergie-Ziegelgebäude,* Mauerwerk 15(3), 176-178, 2011.

[9] M. Schweiker, S. Brasche, W. Bischof, A. Wagner, *Explaining the individual processes leading to adaptive comfort – exploring behaviouralbehavioral and physiological reactions to thermal stimuli,* International Building Physics Conference 2012, Kyoto, Japan, 1019-1025, 2012.

[10] G.Y.Yun, J.Y.Shin, J.T. Kim, 2011. Influence of window views on the subjective evaluation of discomfort glare, Indoor and Built Environment, 20 (2011): 65-74.

[11] G.Y.Yun, H.Y. Kong, H. Kim, J.T. Kim, 2012. A field survey of visual comfort and lighting energy consumption in open plan offices, Energy and Buildings, 46(2012): 146-151.

[12] Bruce Nordman, 2005. Bruce Nordman, Alan Meier, Mary Ann Piette. PC and monitor night status: power management enabling and manual turn-off, Information and electronic technologies, 7: 89-99.

[13] Nicol J, 2002. Nicol J, Humphreys M, Adaptive thermal comfort and sustainable thermal standards for buildings. Energy and Building, 34 (2002): 563-572.

[14] Yun G, Steemers K. Time-dependent occupant behaviour models of window control in summer. Building and Environment, 43 (2008): 1471-1482.

[15] Dirk, 2011. Dirk Saelens, Wout Parys, Ruben Baetens. Energy and comfort performance of thermally activated building systems including occupant behavior, Building and Environment, 46 (2011): 835-48.

[16] R. Tobias & H,-J. Mosler, Einsatz der Computersimulation in der Umweltpsychologie, Umweltpsychologie 2 (21), 22-37, 2007 (in German).

[17] R. Neches, Simulation systems for cognitive psychology, Behavior Research Methods & Instrumentation 14, 77-91, 1982.

[18] P. Hoes, J.L.M. Hensen, M.G.L.C. Loomans, B. de Vries, D. Bourgeois, User behavior in whole building simulation, Energy and Buildings 41(3),295–302, 2009.

[19] I. I. Ajzen, The theory of planned behavior, Organizational Behavior and Human Decision Processes 50, 179-211, 1991.

[20] R.H. Fazio, Multiple Processes by which Attitudes guide Behavior: the MODE Model as an integrative framework, Advances in experimental social psychology 23, 75-109, 1990.

[21] W.F. van Raaij, T.M.M. Verhallen, A behavioral model of residential energy use, Journal of Economic Psychology 3, 39-63, 1983.

[22] B. Gatersleben, C. Vlek, Household consumption, quality of life and environmental impacts, In K.J. Noorman, A.J.M. Schoot-Uiterkamp (eds.) Green Households? Domestic Consumers, Environment and Sustainability. London: Earthscan, 141-183, 1998.

[23] T. Bednar, A. Korjenic, H. Konder, C. Deseyve, M. Kirchweger, N. Morishita, Performance and Experiences with Austrian Demonstration Projects for Lowest-Energy Houses (Passive Houses) in Social Housing, Lecture: ASHRAE Buildings XI Conference, Clearwater Beach, Florida, US, 2010.

[24] A. Korjenic, T. Bednar, Impact of Lifestyle on the Energy Demand of a Single Family House, Building Simulation 4, 89-95, 2011.

[25] M. Schweiker, F. Haldi, M. Shukuya, D. Robinson, Verification of stochastic models of window opening behavior for residential buildings. Journal of Building Performance Simulation, First published on: 09 June 2011 (iFirst).

3. Case Studies of total energy use for analysis and evaluation

Summary

What is covered

Case studies of international office building and residential building are presented in this chapter. The twelve office case study buildings include the following basic categories: data level, location, gross floor area, number of floors, construction years, air conditioning system, cooling and heating sources are outlined. The twelve residential case buildings include these categories: data level, location, number of floors, gross floor area, and construction year. The information follows the office and residential building definitions and typologies of Subtask A and the key results of total energy comparison and occupant behavior of office and residential buildings are presented.

Why it is important

The case studies are real situations where the practicality of the definitions in Subtask A may be applied, checked, and verified. The direct relationship between energy use and occupant behavior may be studied. The features of each building's energy use and occupant behavior may also be described as input data of simulations in Subtask D.

Key points learned

Total energy use of office buildings differs from country to country. For example, heating energy use in Austria, Belgium, Northern China and Norway are similar while heating energy use in France is very different. Huge differences in electricity uses in the case study buildings are seen in the following systems: air conditioning, ventilation, and lighting. Large-scale office buildings consume significantly more electricity than individual office buildings.

Occupant lighting behavior in office buildings is studied through the comparison of the schedule of artificial lighting in weekdays and weekends in four buildings in China, Norway and Belgium. More than 60% of artificial lighting is on during working hours in the four large-scale case study office buildings. 20% of lighting remains on during unoccupied hours in all cases except the base case building in Belgium.

Occupant behavior in multi-family houses shows that by reducing the operating time or amount of space heating and domestic hot water equipment can decrease space heating energy use by 40% to 46% compared to the "energy-wasting" scenario.

Conclusion

The impact of occupant behavior on energy consumption in office buildings shows a weak relationship between external illuminance and the use of artificial lighting in large-scale office buildings. Occupants usually turn on artificial lighting during working hours. Occupants in small-scaled office buildings use more daylight, thus saving more electricity.

The electricity consumption of ventilation and air conditioning (AC) systems in large-scaled office buildings is larger than small-scaled office buildings due to the lack of operable external windows. The building operator behavior (i.e. set point temperature, air change rate, control strategy of circulating pumps and fans, etc.) is the decisive factor in electricity consumption of AC systems consumption.

The relationship between energy consumption and occupant demand of office equipment can be presented in a chart with the vertical axis representing energy consumption and the horizontal axis representing demand. The intercept of each line means inherent energy, which appears in three forms:
1) Energy wasted because of inefficient equipment,
2) Energy lost by steam or heat leakages, and
3) Electricity wasted by standby power during off hours.

Since occupant behavior causes office appliances to be left in the nighttime standby mode, it is the decisive factor is the objective, boundary, and methodology of Subtask B1.

Subtask B1 focuses on the following three aspects:
1) Comparing energy use of office and residential buildings worldwide,
2) Investigating typical occupant behavior with equipment/systems in office and residential buildings, and
3) Studying the impact of typical occupant behavior on energy use in office and residential buildings.

From the literature review (refer to Appendix B1-A and B1-B), and the objectives of Subtask B1, it is concluded that physiological and psychological driving forces are beyond the scope of this subtask (Figure 3.1). Therefore, this chapter will focus on the relationship between occupant behavior and energy consumption by analyzing the following three aspects:
1) Building design that describes the building construction, type of system, and service level,
2) Energy practice that describes the occupants' habits of using energy-consuming devices, and
3) Cognitive norms that explain the environmental requirements and energy-conservation consciousness of occupants.

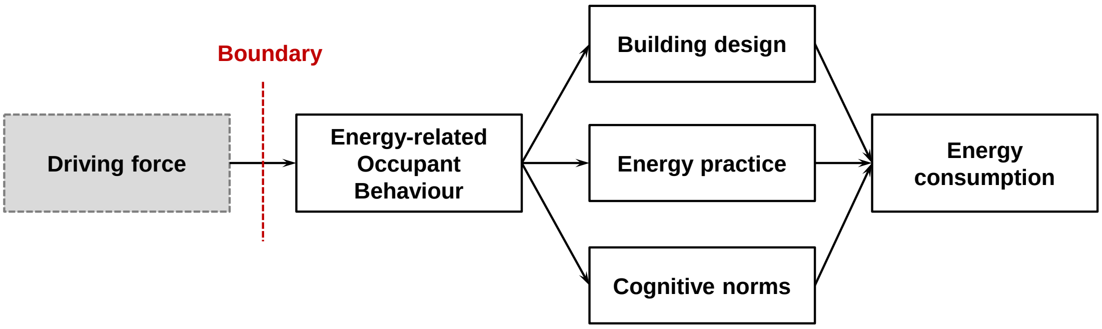


Figure 3.1. Boundary of energy-related occupant behavior in this research.

The methods used in this subtask are interviews, observations, on-site measurements, and data analysis. In order to complete a holistic, in-depth investigation, the subtask followed these seven steps:

1) ***Define a uniform building typology.*** Four building types are studied in Subtask B1: small-scale office buildings (O1), large-scale office buildings (O2), single-family houses (or detached house) (R1) and multi-family apartments (R2). A detailed description of these four building types is shown in Figure 3.2.
2) ***Define the contributors and example template to investigate.*** Seven contributing countries (Austria, Belgium, China, France, Italy, Japan and Norway) provided four types of case study buildings for the research.
3) ***Define an information collection format.*** A MS Excel file to collect for each building was developed. This includes basic information of the building, climate conditions, energy use analysis, occupant use of devices, etc.. The common definitions for basic items related to building energy

use are provided in Subtask A. Three boundaries of energy consumption including E_b, E_t and E_d (refer to Chapter 1) and three data levels (simple, intermediate and complex levels) are defined.

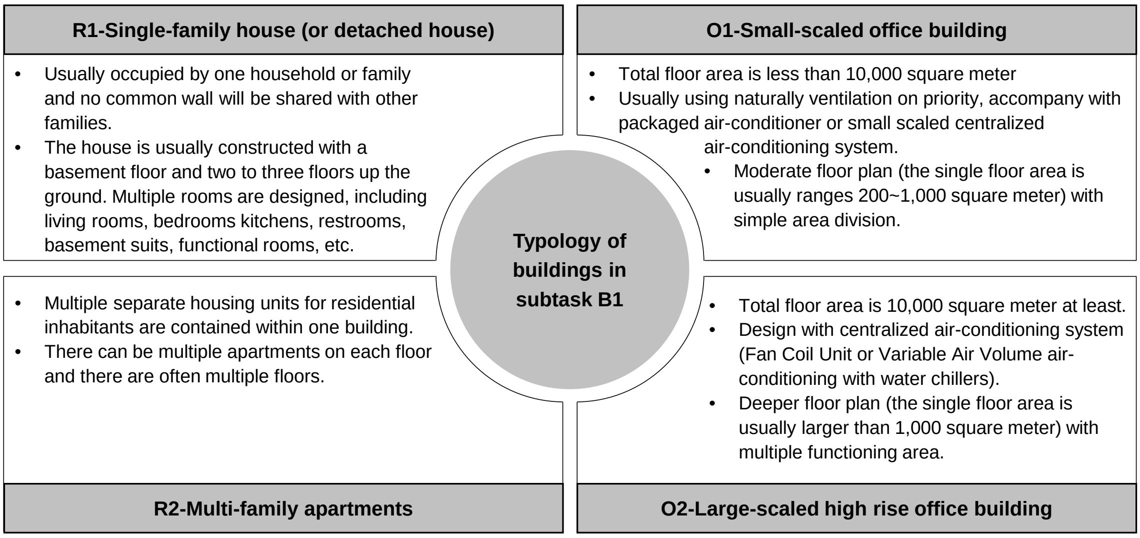


Figure 3.2. Typologies of office and residential buildings in Subtask B1.

4) ***Select cases for further research.*** 24 cases by seven contributing countries were selected to be compared.

5) ***Determine data gathering and analysis techniques.*** Both quantitative and qualitative approaches and different data collection instruments were used, including questionnaire survey, building manager and occupant interviews, energy monitoring and benchmarking system, on-site measurement, etc.

6) ***Analyzing data and accomplishing case database.*** All of the case contributors analyzed the energy and occupant behavior data collected, organized data in the provided spreadsheet and circulated the files to other countries' researchers.

7) ***International comparison of the data.*** Energy use and occupant behavior were compared by the Subtask Leader.

3.1 Case study buildings

A group of 24 case studies of energy use, environmental performance, and occupant behavior consisting of 13 office buildings and 11 residential buildings following the basis of Subtask B1 were collected. The locations of the case studies are displayed in Figure 3.3. Information in these six categories were gathered: climate[1] (as shown in Figure 3.4) and indoor thermal environment, whole building characteristics[2], building envelope[3], building services and energy systems[4], building operation and occupant behavior[5], and energy performance indicators[6]. These categories are described in the source book of each case (see Appendix-B1-E).

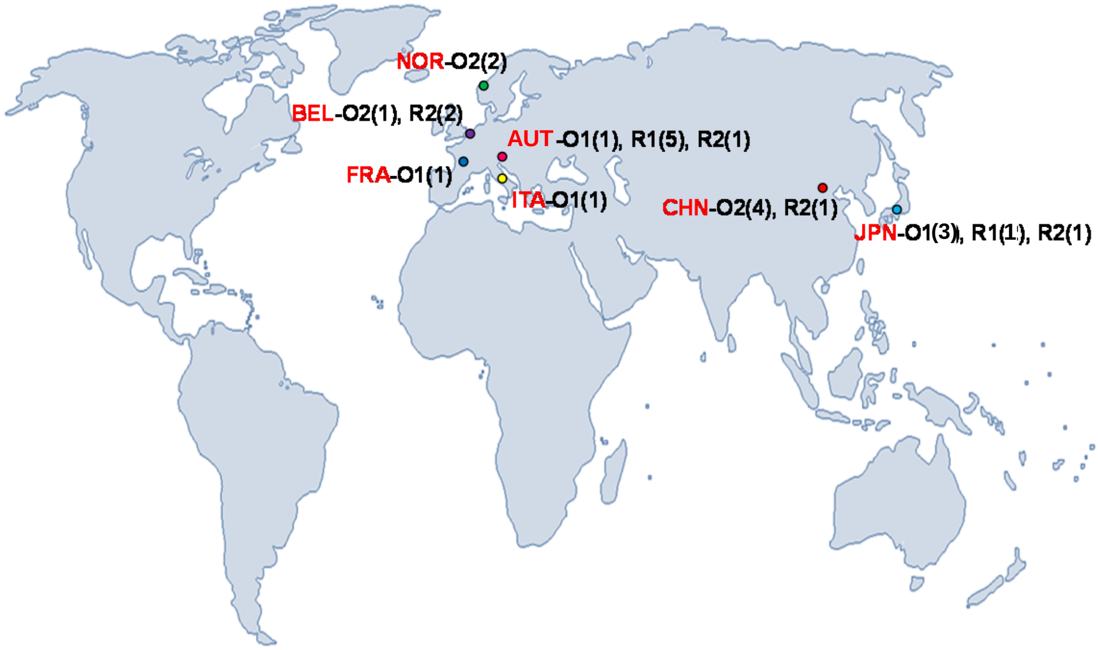


Figure 3.3. Locations of the 24 case study buildings from the seven contributing countries.

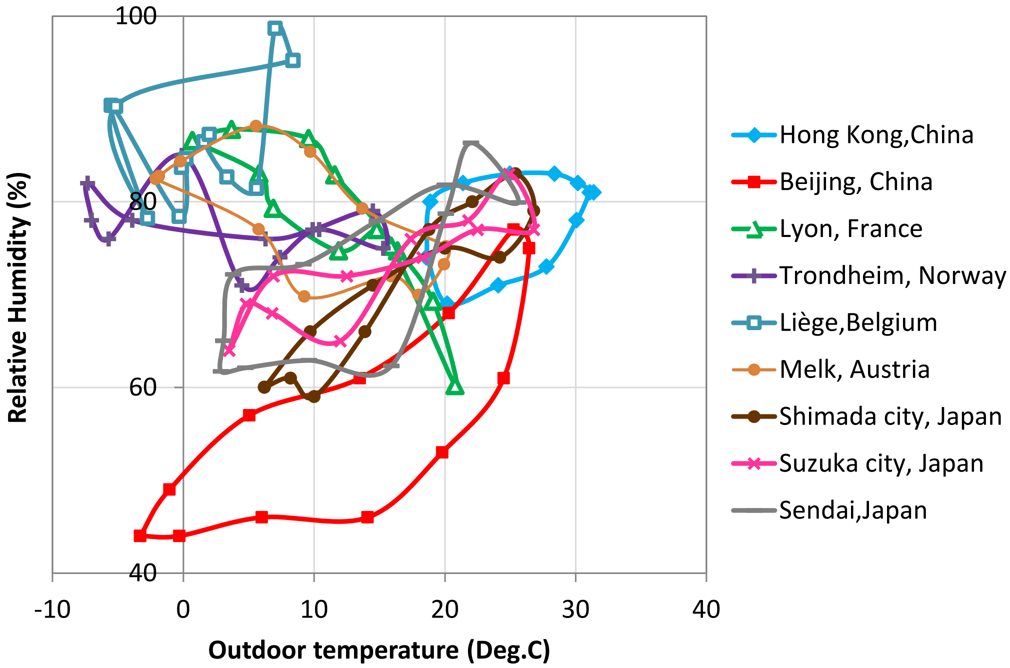


Figure 3.4. Climate comparison of the seven contributing countries.

3.1.1 Office building

The researchers in seven countries contributed thirteen office buildings (including six individual and seven large-scale) (Figure 3.3). Total floor areas range from 1,000 to 150,000 square meters. Two office buildings exceed 100,000 square meters. Only two individual office buildings utilize natural ventilation rather than centralized mechanical air-conditioning system. Basic information is given in Table 3.1.

Table 3.1. Detailed information of thirteen office buildings.

Code	Photo	Case contributor and contact person	Basic information
AUT-01		*Vienna University of Technology* Thomas Bednar Azra Korjenic	Category: O1 Data level: B Location: Melk, Austria GFA: 4,811 m^2 No. of floors: 3 Construction year: 2007 Cooling source: mechanical ventilation with a ground source heat exchanger, decentralized AC for server rooms Heating source: district heating from biomass, mechanical ventilation with a ground source heat exchanger
BEL-01		*University of Liège* Stephane Bertragnolio	Category: O2 Data level: A Location: Brussels, Belgium GFA: 18,700 m^2 No. of floors: 9 Construction year: 1970's AC: AHU, CAV, VAV Cooling source: water-cooled chiller Heating source: natural gas boiler
CHN-01		*Swire Properties, Hong Kong* *Tsinghua University* Cary CHAN Qingpeng WEI He Xiao	Category: O2 Data level: C Location: Hong Kong, P.R. China GFA: 30,968 m^2 No. of floors: 23 Construction year: 1998 AC: AHU, CAV, VAV, FCU, PAU Cooling source: water-cooled chiller Heating source: no heating demand

CHN-02		*Swire Properties, Hong Kong* *Tsinghua University* Cary CHAN Qingpeng WEI He Xiao	Category: O2 Data level: C Location: Hong Kong, P.R.China GFA: 141,968 m^2 No. of floors: 68 Construction year: 2008 AC: AHU, CAV, VAV, FCU, PAU Cooling source: water-cooled chiller Heating source: no heating demand
CHN-03		*Tsinghua University* He Xiao Qingpeng WEI	Category: O2 Data level: C Location: Beijing, China GFA: 111,984 m^2 No. of floors: 26 Construction year: 2004 AC: FCU, PAU Cooling source: water-cooled chiller Heating source: district heating
CHN-04		*Tsinghua University* He Xiao Qingpeng WEI	Category: O2 Data level: C Location: Beijing, China GFA: 54,500 m^2 No. of floors: 21 Construction year: 1980’s AC: VAV, PAU Cooling source: water-cooled chiller Heating source: district heating
FRA-01		*INSA de Lyon-CETHIL* Cécile ERMEL	Category: O1 Data level: A Location: Lyon, France GFA: 1,290 m^2 No. of floors: 2 Construction year: 1970 Renovation year: 1993 Cooling source: natural ventilation Heating source: no heating demand

ITA-01		*Politecnico di Torino* Francesco Causone	Category: O1 Data level: A Location: Vercelli, Italy GFA: 1,096 m^2 No. of floors: 5 Cooling source: natural ventilation Heating source: natural gas boiler
JPN-01		*Chubu Electric Power Co., Inc.* Shigehiro Ichinose	Category: O1 Data level: B Location: Shimada, Japan GFA: 2,734 m^2 No. of floors: 4
JPN-02		*Chubu Electric Power Co., Inc.* Shigehiro Ichinose	Category: O1 Data level: B Location: Suzuka, Japan GFA: 3,695 m^2 No. of floors: 4
JPN-03		*Building Research Center China Vanke Co., Ltd* Ting SHI	Category: O1 Data level: B Location: Sendai, Japan GFA: 4,090 m2 No. of floors: 3
NOR-01		*Norwegian University of Science and Technology* Natasa Djuric	Category: O2 Data level: A Location: Stavanger, Norway GFA: 27,623 m^2 Construction year: 2008 AC: AHU, VAV, FCU Cooling source: water-cooled chiller Heating source: district heating
NOR-02		*Norwegian University of Science and Technology* Natasa Djuric	Category: O2 Data level: C Location: Trondheim, Norway GFA: 16,200 m^2 No. of floors: 6 Construction year: 2009 AC: AHU, VAV, FCU Cooling source: heat pump Heating source: district heating

3.1.2 Residential building

Researchers from four countries (Austria, Belgium, P.R. China, and Japan) contributed data on twelve residential buildings: (Figure 3.3). Six detached houses and six multi-family apartments are included. Total floor areas of detached houses ranges from 159 to 389 square meters. Basic information is given in Table 3.2.

Table 3.2. Detailed information of twelve residential buildings.

Code	Photo	Case contributor and contact person	Basic information
AUT-01		*Vienna University of Technology* Markus Dörn, Naomi Morishita, Thomas Bednar & Azra Korjenic	Category: R1 Location: Vorarlberg, Austria No. of floors: 2 GFA: 280.6 m^2 Construction year: 1987 Data level: B
AUT-02		*Vienna University of Technology* Markus Dörn, Naomi Morishita, Thomas Bednar & Azra Korjenic	Category: R1 Location: Vorarlberg, Austria No. of floors: 2 GFA: 185.2 m^2 Construction year: 1965 Data level: B
AUT-03		*Vienna University of Technology* Markus Dörn, Naomi Morishita, Thomas Bednar & Azra Korjenic	Category: R1 Location: Vorarlberg, Austria No. of floors: 3 GFA: 164.4 m^2 Construction year: 1957 Data level: B
AUT-04		*Vienna University of Technology* Thomas Bednar Azra Korjenic	Category: R1 Location: Vienna, Austria No. of floors: 2 GFA: 100 m^2 Construction year: 1930 Data level: A
AUT-05		*Vienna University of Technology* Thomas Bednar Azra Korjenic	Category: R1 Location: Vienna, Austria No. of floors: 2 GFA:389.4 m^2 Construction year: 2004 Data level: A

AUT-06		*Vienna University of Technology* Thomas Bednar Azra Korjenic	Category: R2 Location: Vienna, Austria No. of floors: 13 GFA: 1330 m^2 Construction year: 2007 Data level: B
BEL-01		*University of Liège* Bertrand Fabry Vincent Dolisy Nicolas Pignon Philippe Andre	Category: R2 Location: Hondelange, Belgium Data level: A
BEL-02		*University of Liège* Bertrand Fabry Vincent Dolisy Nicolas Pignon Philippe Andre	Category: R2 Location: Arlon, Belgium No. of floors: 6 Heated area: 1330 m^2 Construction year: 2005 Data level: B
BEL-03		*JCJ Energetics, Cleide A. Silva* Jules Hannay Jean Lebrun	Category: R2 Location: Belgian coast No. of floors: 8 Data level: A
CHN-01		*Tsinghua University* Yi Jiang Yingxin Zhu Da Yan Chuang Wang	Category: R2 Location: Beijing, China No. of floors: 20 Construction year: 2000 Data level: B
JPN-01		*Tohoku University* Hiroshi Yoshino	Category: R1 Location: Sendai, Japan No. of floors: 2 Heated area: 285 m^2 Construction year: 2008 Data level: C

JPN-02		*Tohoku University* Hiroshi Yoshino	Category: R2 Location: Fukushima, Japan No. of floors: 15 GFA of case family: 72.3 m^2 Construction year: 2000 Data level: C

3.2 Results

3.2.1 Office buildings

1) Case database

Most of the researchers provided Level B to Level C information for the office buildings. This includes building characteristics, weather conditions, building systems, and energy use data. On the other hand, most buildings can only be described regarding Level A information for occupant behavior (such as schedules, control mode of lighting, HVAC system, etc.) since some of the complex occupant behavior data (such as window opening mode, air-side equipment control mode, etc.) is difficult to collect. Table 3.3 illustrates the information provided for each office building.

Table 3.3. Summary of case studies information

	A 1	B 1	C 1	C 2	C 3	C 4	F 1	I 1	J 1	J 2	J 3	N 1	N 2
Climate													
HDD	●	●	●	●	●	●	●				●	●	●
CDD	●	●	●	●	●	●	●				●	●	●
Whole building characteristics													
Year built	●	●	●	●	●	●	●	●	●	●	●	●	●
No. of floors	●	●	●	●	●	●	●	●	●	●	●	●	●
GFA	●	●	●	●	●	●	●	●	●	●	●	●	●
Building envelope													
Material	●		●	●			●	●					
U-value	●		●	●			●	●					
Window to wall ratio			●	●	●	●	●						

Building services and energy systems												
Heating system		●			●	●		●				●
Air-conditioning system		●	●	●	●	●						●
Ventilation			●	●	●	●						●
Lighting			●	●	●	●	●					●
Office appliances	●		●	●	●	●	●					●
Building operation												
Business hours	●	●	●	●	●	●	●	●	●	●	●	●
Occupancy schedule	●	●		●	●	●	●	●			●	●
Space heating					●	●						●
Space cooling		●	●	●	●	●						●
Ventilation		●	●	●	●	●						●
Lighting	●	●		●	●	●						●
Office appliances	●	●		●	●	●						●
Energy indicator												
Energy carrier	●	●	●	●	●	●	●		●	●	●	●
Aggregation of energy	●	●	●	●	●	●	●		●	●	●	●
Normalized energy use	●	●	●	●	●	●	●		●	●	●	●

● Related information is collected and provided by contributors.

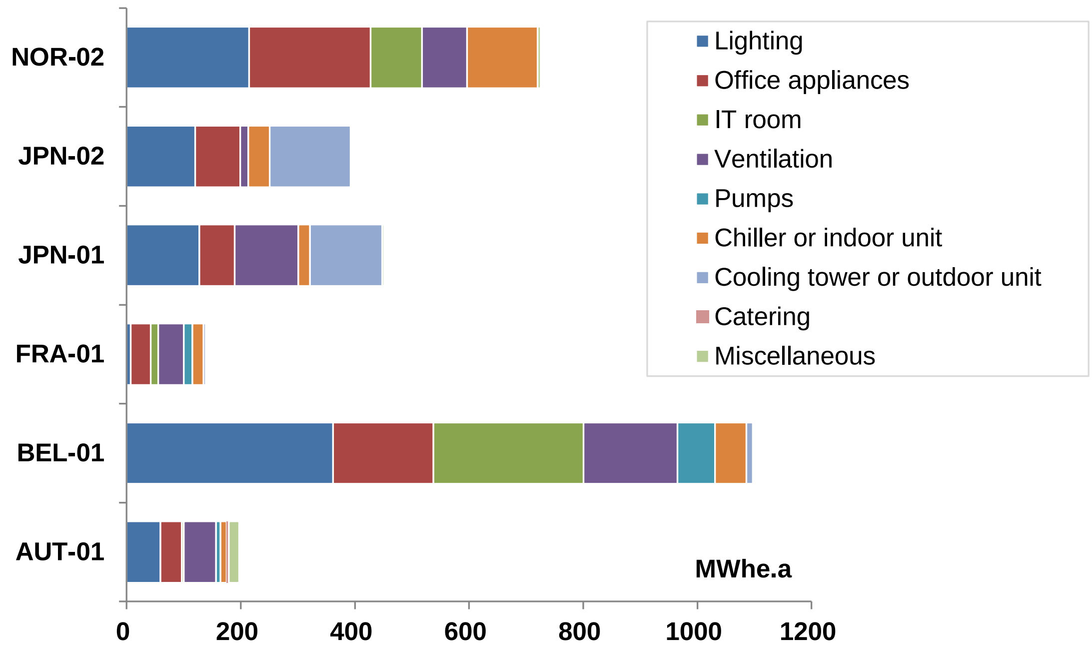
2) **Energy comparison**

Table 3.4 compares the heating energy use and electricity use of eleven office buildings.

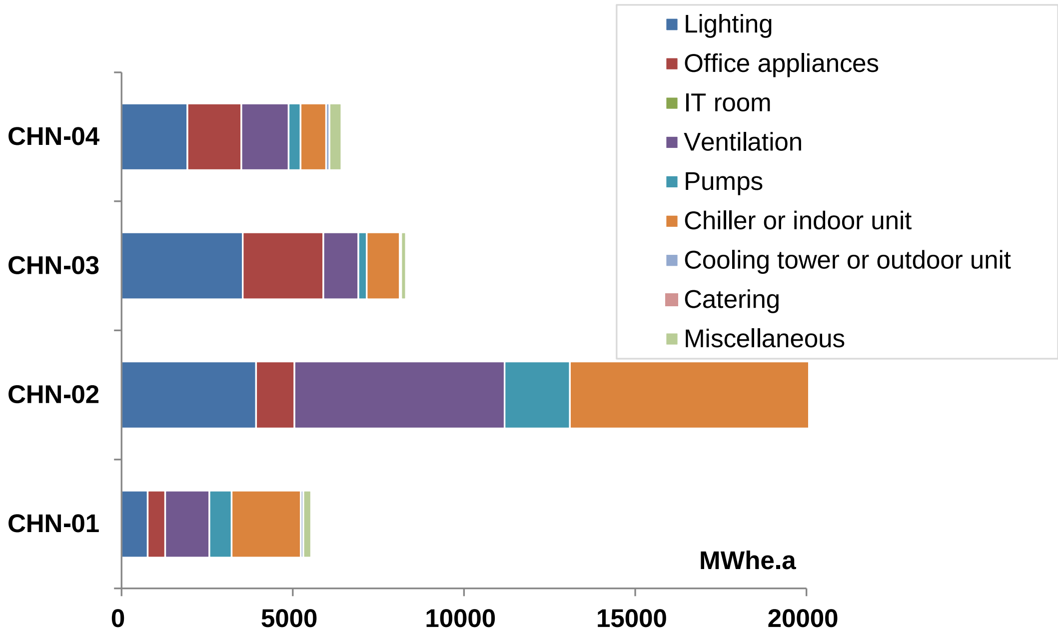
Table 3.4. Energy use of twelve case study office buildings (Unit: $MWh_h.a$)

	A1	B1	C1	C2	C3	C4	F1	J1	J2	J3	N2
Typology	O1	O2	O2	O2	O2	O2	O1	O1	O1	O1	O2
Total heating use (MWh_h.a)	213.8	1074.9	0	0	6873.7	2452.5	220.7	N.A	N.A	N.A	609.7
Total electricity use (MWh_e.a)	197.2	1096.8	5531.3	22520	8298	6420.1	138.6	451.3	392.5	366.9	743.8

The total electricity consumption is relative to the gross floor area of buildings. Figure 3.5 compares total electricity use of buildings less than 30,000 square meters and more than 30,000 square meters separately. The total electricity consumption of office buildings less than 5,000 square meters (AUT-01, FRA-01, JPN-01, and JPN-02) is less than 500 MWh_e per year; the total electricity consumption of office buildings around 17,000 square meters (BEL-01 and NOR-02) is 700~1200 MWh_e per year; and the total electricity consumption of office buildings more than 30,000 square meters is more than 5,000 MWh_e per year. The electricity use of ventilation and cooling systems of large-scaled office buildings are larger than individual offices, by comparing the electricity use per square meter.



(a) Total electricity of case buildings (less than 1200 MWh_e per year)



(b) Total electricity of case buildings (more than 1200 MWh_e per year)

Figure 3.5.Electricity consumption of case study office buildings (Unit: $MWh_e.a$).

3) The impact on energy use of occupant behavior

The use of lighting systems, office appliances and HVAC systems is studied by questionnaires and on-site measurements. This section focuses on occupancy patterns, artificial lighting schedules, turn-off rates of office appliances during off-hours, and the use of blinds, windows and HVAC systems. There are three major findings:

a) *Occupant behavior of artificial lighting can be separated into four stages*

Based on on-site investigations including questionnaires, measurements, and observations, a hypothesis has been proposed to illustrate the decision-making chain from individual demand to overall energy use of the lighting system. This chain can be separated into four stages:

I) Physical demand: the energy use of the artificial lighting system is modified in order to satisfy the fundamental physiological needs for illuminance during working hours.

II) Psychological demand: the energy use of the artificial lighting system is adjusted to provide a more comfortable and pleasing light environment.

III) Space demand: the energy use of the artificial lighting system is changed considering the psychological demands of multiple occupants in an area.

IV) Actual supply: the total energy use of the artificial lighting system of an office or a whole office building.

A simulation model was established, focusing on the energy use of lighting in an office zone with multiple occupants based on the data collected from CHN-02, CHN-03, and CHN-04 (as shown in Appendix III-1 “Technical report ‘Occupant behavior and impact of energy in office buildings’ “).

Key factors that impact each stage include building design (shape and direction), lighting design density, occupancy rate, energy conservation consciousness, service class of the building, group decision impact, zoning design, automatic/manual control, and manager behavior. The quantitative decomposition of each stage's impact is illustrated in Figure 3.6.

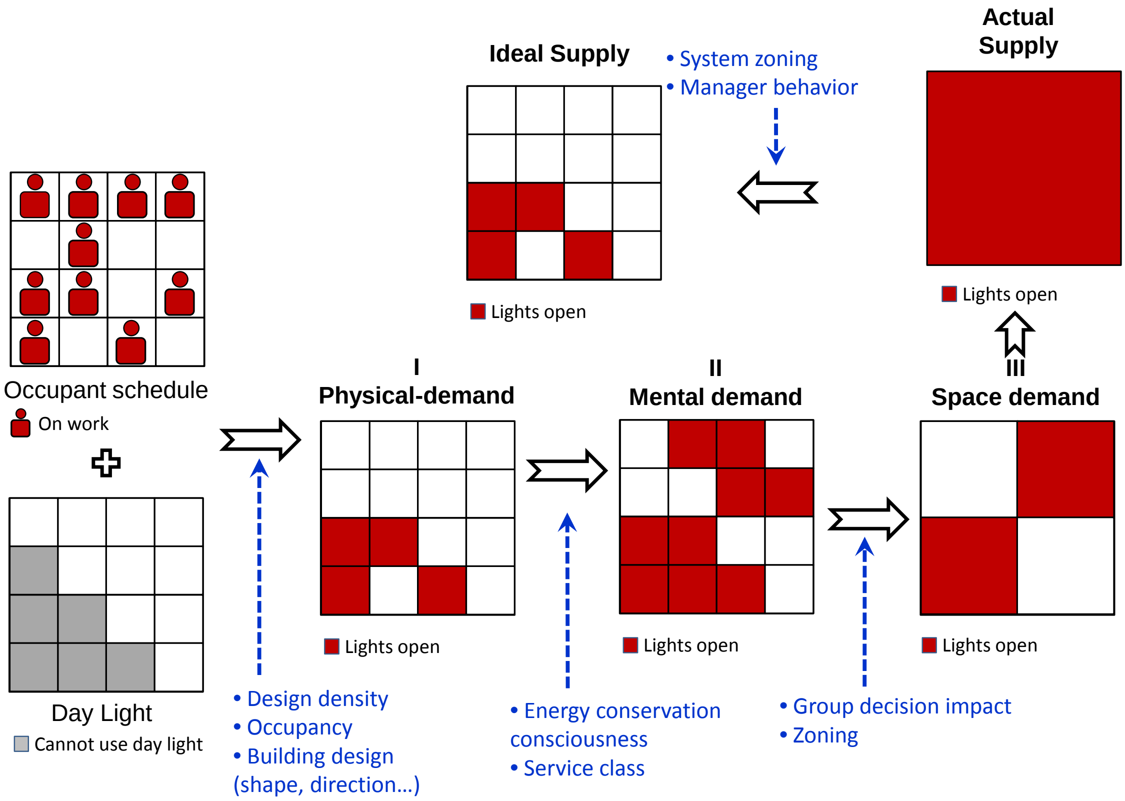


Figure 3.6. Four stages of occupant behavior's impact on artificial lighting utilization.

Based on on-site survey and simulation, the lighting energy use of three office buildings are compared in Figure 3.7. The lighting energy use indicator on a typical working day of CHN-02 is 240 $Wh_e/(m^2.day)$, larger than 180 $Wh_e/(m^2.day)$ of CHN-03 and 50 $Wh_e/(m^2.day)$ of CHN-04. However, the reason for the high energy consumption of CHN-02 and CHN-03 differs. The reason for the former building is the high design capacity of the lighting system (20 W/m^2 lighting capacity), while the reason for the latter building is the high physical demand and energy extensive manager behavior causing longer lighting hours. The lighting system design capacity of CHN-04 is 10 $W/(m^2)$, not obviously smaller than CHN-03, but the shallower building depth effectively decreases artificial lighting hours.

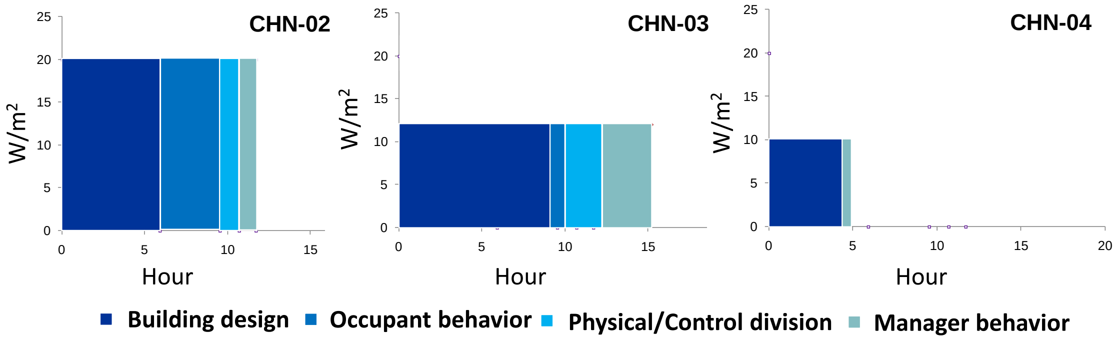


Figure 3.7 Quantitative decomposition of four stages of occupant behavior impact on artificial lighting utilization.

b) ***Power capacity and turn-off rates of offices appliances are different***

The energy consumption of office appliances is determined by the power capacity and integral use hours. According to the survey, the integral use period during working hours does not display great variance, but the turn-off rates during off-hours and the power capacity differs from each other.

For example, the power capacity of CHN-04-A is 46 W per worker, which is less than the other offices, due to the fact that most occupants use laptop computers instead of desktop computers. On the contrary, the computer and larger monitor percentage of CHN-02 is larger than the others. The average power capacity of office equipment is 127 W per worker.

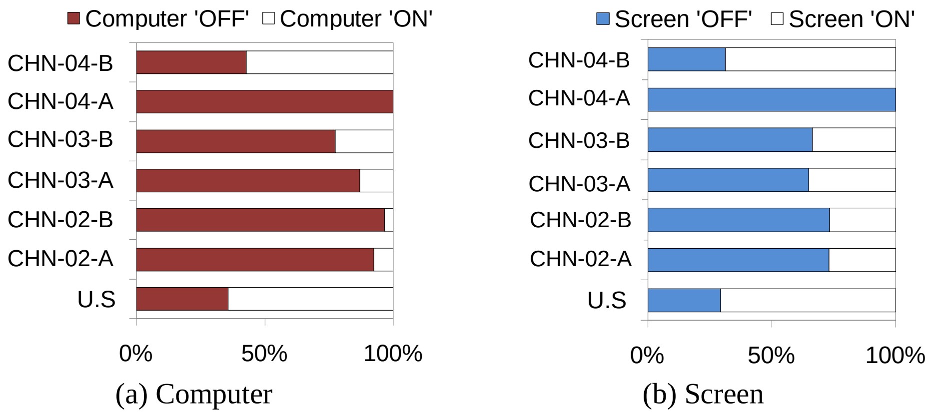


Figure 3.8. Turn-off rate of computers and screens of case building during off-hour (U.S. data source: LBNL, 2001. K. Kawamoto, 2001. K. Kawamoto, J. Koomey, etc. Electricity used by office equipment and network equipment in the U.S: detailed report and appendices, LBNL-45917, Lawrence Berkeley National Laboratory, Berkeley, CA, February, 2001.).

Figure 3.8 shows that the turn-off rate of computers in CHN-02 is higher than other offices. More than 77% of computers are shut off at night. However, the turn off rate of CHN-04-B is close to offices in the U.S., where less than 36% of computers are turned off at night. The turn off rates of monitors is lower than computers', only 30% of monitors are turned off at night in the U.S. and CHN-04-B, and 65% to 75% monitors are turned off in CHN-03 and CHN-02. Due to all of occupants using laptop in

CHN-02-A, almost 100% computers are shut off at night. F. Han[1] once investigated and concludes that turn off rates of computers in campus building in China is usually higher than in the U.S.

c) ***Window operation and ventilation mode has strong relationship with energy use***

Figure 3.9 explains the relationship between window opening and mechanical ventilation systems. For buildings designed with inoperable windows, ventilation can only be realized by mechanical systems such as Air Handling Units, Primary Air Units, or Fan Coil Units. The operation hours are only controlled by the building operator/manager if there is no interacting complaint mechanism in the building. In buildings designed with operable windows, a building operator/manager can control the mechanical ventilation system, as well as windows in public and office areas. Thus, a good feedback mechanism should be set up to balance window opening and mechanical ventilation systems. For example, if many occupants open windows in an office, the Primary Air Units should be turned down or shut off accordingly by the building operator to realize energy conservation. But according to our investigation, few office buildings set up the special control logic connecting window opening and the mechanical ventilation system. The latter one is usually controlled manually by the building operator or automatically by the BMS system with first control logic.

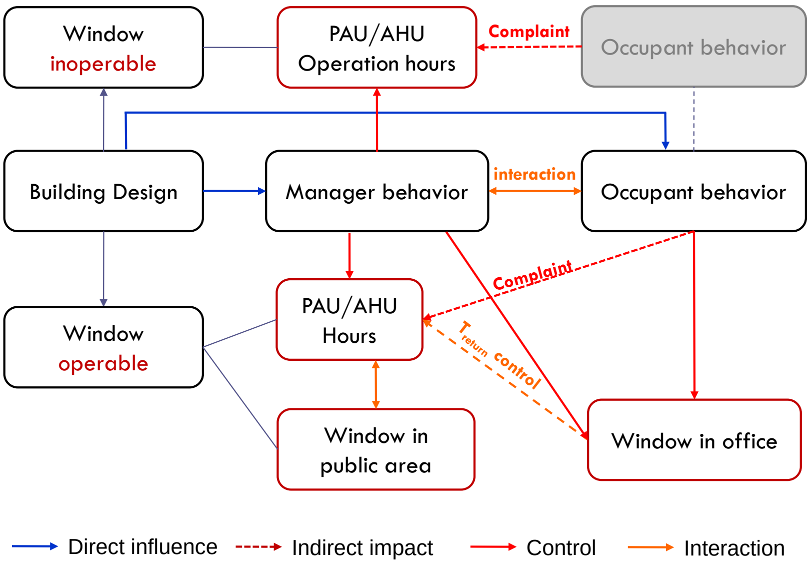
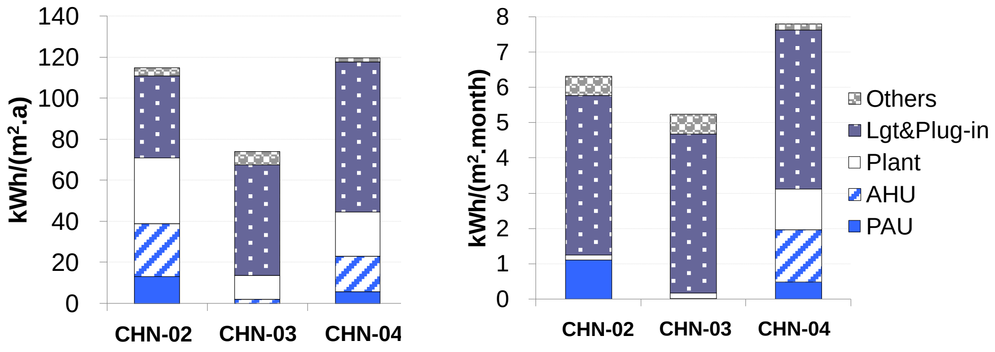


Figure 3.9. Logistical diagram of the relationship between window opening and mechanical ventilation system.

[1] F. Han. Comparison of commercial buildings' energy consumption pattern in China and USA [C]. Department of Building Science and Technology, Tsinghua University, China, 2010.



(a) Annual (b) Transitional season (April)

Figure 3.10. Electricity use intensity of PAU of three office buildings in China.

For instance, the annual electricity use intensity of PAU in CHN-02 is 13.2 $kWh_e/(m^2.a)$, higher than 5.8 $kWh_e/(m^2.a)$ in CHN-04 and 0.2 $kWh_e/(m^2.a)$ in CHN-03, as shown in Figure 3.10. The building manager of CHN-03 must shorten the operation hours of the PAU due to the fact that occupants can manually open some external windows, which greatly reduces the energy consumption of the mechanical ventilation. PAU of CHN-02 operates 14 hours per day, which causes large electricity consumption by the mechanical ventilation system.

3.2.2 Residential building

1) **Case study database**

Similar to office buildings, Table 3.6 presents the information status of each residential building.

Table 3.3. Six categories of case studies information

Building	A 1	A 2	A 3	A 4	A 5	A 6	B 1	B 2	B 3	C 1	J 1	J 2
Climate												
HDD				●			●	●		●		
CDD				●			●	●		●		
Whole building characteristics												
Year built	●	●	●	●	●	●	●	●		●	●	●
No. of floors	●	●	●	●	●	●	●	●	●	●	●	●
GFA	●	●	●	●	●	●	●	●	●	●	●	●
No. of occupants	●	●	●	●	●	●	●	●		●	●	●
Building envelope												

Material	●	●	●	●	●	●	●	●		●	●	●
U-value	●	●	●	●	●	●	●	●	●	●	●	●
Window to wall ratio	●	●	●	●	●	●	●			●	●	
Building services and energy systems												
Heating system	●	●	●	●	●	●	●	●	●	●	●	●
Air-conditioning system										●	●	●
Ventilation						●	●		●		●	●
Lighting							●	●		●	●	●
Domestic hot water	●	●	●	●	●	●				●	●	●
Cooking							●			●	●	●
Building operation												
Occupancy schedule	●	●	●	●	●					●	●	●
Space heating				●	●				●	●	●	●
Space cooling										●	●	●
Ventilation	●	●	●	●	●						●	●
Lighting										●	●	●
Cooking										●	●	●
Domestic hot water											●	●
Energy indicator												
Energy carrier	●	●	●	●	●	●		●	●	●	●	●
Aggregation of energy	●	●	●	●	●	●		●	●	●	●	●
Normalized energy use				●		●						

●: Related information is collected and provided by contributors.

2) **Energy comparison**

All twelve case study buildings are located in cold climate regions, thus heating demand comprises the largest portion of the energy consumption. The source for space heating and DHW in the case study buildings varies widely, including gas boiler, oil boiler, wood burning oven, solar panel, gas furnace, air-to-water heat pump, air conditioner (air-to-air heat pump), urban district heating network, direct electric heater, and electric thermal storage heater.

Table 3.6 and Figure 3.11 compare the heating energy use and electricity use of the twelve buildings. According to the results, electricity use of buildings in China (in the northern city of Beijing), Austria, Belgium and Japan is between 17.5 and 44.6 $kWh_e/(m^2.a)$; heating energy use of these buildings ranges from 45.0 to 155.4 $kWh/(m^2.a)$. There is no large difference of total energy consumption for the case study buildings from these four countries. There is also no strong evidence that an apartment building consumes less than a residential house.

Table 3.4. Energy use indicator of 12 case study residential buildings

No.	Type	Source	Electricity (excluding heating)	Heating (space heating & DHW)	DHW (kWh/ca)
A1	house	gas boiler + wood burning oven	19.2	81.8	N/A
A2	house	oil boiler + thermal solar panels	17.5	80.2	N/A
A3	house	gas boiler + wood burning oven	23.7	51.2	N/A
A4	house	gas furnace (for heating & DHW)	38.8	77.0	N/A
A5	house	oil boiler + wood burning stove + thermal solar panels	22.0	101.4	N/A
A6	apartment	gas boiler (radiant floor heating)	30.0	45.0	N/A
B1	house	air-to-water heat pump (heating floor)	N/A	71.9	1,605.3
B2	apartment	gas boiler (6 radiators, thermostat in living room)	28.1	57.3	901.0
B3	apartment	Electric heater	36.8		N/A
C1	apartment	City heating network	32.1	100.4	341.6
J1	house	Electric thermal storage heater + electric water heater	31.4	112.6	2,293.8
J2	apartment	air conditioner for heating + city gas for DHW & oven	44.6	155.4	2,775.9

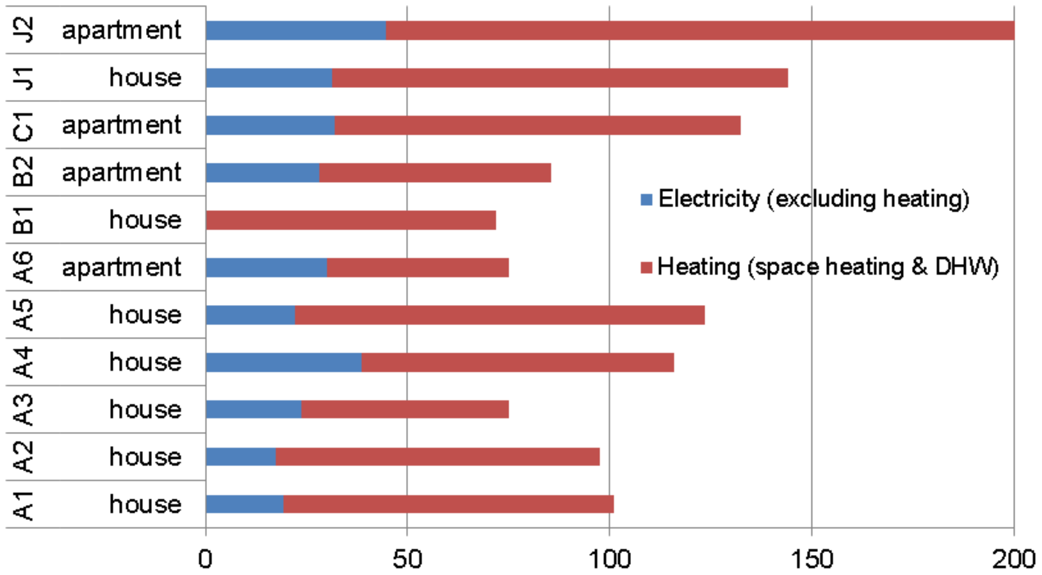


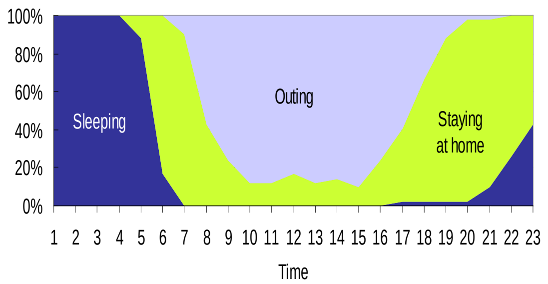
Figure 3.11. Electricity & heating energy consumption of residential case study buildings (Unit: kWh/(m^2.a); electricity use for heating is directly converted to heat by calorific value).

3) **Occupant behavior impact on energy use**

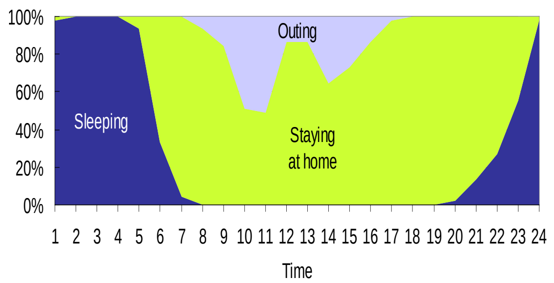
Occupant behaviors, such as occupancy schedules, window opening, use of air conditioner, use of lights, and use of household appliances, have been studied by questionnaire surveys or onsite measurements in order to explore how an occupant behaves at home and the impact of occupant behaviors on building energy use. There are three major findings:

a) ***Occupancy, heating operation schedule, and set point temperature show large differences and results in large differences in building energy consumption***

The occupant schedule is the major investigation target that has been surveyed. Figure 3.12 shows the detailed investigation result of occupant behavior in Japan. According to questionnaire surveys, three scenarios named “Energy-saving”, “Normal” and “Energy-wasting” are compared. It can be concluded that reducing the operating time or amount of space heating and domestic hot water equipment can decrease space heating energy use by 40 to 46% compared to the “energy-wasting” scenario (see Figure 3.13).



(a) Worker



(b) Housewife

Figure 3.12. Typical occupant behavior surveyed in residential buildings in Japan.

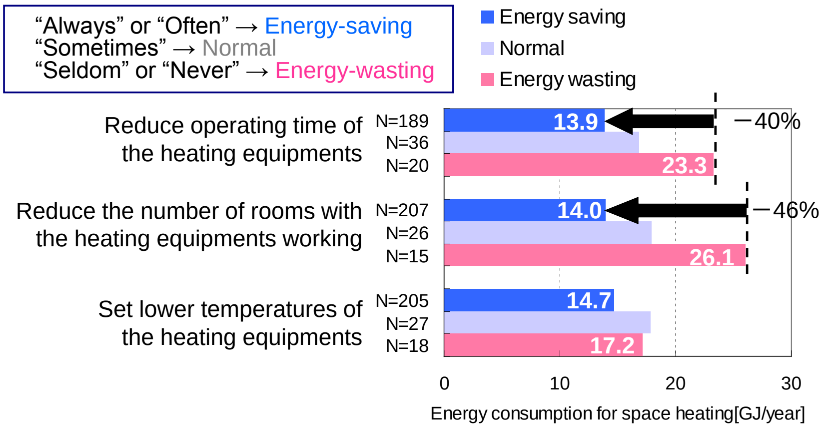


Figure 3.13. Statistical impact of behavior on space heating energy use in residential buildings in Japan.

b) ***Different countries exhibit large differences in DHW use***

Due to different hot water demands (shower, bath, hand washing, etc.), the per capita energy use of domestic hot water (DHW) in China, Belgium, and Japan shows large variations (see Figure 3.14). The DHW use in Japan is highest, followed by Belgium, and in China it is the lowest. According to the investigation, the Japanese strongly prefer bathing in tubs, while the Chinese often prefer showering, leading to a 7~9 time difference in DHW use.

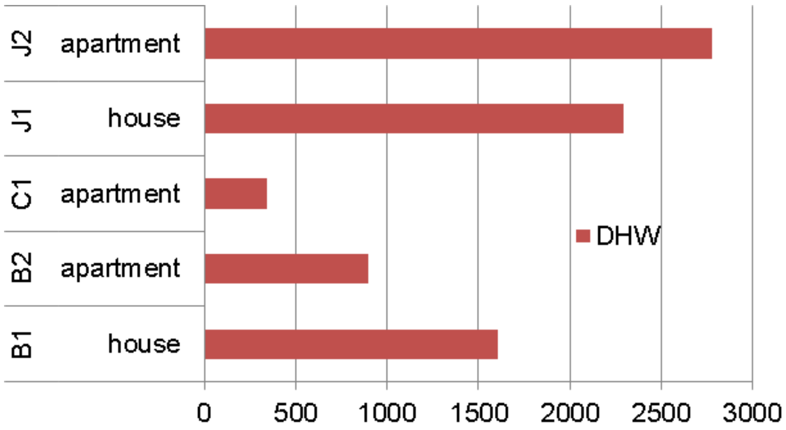


Figure 3.14. DHW energy consumption indicator of residential case buildings (Unit: kWh/(ca.a)).

c) ***Typical behavior patterns can be found in real cases***

Different behavior patterns related to huge differences in energy use have been found in residential buildings. Table 3.7 and Figure 3.15 show several heating patterns and their heating energy use from the Japanese residential database. The four heating patterns are observed from four detached houses, where space heating in 'all rooms' includes both the living room and bedroom, 'part rooms' are either the living room or bedroom only; for a heating period of '24h' means continuous heating all day, and

‘occupied’ means periodic heating when the spaces are occupied. The measured heating energy use due to the four patterns differs by a factor of 5 to 20.
Table 3.8 and Figure 3.16 show several cooling patterns and their AC energy use. The cooling patterns are observed from Chinese residential buildings using split AC units, where for cooling ‘all rooms’ includes both living room and bedroom, ‘part rooms’ includes living room or bedroom only; for cooling period ‘24h’ means continuous cooling all day, ‘occupied’ means periodic cooling when the spaces are occupied, and ‘feel hot’ means periodic cooling when the spaces are occupied and the indoor temperature is higher than some comfort level. The simulated cooling energy use due to the four patterns differs by a factor of 3 to 10.

Table 3.5. Heating patterns in residential buildings

Heating pattern	Time and space
1	All rooms heated for 24h during winter
2	All rooms heated when occupied
3	Only part rooms heated for 24h during winter
4	Only part rooms heated when occupied during winter

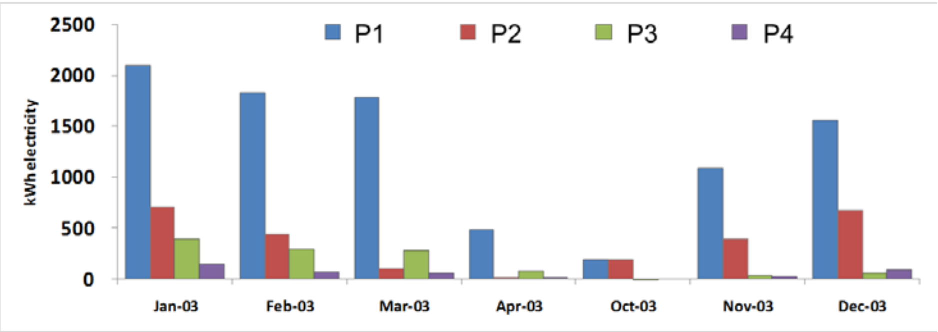


Figure 3.15. Measured energy use of heating patterns in Japan (Unit: kWhe/a).

Table 3.6.Cooling patterns in residential buildings

Cooling pattern	Time and space
1	All rooms cooled for 24h during summer
2	All rooms cooled when occupied
3	Only part rooms cooled when occupied
4	Only part rooms cooled when feel hot

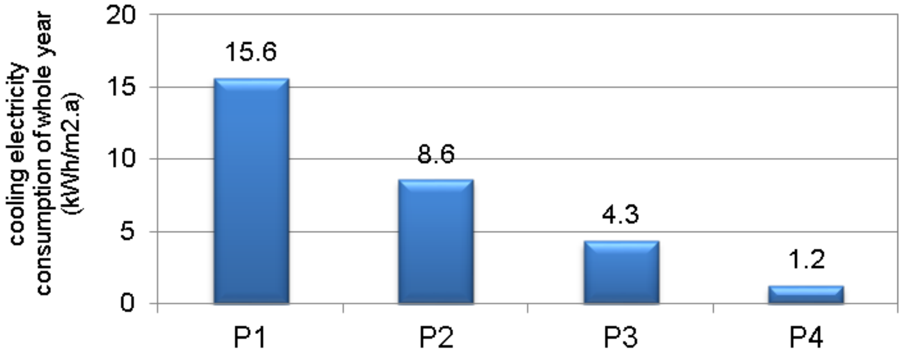


Figure 3.16. Simulated energy use of cooling patterns in China, Beijing (Unit: kWhe/(m2.a))

4. Analysis of data collection systems for building energy management system

ABSTRACT

Monitoring is fundamental when aiming to better understand the energy behavior of buildings. Deficiencies in energy metering and consumption data have been an obstacle to comprehensive analysis and verification of the real energy performance of buildings. The situation is changing, however, with the current rapid introduction of the new automated meter reading technology (AMR) combined with modern information and communication technologies (ICT). Millions of so-called "smart meter" systems, comprising an electronic box and communications link, are being installed all over the world.

The objective of this chapter is to review state-of-the-art online data collection systems and technologies and to analyze some applications developed in different countries for monitoring, analysis and management of energy, water, and other building consumption. This chapter contains a review of five online data collection systems, from Finland, China, Japan, Germany, and Spain. These systems were analyzed to identify the main features and characteristics of various measurement strategies for online data collection and monitoring systems designed for building energy systems and indoor air quality.

Summary

What is covered

Subtask B2 sought to analyze state-of-the-art online information from data collection systems and technologies and to analyze particular applications developed by different countries for monitoring building energy consumption. The work of Subtask B2 has defined different online data collection systems, and examples are listed for further reference. The work also compares different online data collection systems with respect to scale, building type, data type, and data analysis. Subtask B2 reviewed five online data collection systems, from Finland, China, Japan, Germany, and Spain. These systems were analyzed to identify the main features and characteristics of various measurement strategies for online data collection and monitoring systems designed for building energy systems and indoor air quality. Also, an international online date collection platform is proposed.

Why it is important

Monitoring is crucial to better understanding the energy behavior of buildings. New automated meter reading technology combined with modern information and communication technologies are overcoming previous data deficiencies. Millions of smart meters are being installed. In addition, fast-evolving sensor technologies with wireless and other communication capabilities offer cheap means for complementing energy data collection with measurements of various environmental factors. However, there are not precise definitions for these different online data collection systems. Thus, the result of this work may be used also as guidelines for different practitioners, such as designers, operators and other businesses.

Key points learned

- All online data collection systems normally require five components: measuring, obtaining external data (such as weather information), data transfer, data analysis, and reporting.

- Individual and open access systems are the two types of monitoring systems are mostly widely used. Most of these five elements are implemented by one company, who manages a closed system where no one else has access; this is called an ‘individual’ online data collection system. The other type is the ‘open access’ system, which allows bidirectional data transfer. Open access systems can interact with other systems.
- A monitoring system should be able to apply varying factors to measurements, and allow meter replacements and new instrumentation, or even detect instruments automatically.
- Online smart meter systems will create new possibilities for the development of monitoring systems, offering accurate and almost real-time information to various stakeholders.
- Mass production of new-type sensors often with wireless communication capabilities offer cheap and flexible means for measuring both environmental factors and occupation of buildings
- Technologies mentioned above are utilized typically in building automation systems (BAS), which are becoming more popular especially in office and commercial buildings and include also many functions of monitoring systems. Developed and marketed often by big international players, these systems are typically proprietary and closed however, making integration and common utilization difficult.

Conclusions

Subtask B2 reviewed, analyzed, and reported on state-of-the-art online data collection systems and technologies in order to identify the main features and characteristics of various measurement strategies for online data collection and monitoring systems. Real systems were also demonstrated, based on various existing applications in participating countries.

These existing online data collection systems will provide energy users and other actors with timely information about their domestic energy consumption. Based on this kind of data the energy supplier, customer or service provider can view how much energy is used, when it is used, and identify opportunities for saving energy. On-going smart meter rollouts will create new possibilities for the development of monitoring systems, offering accurate and real-time information for various stakeholders. Smart meters transmit data on the usage of electricity in fifteen-minute intervals, thus motivating consumers to shift energy consumption to the time of day when power is cheapest. For utilities, this can mean better management of the power grid and elimination of the need to develop expensive power generating systems. Data and information provided by smart meters should be integrated in real time with building automation systems in order optimize the use of energy in various building systems to capture the full potential for environmental and energy savings.

4.1 Background

4.1.1 Building energy consumption and smart metering

Buildings are responsible for at least 40% of energy use in many countries, with this energy mostly derived from fossil fuels (WBCSD, 2008). Monitoring is fundamental when aiming to better understand the energy behavior of buildings. Deficiencies in energy metering and consumption data are an obstacle to comprehensive analysis and verification of the real energy performance of buildings. The situation is changing, however, with the current rapid introduction of automated meter reading (AMR) technology combined with modern ICT. Millions of smart meters, comprising an electronic box and communications link, are being installed all over the world.

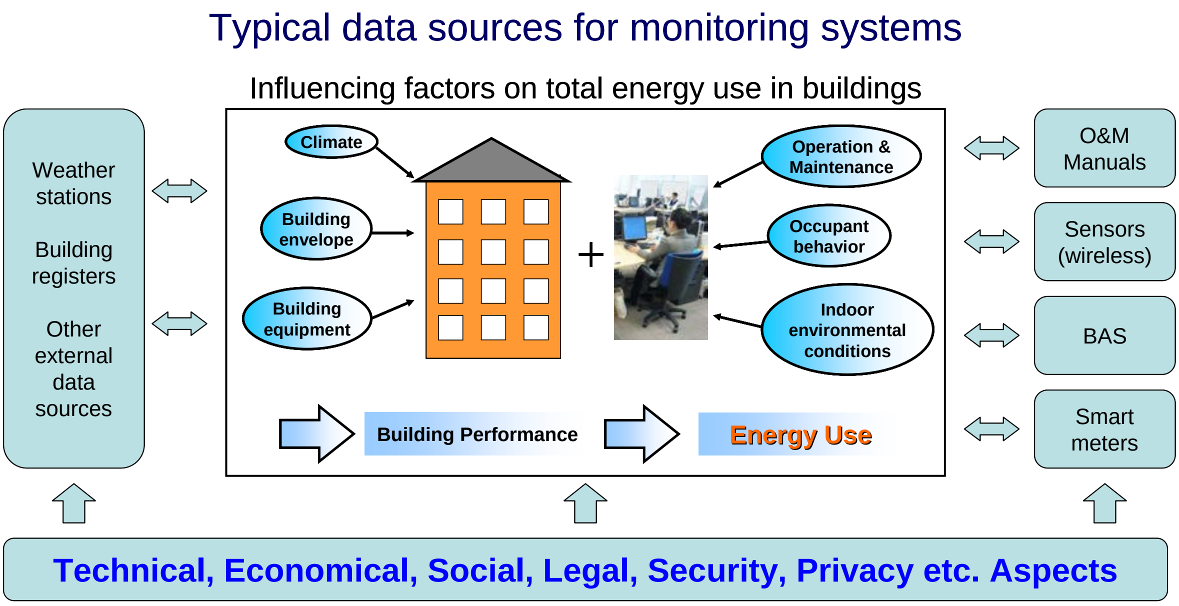


Figure 4.1. Six factors influencing total energy use in buildings and typical data sources.

In addition to the six influencing factors presented in Figure 4.1, the analysis should also take into account potential data sources for the factors as well as external parameters such as “social and economic aspects”. Besides standardization efforts these include also legal, privacy, data security, and other issues, which might put various limitations on the use of data and ability to publish the results.

4.1.2 Relevant European directives regarding smart metering and other data sources

Two recent European Directives, [Directive 2004/22/EC] on measuring instruments (MID), and [Directive 2006/32/EC] on energy end-use efficiency and energy services (ESD), are important with regard to smart metering in Europe. The Energy Performance in Buildings Directive [Directive 2002/91/EC] and the Commission's third legislative package for Electricity & Gas markets [EC 2007] also include issues relevant to smart metering. In addition, the European Commission has issued a mandate (see [ESO 2009]) to the three European Standards Organizations (ESO) – CEN, CENELEC and ETSI – for the standardization of smart metering functionalities and communication for usage in Europe for electricity, gas, heat and water applications (M/441– Annex 1).

The ESD and the EU directive concerning common rules for the internal market of electricity (2009/72/EC) require the implementation of "intelligent metering systems". Such systems must be in place for 80% of electricity consumers by the end of 2020. The number of electricity meters potentially required to be replaced during the coming years makes this standardization work urgent. In response to European Commission Mandate M/441 in the field of measuring instruments for the development of an open architecture for utility meters involving communication protocols enabling interoperability (smart metering), the ESOs established together with the relevant stakeholders the Smart Meters Coordination Group (SM-CG) in 2009. This group is a joint advisory body that provides a focal point concerning smart metering standardization issues. The standardization work of the SM-CG focuses on meeting the needs of the residential (household) and small and medium-sized enterprise (SME) sectors. This corresponds to the focus of Mandate M/441 and the need to improve consumers' awareness of their energy and water usage ("consumption").

The first phase of the mandate requests the ESOs to produce a European standard for communications. In this context, the Smart Meters Coordination Group developed a Technical Report, CEN-CLC-ETSI TR 50572:2011 'Functional reference architecture for communications in smart metering systems', which identifies the functional entities and interfaces that the communications standards should address. It is intended to support the development of software and hardware architecture and related standards. The report is as an appendix of the main body of the Annex 53 final report.

In addition to energy and water consumption, the main influencing factors discussed earlier should also be monitored. Data about outdoor and indoor conditions and occupation should be available using the same frequency (time periods) to enable analysis of the interaction between these other factors and energy consumption. Building automation systems (BAS), if available, can offer this kind of data, but in most cases the influence of human behavior is difficult to separate from other factors, or there is no data available for this kind of analysis. An obstacle for the utilization of BAS data is also the fact that there is no common standard for the identification and format of the data measured and handled in BAS. Systems are closed and proprietary, meaning that interfaces for data must be realized case by case. Because of their business models BAS vendors are often not interested in making their data accessible, which hinders the integration of various data sources and systems. Collaboration between major building owners and other stakeholders would be needed to drive common standards and definitions for BAS projects.

New, increasingly wireless, sensor technologies might offer cost effective solutions for certain needs, but installation and maintenance costs, among other reasons, have limited their utilization in buildings so far. Sensors have been commonplace in the cars and consumer electronics industries for a long time. However, mere baby steps have been taken in the fields of buildings, environmental monitoring and, in particular, healthcare. Sensor systems are usually installed where wires can easily be drawn. Where the construction of a wired network is impossible or too expensive, sensor network development has fallen by the wayside, and usually a wireless network is prescribed as the solution for these applications. Though wireless sensor networks have been the subject of intensive research for two decades, very few have actually been built, with the exception of military applications. Unrealistic expectations placed on wireless sensors might be one of the reasons for the current situation. The future role of sensors and sensor networks is discussed more in details in an article by Heikki Seppä from VTT, which can be found in appendix IV “Data collection systems for the management of building energy system”.

The maximum demand for electricity is highly concentrated in 1% of the hours of a year. If there was a way to shave off some of this peak demand, this would eliminate the need to install ‘peak’ generation capacity that is used less than a hundred hours a year. Peaking plants also run infrequently, making investment in greater efficiency unattractive. The Time of Use (TOU) rate divides the day into two or more time periods, with a different rate for each period, see Figure 4.2 (Faruqui 2009). At present, wireless sensors and devices are limited by the power they need. A few operating systems were specially designed to ensure that the node uses very little energy when the sensor does not need to act (Jang, 2008). Oksa (2008) presented tremendous opportunities for future energy monitoring systems. Sung (2010) introduced the characteristics of the ZigBee wireless communication technology which is both low power and low cost, so it suits the control and sensing needs of industry, households, and healthcare. The ZigBee software standards were primarily set by IEEE 802.15.4, which defined two physical layers (PHY) – the free 900 MHz and 2.4 GHz transmission.

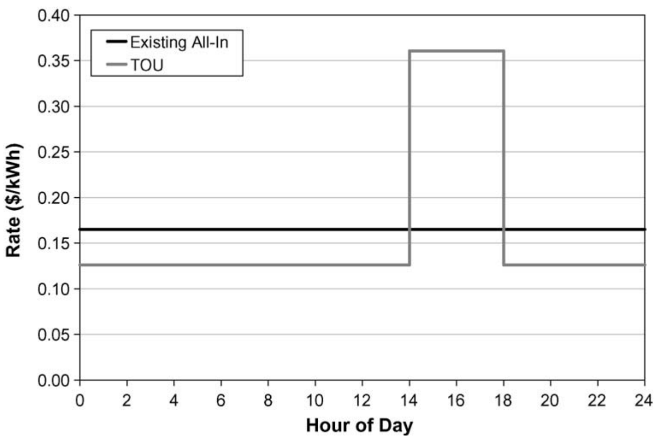


Figure 4.2. Illustration of TOU

4.2 Definition of an online data collection system

All online data collection systems require components for measuring, obtaining external data (such as weather information), data transfer, data analysis, and reporting. Typically, most of these five elements are implemented by one company, managing a closed system where no-one else has access; this is called an 'individual' online data collection system. Another type is the 'open access' system, which allows bidirectional data transfer. The open type of online data collection system can interact with other systems.

4.2.1 Energy Monitoring, Management and Information Systems

There is widespread recognition of the large gap between building energy performance as designed and energy consumption measured post-occupancy. A growing body of evidence indicates the value of permanent interval metering and monitoring, particularly in the context of monitoring-based and continuous or retro-commissioning [Mills and Mathew 2009; Capehart and Middelkoop 2011; Granderson 2010; Motegi 2003; Smith 2011]. Also pointing to the value of monitoring, researchers have increasingly documented the positive behavioral impacts of making energy consumption visible to building occupants and residents. The Energy Information System (EIS) is viewed as a promising technology for addressing this gap.

The EIS is motivated by two closely related concepts. The first is the idea that buildings are complex, dynamic systems, and that realizing optimal energy performance requires higher-granularity time series data than can be gained from monthly utility bills. The second is the notion that an EIS is critically important because it can process data into actionable information, and thereby serves as the informational link between the primary actors influencing building energy efficiency. As depicted in Figure 4.3, the EIS is broadly defined as performance monitoring software, data acquisition hardware, and communication system used to store, analyze, and display building energy data. Time-series data from meters, sensors, and external data streams are used to perform analyses such as baselining, load profiling, benchmarking, building-level anomaly detection, and energy performance tracking.

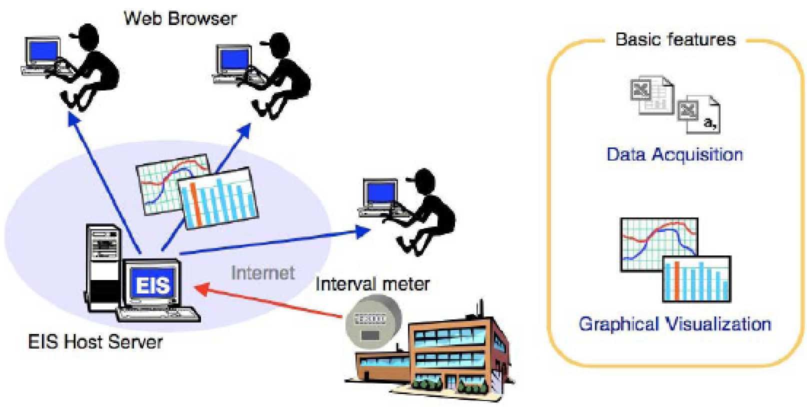


Figure 4.3. Basic energy information system (Motegi and Piette 2003).

4.2.2 ‘Open access’ online data collection system

One typical example of open access data collection system is the e3Portal (http://e3portal.vtt.fi), developed by VTT in collaboration with Finnish municipalities. e3Portal is targeted especially to municipal building owners and offers general information about energy monitoring, management, auditing, etc. In addition, it includes continuously updated data about energy and water consumption in thousands of municipal buildings like schools, kindergartens, offices, hospitals, other health care facilities, etc. Heating energy is made comparable between years and different locations (climate) based on heating degree days. e3Portal acts as a benchmarking platform for individual towns and other municipalities, as well as individual buildings. Anonymous aggregated yearly data is available for all users of the Internet, but access to building level data requires password. The main user interface is shown in Figure 4.4.

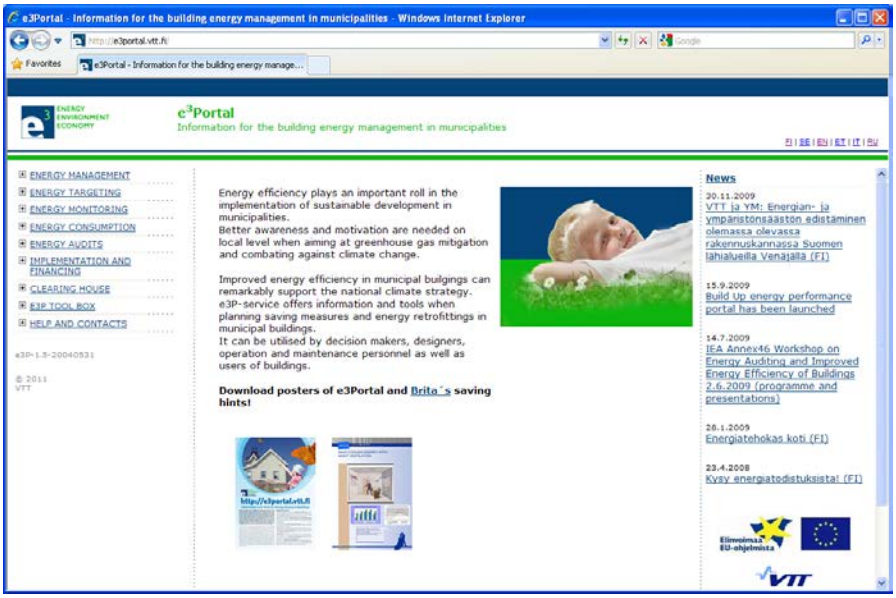


Figure 4.4. Main user interface of e3Portal (http://e3portal.vtt.fi)

The portal also includes tools for updating basic building information and yearly consumption figures via a standard browser. Various kind of reports are available (see Figure 4.5 for examples) on the building level, and the user can easily extract performance ratings for chosen building types, for example according to the Finnish energy performance certification system implemented according to the EU´s EPBD Directive. The portal also includes preliminary map-based reporting features. In addition to providing the consumption data, reports of implemented energy audits are available and summaries of saving measures implemented can be produced. An Estonian version, including similar information about municipal buildings, has also been developed. The portal can compare real energy and water consumption in similar building types both in Estonia and Finland. Thus e3Portal offers also an example of international, cross-border, data exchange. An extension to Russia is under discussion at the moment.

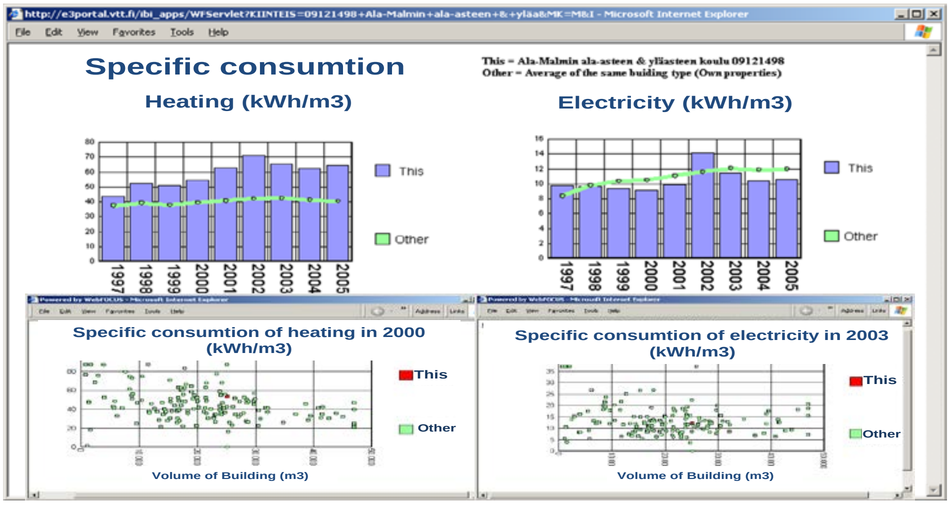


Figure 4.5. Example of an output of e3Portal

The concept realized in e3Portal has been replicated and utilized at VTT for the development of open data collection system for certain special building types. At the moment, the same kind of energy performance information service is available for hundreds of public swimming pools in Finland (http://uimahallit.vtt.fi). Web based tools for updating building characteristics and consumption data are available but require passwords in order to ensure data reliability. Access to various reports including "ranking lists" of specific energy and water consumption, e.g. per user (customer) etc., is open to everybody. Swimming pool operators, for example, can easily locate their position in the performance ranking and compare it to similar kind of pools (some examples in Figure 4.6). Then they can find contact information to the better-performing pools and ask for more information about their technologies and energy saving measures. Building type specific benchmarking reports can be produced such as yearly amount of energy, water and users per pool square meter, in addition to the "normal" m2-, m3- and user/customer related specific consumptions. A similar type of open access data collection and reporting services is under construction for hundreds of Finnish ice skating rinks (http://jaahallit.vtt.fi), but the concept can be easily applied to other public building types as well as schools, kindergarten, hospitals, theaters, etc. For buildings hosting commercial activities like shopping malls, department stores, hotels etc., competitive factors can represent an obstacle or at least restrict the openness of data sharing.

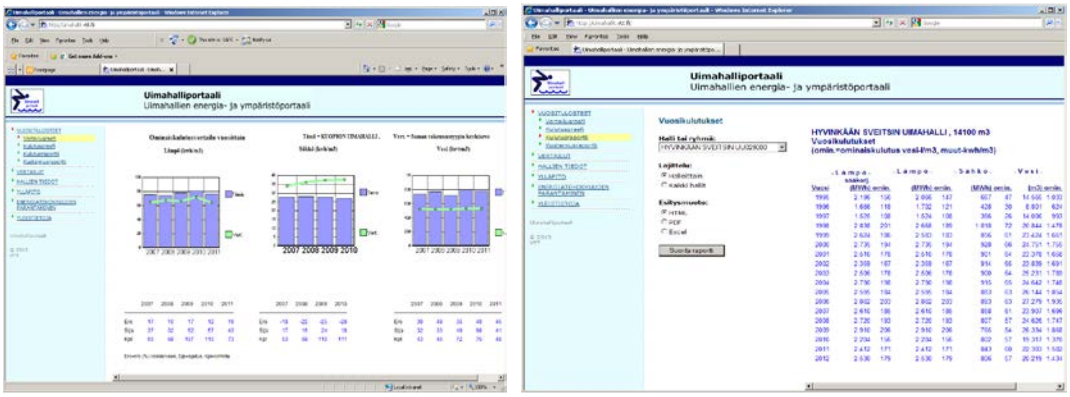


Figure 4.6. Ranking lists and performance benchmarking for public swimming pools in Finland

Another on-going project in the Finnish high-technology Cluster for Energy and Environment (CLEEN Ltd.) offers a completely new approach, shown in Figure 4.5. The idea of the CLEEN MMEA project is to establish an open online marketplace, where services and data from different companies or other public or private organizations can meet. The interfaces are made public so that anyone can join the network easily to buy or sell services. A company can bring all the measured information to the platform and buy different analytic services from several different companies, which then return the results to the platform for other companies to report to the owners of the original company – or alternatively, the analysis results can be given to an energy services company, which can then make a service offer to the owners. Naturally, everything works over secured connections that only show data to those who have been given viewing rights. The general target of the platform is to open the data as much as possible and at the same time create a basis for new types of applications and businesses. The next section introduces some examples of existing systems that could be connected to the MMEA platform to offer energy analysis and reporting services.

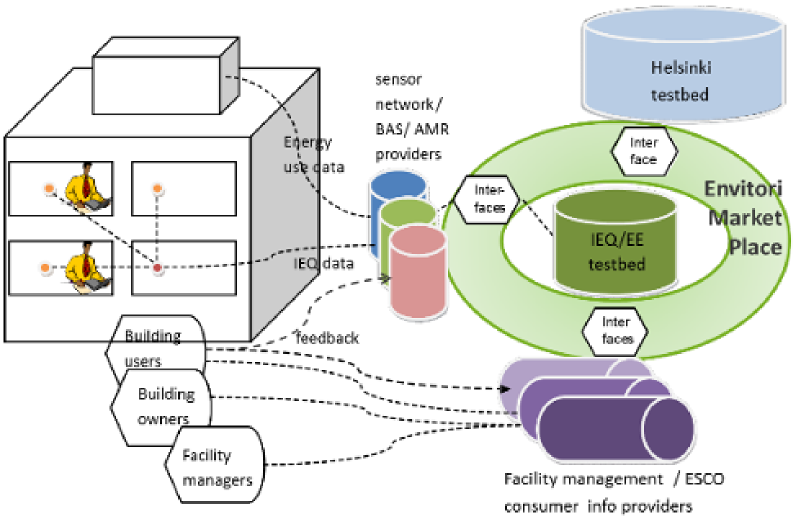


Figure 4.7. Data collection structure of the MMEA project.

4.2.3 Individual online data collection system

The individual online data collection system can have different focuses, such as benchmarking, monitoring or commissioning. One example is the Kulu system developed originally by VTT for municipal building owners. This system has been used by the city of Helsinki for almost 30 years, and today the web-based system eliminates the need for any installations and updating on the user side. The current WebKulu system is briefly described in Figure 4.8. User interfaces are created using standard html and are therefore compatible with most browsers. The Information Builders BI-tool WebFOCUS is used to perform the analyses and create the reports. Information can be added to WebKULU either by reading from data storage or, manually, by using html-type interfaces via a browser. WebFOCUS can also use iWay adapters to connect to different data sources. Results of monitoring can be presented also via the e3Portal.

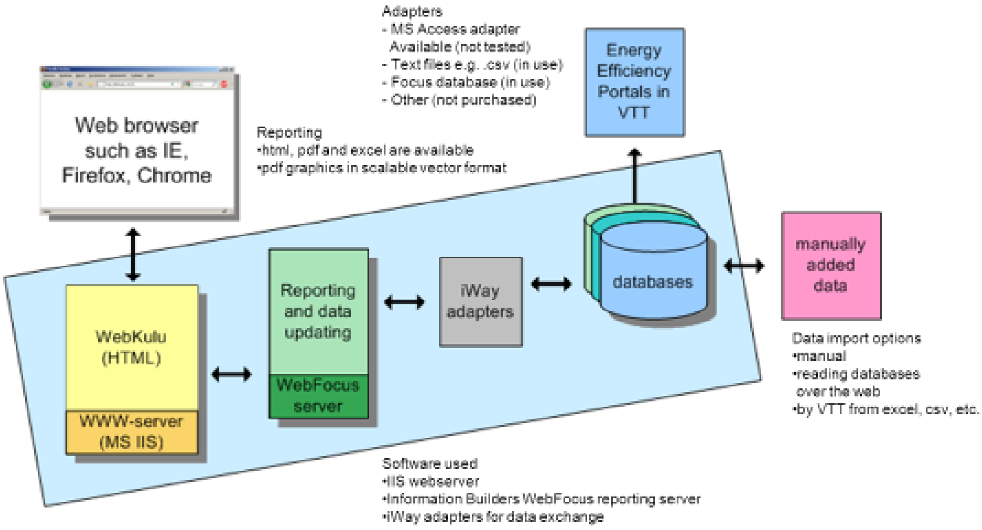


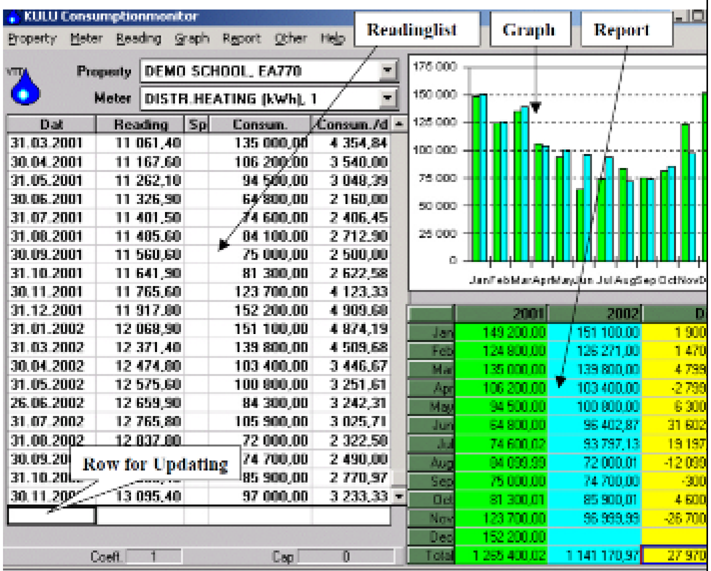
Figure 4.8. WebKulu technical overview.

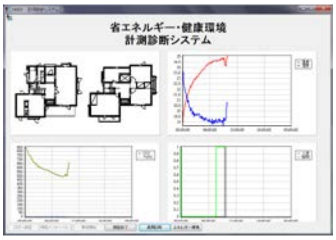
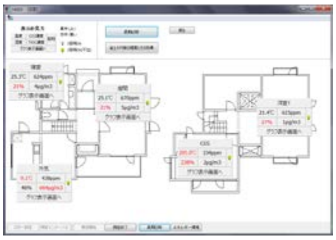
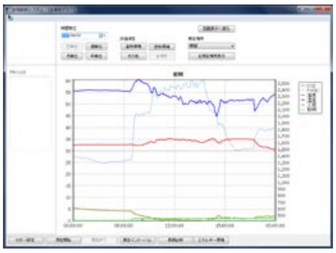
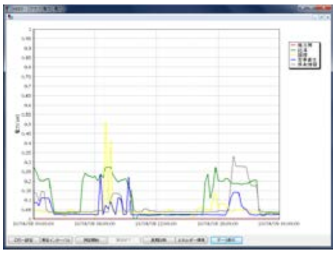
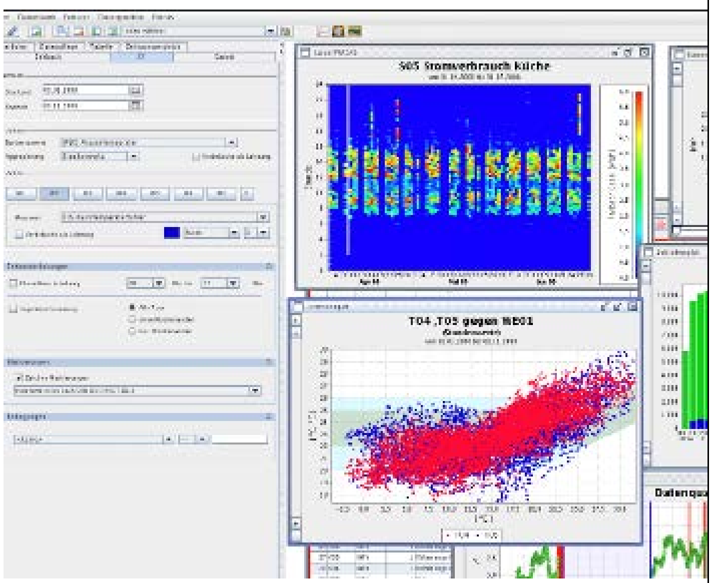
Numerous users in city administration can obtain information on the energy consumption of their own building or building portfolio using the website. It is easy to benchmark the buildings earlier consumption to itself or to other similar types of building. This supports the control of actual performance and planning of improvements. The system can produce feedback to various stakeholders like O&M personnel, designers, managers, occupants, and policy makers. Also the influence and persistence of various saving measures can be analyzed and the feasibility of different technologies can be assessed. As part of EU-wide and national CO_2 and energy saving commitments, the city has defined yearly saving targets for every building owned, and their fulfillment is tracked on a monthly basis by the system. The bonus system of the building managers is connected to these targets and their monitoring.

4.3 Different online data collection systems

Five online data collection systems from Finland, China, Japan, Germany and Spain have been reviewed. The user interfaces of these systems are summarized in Table 4.1 below.

Table 4.1. Summary of different on-line data collection systems.

	Main features	User Interface
Finnish version: VTT Kulu For public buildings	Versatile monitoring tools in standard web browsers. No installations - only access to the internet required. Updating of meter readings, analysis, and reporting can be carried out over the internet. Readings from smart meters and other data sources can be transferred automatically to the Kulu database.	
Chinese version: Energy Sage 1.0 For public buildings	Electricity distribution system and energy consumption features of terminal equipment. Multi-layer data collection system. Breakdown of HVAC system electricity consumption. Hourly data in one sub-system of the data collection system.	

Japanese version: For residential buildings	Real time measurement system that includes information on energy consumption and indoor environment. Diagnostic system: Real-time diagnosis and long-term diagnosis.	 *(a) Top page*  *(b) Present values in each room*  *(c) Indoor environment of a room*  *(d) Electric consumption by use*
German version: MoniSoft monitor-ing software For all buildings	Unified, scalable database structure for all buildings. Automatic interpolation of different measure intervals. Calculation of specific consumptions with user-definable reference values.	

Spanish version: For multi-family residential buildings	Three-level system: The measured parameters range from overall electric and gas consumption (first level), through sub-metering of main electrical consumption, comfort parameter measurement (second level), to energy for heating, hot water, and solar system energy input (third level).	

4.4 **Functions and levels of monitoring systems**

4.4.1 Functions of a monitoring system

Besides meters and sensors, a typical monitoring system consists of three elements visualized in the Figure 4.9 based on metering guidelines of the U.S. Department of Energy [U.S. DoE 2007]. These are data retrieval and collection, data transfer including also processing and storage of results. The delivery of the information produced to various stakeholders is also essential in order to improve their awareness and motivation, which finally can lead to real actions and measures.

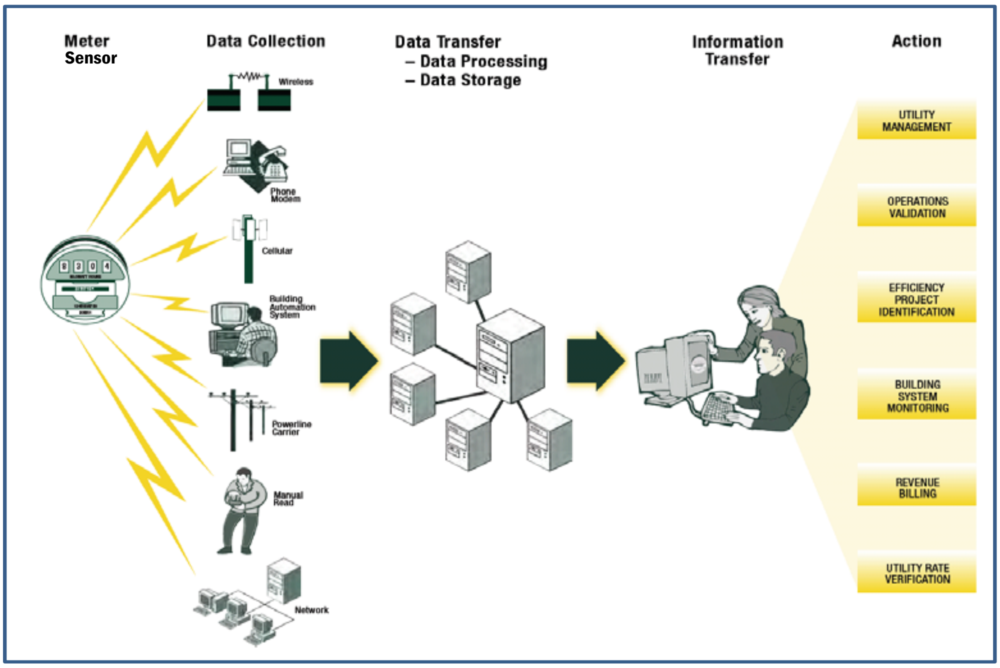


Figure 4.9. Basic elements of a monitoring system

Collecting data from a building for the purpose of detailed monitoring can involve hundreds of sensors delivering data at intervals of a few minutes over several years. Accessing the huge amount of information hidden in this data is a challenge that requires suitable means for data handling and visualization. This is even truer when benchmarking a larger number of buildings. This chapter gives an overview of the functions a monitoring system should have. In most cases, the data for analysis comes from many different sources, even in one building; different recording intervals that induce arbitrary timestamps, some regular, some irregular, and some only when a state or condition has changed (event sensor, e.g. cooling on/off). Regular time intervals, such as hourly, daily or monthly averages and consumptions, are nonetheless required when analyzing data. A monitoring system should therefore be able to interpolate/extrapolate any measurement interval and provide processed data at any desired interval.

Apart from measurement intervals, consideration must also be given to different measurement types. Different calculations might need to be made in order to provide values for the intervals mentioned. Several methods can come into play when calculating averages: arithmetic average, moving average, weighted average, and others. While the type used depends on the task involved, a monitoring system for detailed analysis should offer a choice. Further factors need to be considered regarding the type of measurement. Meters or sensors may be replaced over time. A replaced meter may have a different conversion factor and suddenly deliver MWh instead of kWh. Similarly, the first reading of the new meter will be lower than the last reading of the old meter. A monitoring system should therefore be able to apply varying factors to measurements, and allow for meter replacements or detect them automatically.

4.4.2 Levels of monitoring system

Within Annex 47, Cost Effective Commissioning of Existing and Low Energy Buildings, a survey on sensor deployment and energy metering was performed by Hiroshige Kikuchi from Japan. The survey included most of the participants from Annex 47. Different actors, such as engineers, consultants, contractors, monitoring equipment suppliers, researchers and others, were surveyed. The motivations for this survey came from measurement issues and a lack of a systematic approach to data use from measurements for energy analysis. The survey included many questions related to measurement issues and measurement equipment. The most relevant question for Annex 53 from this survey is, "*Do existing buildings have enough sensors to carry out energy management?*" This question was answered by choosing one of the possibilities below for the different levels of measurements:

A. Total energy amount on monthly level;
B. Total energy amount on daily and hourly level;
C. Energy use measurement by user type (lighting, air conditioning, satellites, elevators, etc.);
D. Energy use measurement by system (office system, conference room system, executive office system, computer room system, parking area system, etc.);
E. Energy use measurement by floor; and
F. Energy use measurement by specific machines or subsystems (cooler, heating system, etc.).

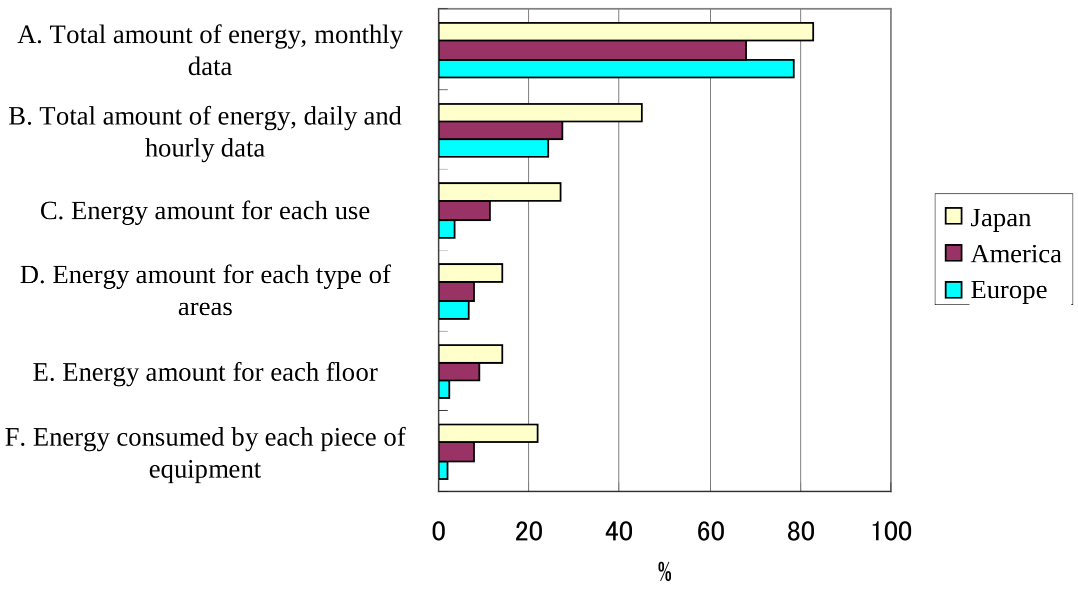


Figure 4.10. Actual energy management level

This question included two parts. The first part aims to explain the current situation, and the second part aims to explain what experts would like to have for proper building energy estimation. The results of the respondents to the survey are given in Figures 4.10 and 4.11. Figure 4.10 above shows the current monitoring situation in Japan, USA and Europe. Figure 4.11 below shows the required monitoring level, according to the surveyed international experts.

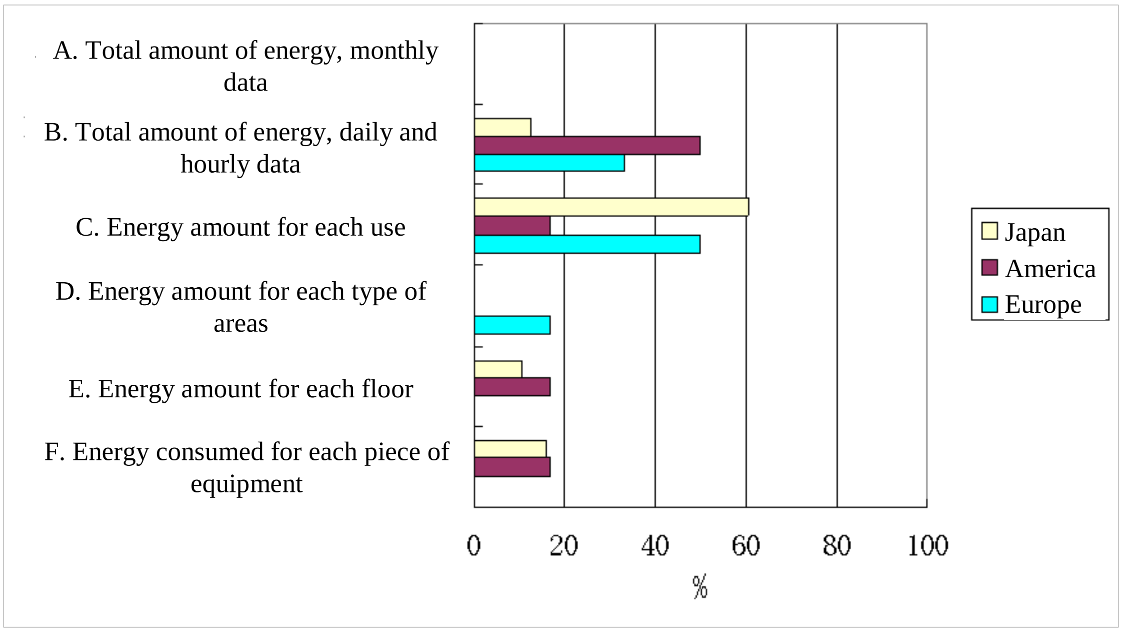


Figure 4.11. Required energy management level

By comparing the results from Figures 4.9. and 4.10, it is possible to note that the survey's respondents (experts) are interested in detailed energy measurement rather than in total energy measurement (level A). Their requirement is to implement energy use measurement by user type (level C) or daily or hourly measurement for the entire building (level B) wherever possible. Most of the respondents prefer level C (energy use measurement by user type) of energy measurement when undertaking an energy conservation investigation. Level B (short-period measurements) is considered optimal for obtaining energy consumption trends and profiles [1]. It should be noted however that the survey was undertaken in 2007/2008, and most smart meter rollouts took place after this date. This has caused the availability of daily and hourly data to increase substantially.

An additional reason for variations among the results in the figures above is the role of the respondents. For example, a supplier of monitoring equipment is interested in very detailed energy monitoring and detailed instrumentation, because that increases his or her business. On the other side, a contractor cannot sell a project that is more expensive due to an advanced monitoring system. Furthermore, building ownership largely defines whether or not someone is interested in good building monitoring. Finally, it can be concluded that the expert role, project type, and specific local and business issues can influence the choice of energy monitoring level.

4.5 **Alternative business models**

Communication technologies undergo constant development. Advanced systems for building energy monitoring have nonetheless failed to achieve a breakthrough in the market owing to diversities in the building industry, scarce economic opportunities, and a continuing lack of awareness. It is therefore important to develop programs that enable open data transfer and manipulation. While some open energy monitoring platforms are currently available, most cannot capture all of the energy performance data. The reason for this might be a difference in the building age and installation of the energy monitoring system, or a lack of interoperability between the building energy management system (BEMS) and the energy monitoring platform. Often energy consultants, energy services companies, etc. use the data from energy monitoring platforms. Even though many manufacturers of the equipment claim that monitoring their equipment is simple because the control unit of the equipment is interoperable with the BEMS platform, communication between the equipment and BEMS can be problematic (Djuric et al. 2012). Consequently, energy data transferred to energy monitoring platforms can be changed, labeled incorrectly, or lost due to different data transfer issues. As explained in Report 2 of Annex 47 (Annex 47 Report 2010), existing buildings pose additional constraints compared to new construction. For new construction, monitoring may already be considered during the design phase and thus be integrated in planning HVAC systems and BEMS.

Enabling rich and safe data transfer from sensors to the BEMS and on to the energy monitoring platform, together with the necessary data manipulation, is therefore necessary (Annex 47 Report 2010). Systematic approaches for the energy evaluation of data – approaches that go beyond simple benchmarking – are often missing. Consequently, it is often unclear to the building owner or operation staff which measurements or sensors are necessary. One future task is thus to establish the relationships among data from buildings, HVAC systems, and energy supply systems. Unfortunately, a general monitoring manual or standard is still not available (Djuric et al. 2010). The Japanese document, Energy Performance Measurement Manual for Building Equipment, provides a good starting point for this work (MMPE 2005). Finally, it can be concluded that this business should cover the development of a generic energy performance data framework, enable data transfer among different applications, allow simple and open data manipulation, and give guidance on further use and data manipulation.

As mentioned in “A Specifications Guide for Performance Monitoring Systems”, those who evaluate the performance of buildings and their energy using systems known that it requires a knowledgeable and dedicated team to obtain the quality of data necessary to determine how well a building is actually performing as well as identifying means for improving it. This team may include a measurement analyst, instrumentation vendors, an installation contractor and the owner’s staff. The problem is that buildings are not designed for measuring their performance. This is particularly true when the flow of air or liquids in building pipelines is considered. It is also believed that obtaining such data is a luxury and that it is not needed for system control or day to day operations (Gillespie 2007). Therefore, experiences and tools developed under Annex 53 need to spread to enable smart use of energy data. Regardless of the decision level (planning, retrofitting, energy labeling, etc.) the same energy data are used for different purposes.

4.6 **Conclusion**

Monitoring is fundamental when aiming to better understand of the energy behavior of buildings. To date, deficiencies in energy metering and consumption data have been an obstacle to comprehensive analysis and verification of the real energy performance of buildings. The situation is changing, however, with the rapid introduction of automated meter reading technology combined with modern ICT. Thousands of “smart meter” systems, comprised of an electronic box and communications link, are being installed all over the world. However making the utilization of smart meter data easier and more efficient requiers standardization and interoperability. Activity is underway in the EU for instance and results will be available soon. However, large energy companies, often having a monopolistic position on the market, have not shown much interest in shering the data. There are also legal and privacy issues, which must be resolved before new, open services will be seen in energy monitoring.

Besides energy data, information about the influencing factors should be available for effective monitoring. New (increasingly wireless) sensor technologies may offer cost effective solutions for certain needs, but installation, maintenance costs and other factors reduce their use in buildings. The future role of sensors and sensor networks is discussed in more detail in an article in a separate report (Seppä, 2002). Additional information about a non-intrusive appliance load monitoring system based on a modern kWh-meter can be found in Appendix IV “Data collection systems for the management of building energy system” (Pihala, 1998).

Mass production of sensors has leaded to a dramatic decrease in sensor prices but installation costs are still an issue. Especially in wireless applications, maintenance work, such as changing batteries, and costs can place limitations on the use of sensors, though they could offer a flexible means of monitoring the various environmental factors. However, sensors are increasingly utilized in BAS, which are typical in office and commercial buildings and also include many functions of monitoring systems. However there is no common standard for the identification and formatting of the data measured and handled by sensors in a BAS. Typically, systems are closed and proprietary meaning that interfaces for data must be realized case by case. Because of their business models BAS vendors are often not interested in sharing their data which hinders the integration of various data sources and systems. It is necessary to collaborate with major building owners and other stakeholders to create common standards and definitions for BAS projects. This would allow the flexible use of the data for monitoring and other purposes.

4.7 Reference

[1] C. Neumann, et al., Editors, *Annex 47 Report 2, Commissioning tools for existing and low energy buildings*, in Annex 47, International Energy Agency, Energy Conservation in Buildings and Community Systems Programme, 2010.

[2] Atos Origin. http://www.atosorigin.com/en-us/Business_Insights/Case_Studies/case_studies_container/cs_erdf.htm.

[3] Bayindir, R., E. Irmak, et al., *Development of a real time energy monitoring platform,* International Journal of Electrical Power & Energy Systems 33(1), 137-146, 2011.

[4] Directive 2004/22/EC of the European Parliament and of the Council of 31 March 2004 on measuring instruments.

[5] Djuric, N., V. Novakovic, F. Frydenlund, I*mproved measurements for better decision on heat recovery solutions with heat pumps,* International Journal of Refrigeration, 35(6), 1558-1569, 2012.

[6] Djuric, N.,V. Novakovic, *Correlation between standards and the lifetime commissioning,* Energy and Buildings 42(4), 510-521, 2010.

[7] Faruqui A., Ryan Hledik, John Tsoukalis, *The Power of Dynamic Pricing,* The Electricity Journal, Volume 22, Issue 3, 42-56, April 2009.

[8] Gillespie, K.L.J., P. Haves, R.J. Hitchcock, J.J. Deringer, K. Kinney, *A Specifications Guide for Performance Monitoring Systems*, Lawrence Berkeley National Laboratory, Berkeley, CA, 2007.

[9] Jang, W., W. Healy, et al., *Wireless sensor networks as part of a web-based building environmental monitoring system,* Automation in Construction 17(6), 729-736, 2008.

[10] Oksa, P., M. Soini, et al., *Kilavi platform for wireless building automation*, Energy and Buildings 40(9), 1721-1730, 2008.

[11] Sung, W.-T. and Y.-C. Hsu , *Designing an industrial real-time measurement and monitoring system based on embedded system and ZigBee*, Expert Systems with Applications 38(4), 4522-4529, 2011.

[12] U.S. Department of Energy, Guidance for Electric Metering in Federal Buildings, February 3, 2006

[13] WBCSD, *Energy Efficiency in Buildings Executive Brief #2-Our Vision: A World Where Buildings Consume Zero Net Energy*, World Business Council for Sustainable Development, 2008.

[14] Heikki Seppä, *The future of sensor networks*, VTT Impulse 2/2012

[15] Hannu Pihala, Non-intrusive appliance load monitoring system based on a modern kWh-meter, VTT report 356, 1998.

5. Statistical analysis of total energy use

Summary

What is covered

The following chapter assesses the potential application for statistical analysis to predict total energy use in buildings and to identify the most significant influencing factors. The Subtask C working group first conducted an extended literature review, followed by the collection and critical analysis of experiences of the working group with reference to individual buildings and large building stocks.
A deep connection has been established between Subtask-C and the Taskforce of Occupant Behavior (OB) relating to the explanation of OB through statistical and probabilistic methodologies and Subtask A connects to this subtask in terms of the definitions for the structure of the database ("database typologies").

Why it is important

To select a suitable methodology, the understanding of the "scale" of the analysis is essential. To this aim, three main descriptors have to be considered: number of buildings in the data set (from an individual building to very large building stocks), number of items describing each building, and time frequency available for time dependent parameters (annual to sub-hourly time frequency). This fits with the proposal of the Three Level Database in Subtask A and relates to the different database typologies.
The main fields of application for statistical analysis are:

- Energy diagnosis for individual buildings,
- Measuring energy consumption, targeting, and benchmarking for large building stocks, and
- Trends for energy policies for analysis at a regional or national level.

Key points learned

- The availability of suitable databases is a fundamental pre-condition to perform consistent analyses.
- Even when using statistical tools, the physical meaning of the parameters should not be forgotten.
- Energy use can very often be described by a few main influencing factors.
- Among the influencing factors, at present only a few databases contain items related to occupant behavior.
- Among the statistical models, regression models are mainly used for total energy use ranging from simple linear regression to complex neural networks.
- Often, increasing model complexity does not increase the prediction accuracy.

Conclusions

Suitable statistical models to apply for energy use analysis have been highlighted: recommendations about the proper application of the different models as a function of the goal of the analysis are offered. These recommendations depend on the time scale (dynamical models are for a time scale of hours, static or statistic models are for a time scale of months or years) and on the space scale (the variance is larger for individual buildings than for a large building stock). The most important factors influencing total energy have also been highlighted. The potential to use these models is very high for both

individual building and large building stocks, but the pre-conditions are the clear definition of the goal of the analysis and the availability of suitable data where the influencing factors required for the analysis are collected.
It is important to the community that the potential applications of the tools are assessed in relation to the field of total energy use research. The benefit of the analyzing the relationship between building and occupant behavior is energy saving, cost saving, and a comfortable indoor environment. We highlight the most important parameters and show that models are different in terms of space and time.

5.1 Introduction

Subtask C deals with the analysis of the ability and limitations of statistical tools to better describe the energy end-uses in buildings. In addition, the identification and the analysis of the main factors that affect the energy end-use in buildings become crucial, especially those related to user behavior.

Interest in the analysis of actual building energy consumption has rapidly increased during recent years when the attention of researchers started to move from the calculated standard energy demand to the real energy consumption of buildings.
This change is mainly due to challenges associated with realistically predicting building energy consumption when the “direct” calculation model is not suitably calibrated using detailed knowledge of the real building behavior. When studying actual energy consumption, statistical approaches are very useful in analyzing trends and statistics about building energy consumption. This change of perspective from standard building energy performance to actual building energy use is nowadays an important topic of research.

In the first decade of this century, a large emphasis was placed on defining indicators that can characterize the energy performance of a building. The significant movement connected to the development and dissemination of building energy certification in Europe, which started with the Energy Performance of Building Directive in 2002, is an example of the technical and research community and political bodies working together.

According to the definition proposed by the Directive, building energy performance has been mainly interpreted as an indicator of the building energy behavior related to “standard” operative boundary conditions. The word “standard” highlights a crucial part of the Directive and it can be clearly explained by observing the picture proposed at the start of IEA-EBC Annex 53 (see Figure 1.1).

In the picture, the influencing factors of building energy consumption are grouped into six main categories. The three categories listed on the left side of the picture (climate, building envelope, and equipment) are related to variables influencing building energy performance. This is calculated by fixing standard conditions for the other three categories listed in the right side of the picture (operation and maintenance, indoor environmental conditions, and occupant behavior) which are specifically related to actual building functions. As a consequence, the building energy performance is calculated assuming that all of the analyzed buildings operate under the same standardized functioning conditions.

This approach allows a coherent comparison of the building energy performance calculated for different dwellings, but this energy performance is not strictly related to the actual energy consumption.

When the attention moves to real energy consumption, all of the six categories of influencing factors have to be taken into account. To give a complete picture, a seventh category (social aspects) has also to be considered.

As demonstrated in practice, buildings located in the same place (same climate) with the same building envelope and system characteristics, and consequently with the same value of the building energy performance index, may show large differences in real energy consumption (see Figure 5.1):

- Different actual operation and maintenance;
- Different actual indoor climate quality level; and
- Different behavior of the occupants (ranging from energy conscious to energy unconscious).

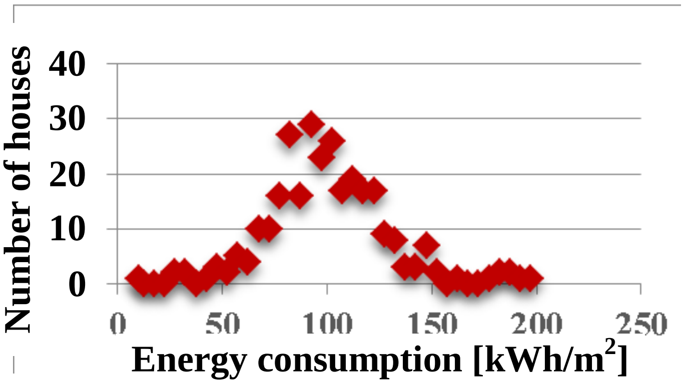


Figure 5.1 Frequency distribution of heat consumption in 290 investigated "identical" houses in Denmark, Andersen 2012).

As shown in 1, the range of variability of actual energy consumption due to space heating could be very broad; in these particular buildings the highest consumption is 20 times higher than the lowest. However, the majority of the houses annually consume between 50 and 150 kWh/m² resulting in a ratio of three between the highest and lowest consumption.

Increasing the number of the influencing factors from three (related to standard energy performance, as in Figure 1.1) to six (related to energy use) strongly amplifies the complexity of the problem, especially because the last three categories of influencing factors are connected to parameters which are not deterministic and constant, but can change stochastically with the time.
This consideration allows the difficulties of realistically predicting building energy consumption through energy calculation tools and even dynamic energy simulations based on so-called "direct methods" to be shown. In fact, it is very difficult to suitably describe the stochastic variation of the input parameters for the energy calculations connected to the three standard energy performance categories. At the same time, other important questions arise:

- Do all of the influencing factors have the same magnitude of impact on building energy consumption?
- Which factors have a large influence on building energy consumption?
- Which are the dominant factors on total building energy consumption?

To answer to these questions, it is necessary to focus on those factors showing the highest impact. Moreover, the identification of those factors may allow the development of a prediction model based on "inverse modeling" techniques by which the relationship between influencing factors (independent variables) and energy use (dependent variable) is explained.

In order to perform such an analysis, the availability of a database where the information about both the energy consumption and the parameters related to the six influencing factors is suitably collected is fundamental.

The database may have different characteristics according to the subject of the study (ranging from an individual building to a national building stocks), the categories of influencing factors (from climate only to all six categories) considered, the variables collected within each specific category, and the time frequency of time dependent and consumption variables are recorded (from annual to sub-hourly periods).

Moreover, the creation of a suitable database is the first step towards performing a number of statistical analyses aimed at describing the properties of the study subject. The use of statistical parameters (mean value, standard deviation, etc.), and the frequency distributions of the collected data are simple but powerful tools as they can provide significant information to understand the characteristics of the subject.

Statistical investigation of databases helps discover the main influencing factors of the trend and performance, and then "inverse" models can simulate actual energy use in buildings.

In recent years, energy and indoor environment long term monitoring systems, using both wired and wireless technologies have proliferated. Thanks to the strong improvement in data acquisition and transmission technologies, it is now possible to have a real time picture for energy consumption and indoor environmental quality levels in buildings. At the same time, it is fundamental to design a clever monitoring plan in order to collect data coherently and in a way that will help to identify the main influencing factors. To this end, it is important to clearly define which parameters have to be monitored, where the sensors have to be placed, how many sensors are needed, and what is the suitable frequency of sampling. These decisions are related to the available budget and the results of cost-benefit analysis. For these reasons, identifying the most significant influencing factor is also fundamental to reduce the number of parameters to be monitored.

5.2 **Database Structure**

The literature review of international research journals related to statistical analyses and the inverse modeling approach for prediction of building energy consumption pointed to a need to define a reference structure for any database. In order to understand the "logic" of the database format, the analyzed papers have been organized into a specific format described below.

First of all, the subject of the analysis needs to be clearly defined at the beginning of the investigation process. In order to differentiate between analyses, the subject of the statistical investigation is divided into three groups:

- Individual building: the analysis focuses on one specific single building (or a group of individual buildings)
- Large building stocks: the analysis focuses on a group of statistically representative buildings, typically showing similarities in terms of use (residential, office, school, etc.)
- Regional/national level analyses: analysis focuses on a large database with a large number of buildings in a region or country.

According to the specific goals of Annex 53, the analyses and databases only refer to residential (detached and multi-family houses) and office (small and large) buildings.

In general, to perform suitable statistical analyses using a building database, the number of buildings grouped in the sample and the (minimum) number of parameters required to describe each building are related, as shown in the diagram of Figure 5.2.

When a single individual building is the subject of the investigation (see the upper-left side of Figure 5.2), a large number of parameters describing its energy behavior are required (one building with lots of information) and the analysis can be detailed for each specific energy end use.

On the other hand, when the analyses are performed at a national level, data for a few parameters are available for many buildings and the investigations address the delivered or primary building energy consumption.

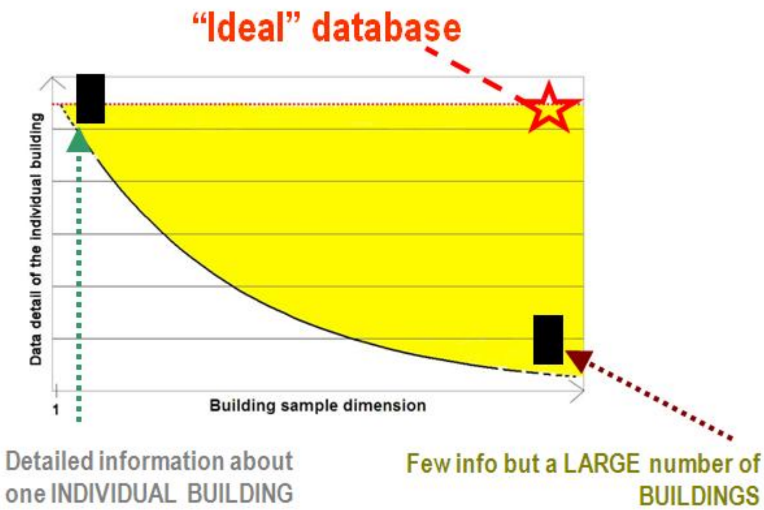


Figure 5.2 Diagram of collected information in the database according to building sample dimension.

When the subject of the study is chosen, the ideal database to utilize may be identified through two main characteristics:

1) Categories of influencing factors which are collected, according to six categories previously defined
2) Sampling frequency of the time dependent variables (consumptions and parameters belonging to the six categories of influencing factors)

In terms of point one above, the database structure can be referred as one of three levels of complexity:

- Level 1 - Categories of influencing factors: climate, envelope and equipment
- Level 2 - Categories of influencing factors: Level 1 + operation and maintenance, indoor environmental conditions
- Level 3 - Categories of influencing factors: Level 2 + occupant behavior

The three levels may also contain information about the seventh factor (social aspects).

In terms of sampling frequency, the database can be referred as one of the following cases:

- Level 1* - Frequency: annual
- Level 2* - Frequency: monthly
- Level 3* - Frequency: hourly (or sub-hourly)

As a consequence, the databases used in practice can be classified according to their reference structure and placed within a matrix as shown in Table 5.1. The database structure is strongly connected to the statistical and prediction methods that may be adopted for the data analyses and elaborations.

Table 5.1 Generalized database structure according to categories of influencing factors and time sampling frequency of dependent variables.

		Categories of influencing factors		
		Level 1	*Level 2*	*Level 3*
		Climate / Envelope / Equipment	Level 1 factors Operations & maintenance Indoor environment condition	Level 2 factors Occupant behavior
Sampling frequency of the time dependent variables	*Annual*			
	Monthly			
	Hourly (sub-hourly)			

The generalized database structure previously suggested is also used to define a criterion for the classification of the selected and analyzed papers from the literature review. More than 50 international papers were examined and classified.

In particular, the following items were characterized for each paper:

- Authors
- Title
- Categories of influencing factors (according to Level 1, 2 and 3 previously introduced for the database reference structure)
- Subject of the analysis
- Goal of the analysis
- Adopted method for the data analysis finalized to energy consumption investigation/prediction

This information is synthesized as presented in Table 5.2 where, for the sake of brevity, only a few of the 50 analyzed papers are shown.

This preliminary work has been fundamental to defining a harmonized picture of the state-of-the art of the application of statistical analysis to assess building energy consumption.

Table 5.2 Organized structure of the literature review activity.

Author	**Title**	**Categories of influencing factors**	**Subject of the analysis**	**Goal of the analysis**	**Adopted method**
Merih Aydinalp, V. Ismet Ugursal, Alan S. Fung	Modeling of residential energy consumption at the national level	*3+*	Large building stocks/residential	Comparative assessment of the three methods	*Engineering method/conditional demand analysis method/artificial neutral network*
H. Farahbakhsh, V. I. Ugursal, A. S. Fung	A residential end-use energy consumption model for Canada	*2*	Large building stocks/residential	Forecast building energy consumption	*Engineering method (CREEM)*
Merih Aydinalp-Koksal, V. Ismet Ugursal	Comparison of neural network, conditional demand analysis, and engineering approaches for modeling end-use energy consumption in the residential sector	*3+*	Large building stocks/residential	Forecast building energy consumption	*Conditional demand analysis method*
Merih Aydinalp, V. Ismet Ugursal b, Alan S. Fung	Modeling of the space and domestic hot-water heating energy-consumption in the residential sector using neural networks	*3+*	Large building stocks/residential	Forecast building energy consumption	*Artificial neutral network*
Merih Aydinalp, V. Ismet Ugursal, Alan S. Fung	Modeling of the appliance, lighting, and space-cooling energy consumptions in the residential sector using neural networks	*3+*	Large building stocks/residential	Forecast building energy consumption	*Artificial neutral network*

Note: in “Categories of influencing factors”, the symbol + means that also data referring to “social aspects” are collected.

5.3 General approach for statistical analysis

The general approach for statistical analyses and prediction methods followed in Annex 53 are described below. The diagram presented in this section shows the general scheme adopted in the Subtask C final report to discuss the topics related to statistical analyses and prediction methods for total energy use in buildings. As shown in Figure 5.3, two sequences of three levels of investigations are pointed out. These three levels are determined by the database, according to the database structure.

The first, "Level 1", is related to statistical analysis aimed at the "description" of the subject of the study. It usually refers to frequency distributions, benchmark, etc.

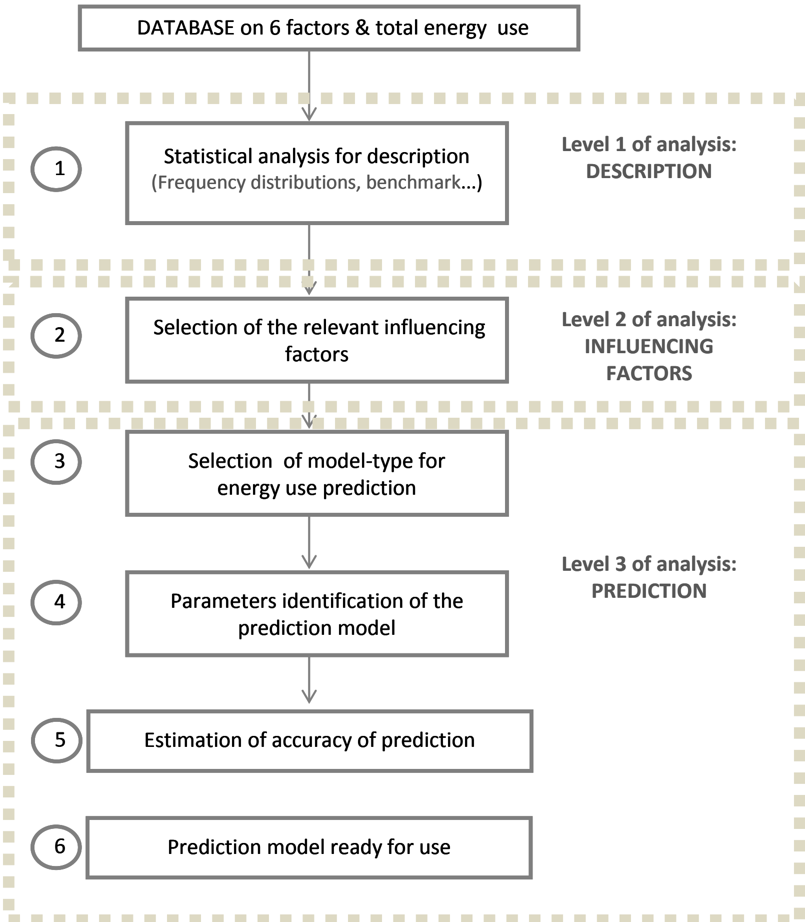


Figure 5.3 Flow chart for the general approach for statistical analysis and prediction methods.

The second level of investigation is represented by the "selection of main influencing factors" by means of sensitivity analysis.

The last sequence refers to the "prediction" methods and concerns the model type definition, the identification of the parameters of the model, and the estimate of the accuracy of the prediction.
In order to carry out a critical examination of the potential and limitations of applying statistical and predictive inverse models to estimating the energy consumption of buildings, the experiences of the different partners of Annex 53 are collected and shared.

First, these experiences were collected through a common format. In particular, information about the studies conducted by the partners is provided in two specific formats: one format includes a two-page summary of each contribution, and the other format is a ten-page overview or "extended" version of the contribution. These contributions are available in the Subtask C final report.

The "extended" contribution contains a critical discussion of the following:

- Database structure and collected influencing factors according to the goal of analysis;
- Investigation method used in the study and the main results; and
- Overall judgment of the potential for the investigation method and its most suitable field of application, highlighting the reasons the method was used and whether it was effective for surveys.

The activities are divided with reference to the subject of the analysis:

- Individual Buildings
- Large Building Stocks
- National or Regional level

Subtask C gathered a total of 17 contributions that deal with both residential and office buildings. Contributions from Austria, France, Germany, and Norway analyzed individual buildings; Italy and Japan concentrated on both individual buildings and large building stocks; and Canada and Spain addressed large building stocks. The national or regional analysis issue is dealt with by Italy in the regional database, China in the national database, and the U.S. in the national database. In the following table (Table 5.3), each contribution is summarized.

Table 5.3. Distribution by subject of the analysis of the obtained contributions

Partner	**Individual buildings**		
	Residential	*Office*	*Other*
CETHIL, INSA de Lion (France)			Synthetic 1 school
Karlsruhe Institute of Technology (Germany)	Synthetic and Extended 1 Multi- family house	Synthetic and Extended 1 Multi-story office	
NTNU Trondheim (Norway)		Synthetic and Extended 1 Office building	
Polytechnic of Turin (Italy)		Synthetic 1 Office building Extended 1 Office building	
Tohoku University (Japan)	Synthetic and Extended 6 houses (single and multi-family)		

Vienna University of Technology (Austria)	Synthetic 3 Multi- family houses 8 Single- family houses	Synthetic 2 Office buildings	
Partner	**Large building stock**		
	Residential	*Office*	*Other*
CIMNE (Spain)		Synthetic and Extended 9 office buildings	
Concordia University (Canada)	Synthetic and Extended 4 contributions 80 houses (Single and multi-family)		
Polytechnic of Turin (Italy)		Synthetic and Extended 4000 office buildings	
Tohoku University (Japan)	Synthetic and Extended 682 houses 80 houses (Single and multi-family)	Synthetic and Extended 1121 office buildings	
Tohoku University (Chinese houses)	Synthetic and Extended 635 houses		
Partner	**National/Regional level**		
	Residential	*Office*	*Other*
Tsinghua University (China)		Extended 4600 office buildings	
LBNL (U.S.)		Synthetic and Extended 824000 offices (CBECS database)	
Polytechnic of Turin (Italy)	Synthetic and Extended 66000 houses (Piedmont regional database)		

Examining the contributions, the main *goals of the analysis* can be synthetically divided into:

- Descriptive analysis (statistical characterization of the subject, benchmarking, etc.), and
- Prediction (forecasting) of the energy consumption of the subject.

The contributions provide a significant picture of the possible applications of statistical analysis to address the building energy use. Details can be found in the Subtask C final report.

Within the contributions on individual buildings, a large part is dedicated to the statistical characterization of the subject. The use of statistics to describe the subject is delineated with different aims: Norway uses statistical analysis to identify of driving variables that contributed to energy use, while the Austrian and German analyses are related to the topic of determining an accurate profile of user behavior (both in offices and in residential buildings) to represent the energy related behavior of the occupants. Even if the characterization of occupant behavior assumed in the research follows different paths, it highlights the increasing importance of this specific topic.

Both Japanese and French groups utilize prevision (forecasting) of the energy consumption for individual buildings. In particular, the main goal of the French forecasting analysis to express the heating load as a function of the outdoor temperature; the Japanese analysis in 6 detached houses focuses on the prediction of the energy supply and demand in residential areas.
Finally there is a third field of application, where the first statistical analyses are used to calibrate the model and to forecast building energy performance. Italy focused on the determination of total heat loss coefficient and the influence of solar and internal heat gains through a statistical characterization of the building and then calibrated the numerical model by comparing both expected energy need and the real measured consumption, and the expected and real aggregated parameters using the results from the first analysis.

Characterization of the sample is the most common aim within the analysis of a large building stock. In particular, certain groups (Italy, Japan, Spain, and Canada) focused the investigations on understanding the influential factors that determine the energy consumption, and using this information to establish reliable building energy demand models. Benchmarks for electrical energy uses and for total primary energy consumption for the whole building stock was a goal of some investigations, like in the Italian case with data for 4,000 bank branches.
Prediction is also dealt with in large building stocks, in particular with the aim of establishing predictive energy model for buildings and assessing the goodness of fit in the case of research on Italian bank branches and Canadian residential buildings.

Due to the huge amount of data in each national or regional database, the main goals of the investigations are to estimate the energy demand for different end uses (China and US) and to define building typologies to estimate the energy demand of a building stock (Italy).

With reference to prediction (forecasting) models, the collected materials (from literature review and the experiences of Annex 53 participants) show that the most commonly used methods are:

- Variable-base degree-day model,
- Linear regression model,
- Change point model,
- Artificial neural networks model,
- Data mining method, etc.

Further details can be found in the Subtask C final report.

5.4 Statistical analyses: Example of applications

Focusing on single building statistical methods can be useful for different purposes related to dealing with total energy use. For the description of influencing factors, the analyses of the relevant influencing factors, the parameter identification for the prediction model, and the estimation of the accuracy of the prediction statistical methods can be used.

For description of the climate, the building, the operation and maintenance, and the occupants, typically descriptive statistics (Average values, standard deviations, distributions, etc.) are used. Also, the total energy use can be investigated with descriptive statistics. Yoshino et. al. analyzed energy consumption in six detached houses out of a 80-house field survey. Figure 5.4 presents the frequency distributions of peak load electricity for different time spans as a histogram and as a cumulative distribution.

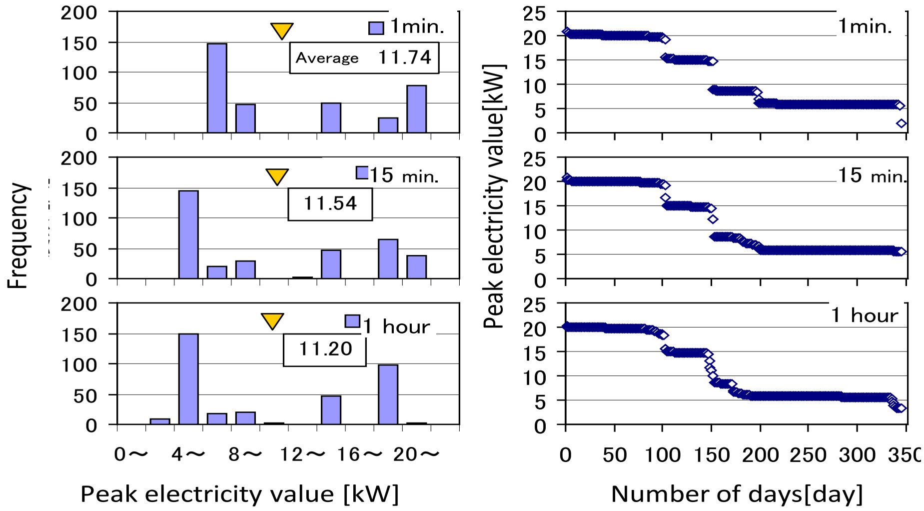


Figure 5.4. Frequency Distribution of peak value of a year.

Another application of statistical methods is to find correlations between energy consumption and parameters describing the objects. In the next figure, shows an example from Austria where the consumption of hot and cold water and electricity for household equipment is correlated with the number of persons in the household.

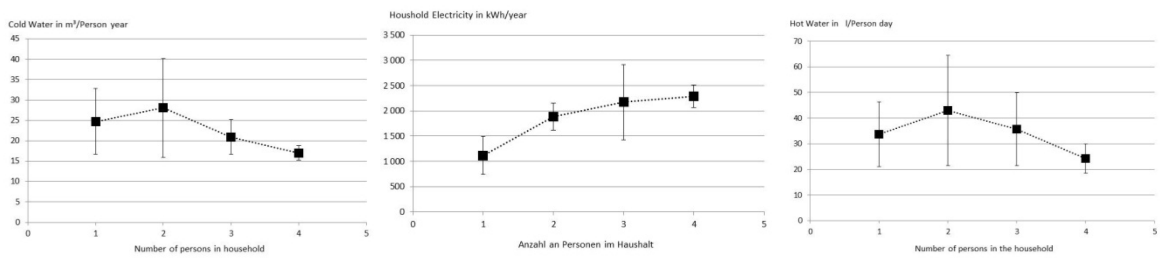


Figure 5.5. Analyses of measured consumption of cold and hot water and electricity in a multifamily building in Vienna

In the development of prediction models for single buildings, statistical methods are used to identify the important parameters. In Norway, the data from a Building Energy Management System of a real office building is analyzed with a multivariable regression method looking for the important parameters that govern heating energy use, electricity consumption, and fan energy use. In that experience a partial least squares regression (PLSR) and principal components regression (PCR) are used to model a response variable when there are a large number of predictor variables, and those predictors are highly correlated or even collinear. Both methods construct new predictor variables, known as principal components (PCs), as linear combinations of the original predictor variables. In the following figure the importance of an original variable is presented for the four most important PCs by showing the PLS weights.

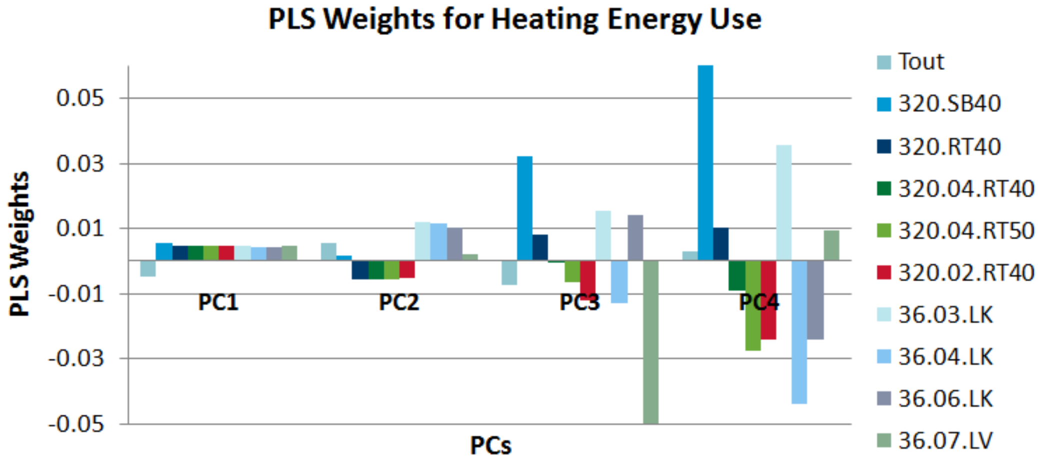


Figure 5.6. PLS weights for heating use of the four most important principal components

By using a procedure for model scaling and finding driving variables based on PLS weights, it was found that the most important variables of the heating energy use are outdoor temperature, control parameters and temperatures in the substation, and some of ventilation parameters. These ventilation parameters were related to the AHUs used in the building.

In a contribution from Austria, based on a probabilistic occupant model, the heating energy demand of single family buildings with three different types of building envelopes have been calculated with a detailed building simulation. From this database of 1000 “virtual families” in three types of buildings, minimizing the difference between the average of the ensemble and the simplified calculation with the average values explains the most important occupant related parameters (average indoor temperature, average internal loads and average outdoor air exchange). The parameters have been identified using two of the three types of buildings help identify the parameters and the third type of building is used to analyze the accuracy.

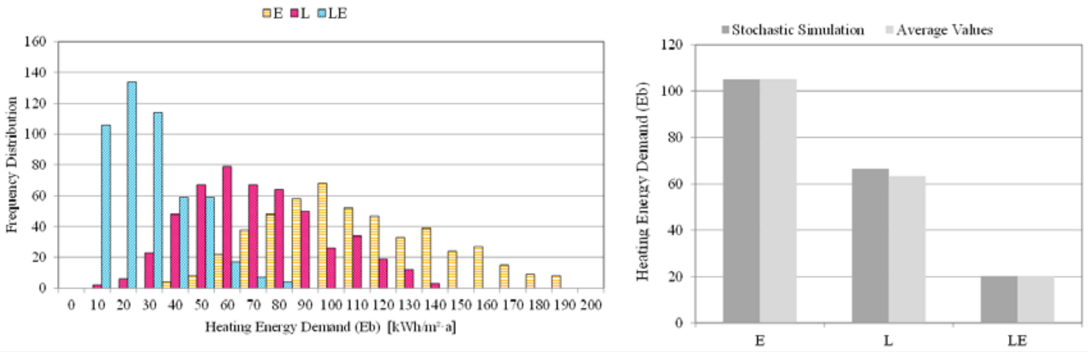


Figure 5.7. Frequency distribution of heating energy use calculated with a full building simulation and a probabilistic occupant model (left) with three different building envelopes (E=Existing building from 1970, L=Low energy house, LE=Lowest energy house).

5.5 Conclusion

Subtask C highlighted suitable statistical models for building energy use analysis and prediction. Different models have different applications as a function of the final goal of the analysis. The review makes clear that predictive models based on statistical analysis differ in functionality and applicability, depending on time scale (statistical models dealt with yearly or monthly time scale, whereas dynamical models are useful tools in case of an hourly time scale).

Moreover, the most important factors influencing total energy use have been investigated. The potential in using these models is clear both for individual buildings as well as for the larger building stock. Nevertheless, a pre-condition for the operability of these methodologies is the clear definition of the analysis target and the availability of a suitable database, in which it is possible to detect the influencing factors required for the analysis.

There is great potential for applying statistics in the field of total energy use, A more accurate prediction of both building and user energy related behavior may result in benefits for energy savings, cost saving, as well as improving the comfort of the indoor environment.

5.6 References

[1] Andersen R. The influence of occupants' behaviour on energy consumption investigated in 290 identical dwellings and in 35 apartments. Proceedings of Healthy buildings 2012, Brisbane, Australia

6. Energy performance evaluation

Summary

What is covered

Subtask D is concerned with Energy Performance Evaluation. This includes the use of simulation models in order to improve the evaluation of energy flows in buildings. Simulation models are available to calculate the energy and thermal comfort performance of buildings. Building practitioners use increasingly more sophisticated tools to estimate energy demand (or consumption) as well as to predict the thermal comfort status.

Why is it important

It is frequently observed that the predictions calculated by these tools, although obtained from “detailed” calculations using models submitted to various “validation” exercises, can be quite far from the results of observations realized in actual buildings. There are a number of reasons that may explain this; an important factor being the fact that fixed values are usually entered to represent the human factors related variables. The models embedded in simulation tools are not perfect; they always provide a simplification of the reality, ignoring certain processes: parameters are fixed according to arbitrary or approximate procedures. Within these parameters, those related to the description of occupant behavior were not, until recently, the object of detailed consideration. Most of the time, simulations use arbitrary and standard user profiles concerning a number of behavioral aspects: selection of set points, control of shading devices, opening of windows, etc.

Key points learned

When using a simulation model, it is important to keep in mind that the results of the calculation greatly depend upon the chosen hypotheses. The output by the calculation is the result of the assumed behavior. Consequently, using of simulation models today presents a number of traps.

Different users of simulation programs can be identified:

- The *designer* (architect, HVAC engineer, installer, etc.) who tries to optimize the solution he or she is developing. Therefore, a number of design alternatives are compared;
- The *building manager* who is seeking the appropriate behavior (sufficient comfort, limited consumption, minimal claims, etc.). The objective is to identify and to apply the best management strategies and to understand why the building does not follow the optimal trajectory;
- The *policy maker* who is interested in the macroscopic impacts of a number of energy conservation measures,

The presentation of results is very much dependent upon the user being addressed.

Conclusions

In order to get maximum benefit from the use of simulation models to analyze energy consumption in buildings, specific methodologies have to be developed and applied. These methodologies use specific concepts like sensitivity analysis and uncertainty analysis and highlight the importance of model calibration when analyzing an existing building. Combining these approaches makes it possible to realistically take into account the influence of the building user.

6.1 **Objectives and contents of Subtask D**

Simulation models can provide important added value in the realistic analysis of energy flows in buildings. Such models are developed to compute different aspects of building energy performance: thermal losses through the envelope, HVAC system operation and efficiency, thermal bridges, control features, etc.

In Annex 53, the objective of using simulation models is to improve the knowledge and the understanding of total energy use in buildings. Models increase the possibility of disaggregating the flows of energy and identifying the causal link with the influencing factors that are known to have an impact on those flows.

The first step is, by running simulation models on different case study buildings, to identify the cause and effects relationships between the influencing factors and the energy performance of buildings. Typical case study buildings are defined in each country, corresponding to national standard buildings; the main parameters affecting energy use are identified and quantified and a large number of simulation runs are carried out in order to estimate the sensitivity of some performance indicators to those factors.

In the second step, new indicators are proposed to better capture the building performance, in a standardized way, allowing comparison between two different case studies located in different climates and subject to different occupants' behavior.

In the third step, models are applied to real cases (the case studies of the Annex) in order to characterize the energy flows in those cases and to provide a quantitative method to assess the efficiency (in terms of energy savings) of different energy conservation measures, for either the building envelope or the HVAC system; including its control. This requires calibrating the simulation models to the case studies by comparing the models with the measured performance and adapting some of the sensible model parameters. With calibrated simulation models, the energy savings can be predicted with better accuracy and reliability. This prediction considers all factors showed to influence the performance, including human factors.

When applied to the typical cases in each national context, this methodology allows an extrapolation of the macro-scale (global) impact of some energy conservation measures to a building stock (located in a country or in a region) and from there to provide quantified and objective support for energy policies in that country.

Therefore, Subtask D was divided in three work items:

1) Work Item D1: Analysis of the effects of six factors on building energy use
2) Work Item D2: Evaluation of existing and new performance indicators of total energy use considering the influence factors
3) Work Item D3: Demonstration of knowledge and methods developed in this Annex to predict the effect of energy saving technologies and occupant behaviors and lifestyle on building energy use.

Building Life Cycle and identification of applications of simulation

The practical use of simulation in different steps of the building life cycle has been previously established. For instance, IEA EBC Annex 30 focused on the process of “Bringing Simulation to Application” and recognized that the concept of building life cycle was central. This cycle is usually, whatever the building culture, divided into a number of steps (Figure 6.1):

- Building design in three successive phases:
  - Conceptual design
  - Preliminary design
  - Detailed design
- Building construction
- Commissioning
- Operation, including fault detection and diagnosis
- Renovation

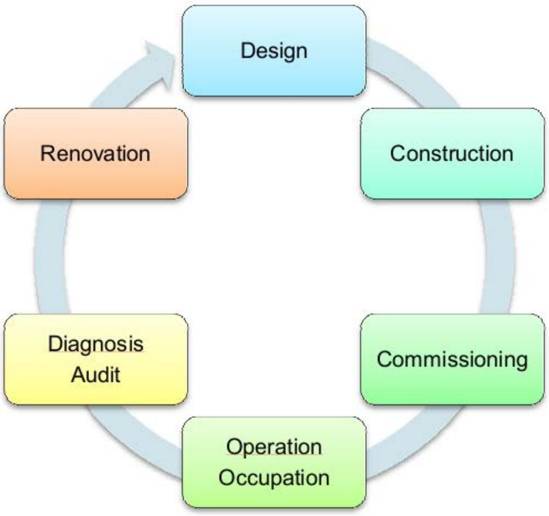


Figure 6.1 Building life cycle.

Simulation may be used at each of these steps, requiring different levels of data and producing different results. This helps to classify the possible use of simulation according to Table 6.1.

Table 6.1 Proposal of framework Subtask D simulation.

# of buildings	User profile # of users	Time scale: Short (s, h)	Time scale: Long (season, year)
Single object	Known user	Commissioning	Audit
	Unknown users	Design	Policy making
Multiple objects	Known user		Standardization
	Unknown users	Demand	Economical

In Annex 53, a framework for the identification of the possible uses of simulation has been proposed. It considers the following criteria to distinguish between the possible uses:

- Number of buildings: usually analysis is carried out on one building and the optimization of the design or the operation is tailored to this building; however, some applications like standardization or macroscopic assessment of energy conservation opportunities (or measures) may require the extrapolation of simulation results to a large building stock;
- Level of knowledge of the user of the building: the behavior of the user may be totally or partially unknown (e.g. because the project concerns a new building where the user is not yet identified) or may be addressed when the occupied building is audited;
- Time frame of the analysis: the analysis of the performance of the building may have a relatively short time frame (e.g. to identify the instantaneous impact of the building on the energy system) or a longer time scale (e.g. to extrapolate through a detailed audit procedure the seasonal performance for instance).

Combining the different criteria leads to the simulation applications shown in Table 6.1.

In IEA EBC Annex 53, it was not possible to cover all the applications listed in this table. The cases which were analyzed allowed the illustration of parts of the case studies: design, audit, maintenance.

6.2 **Progress in modeling**

Annex 53 is more about defining and improving possible applications of simulation than producing and developing new models. Indeed, models to assist engineers at different stages of the building life cycle are available from numerous software programs or research projects. This annex specifically addressed the segment of building and systems modeling related to modeling user behavior. An extensive state-of-the-art review of the currently available modeling approaches to represent user behavior was performed by the “Task Force” established within the annex and is fully reported in the Task Force report. As a summary, modeling of user behavior in buildings may be tackled by the following approaches:

- Theory of the planned behavior
- MODE model of attitude-behavior process
- Modified norm-activation model
- Knowledge-desire-ability-action model

A more detailed description of the characteristics of these modeling issues is given in the Task Force final report.
An analysis was carried out to identify the level of detail required for the occupant behavior modeling as a function of the following building life cycle phases: design, commissioning, and operation.

6.3 Analysis of the effect of the six factors on energy use

This part of the work was performed by running different simulation models on a number of cases and by generating sensitivity analyses. The Belgian team analyzed residential as well as office buildings, the Japanese team analyzed houses and apartment buildings, and the US contributor focused on office buildings. Results were given in terms of statistical indices (Figure 6.2) or energy consumption figures (Figure 6.3).

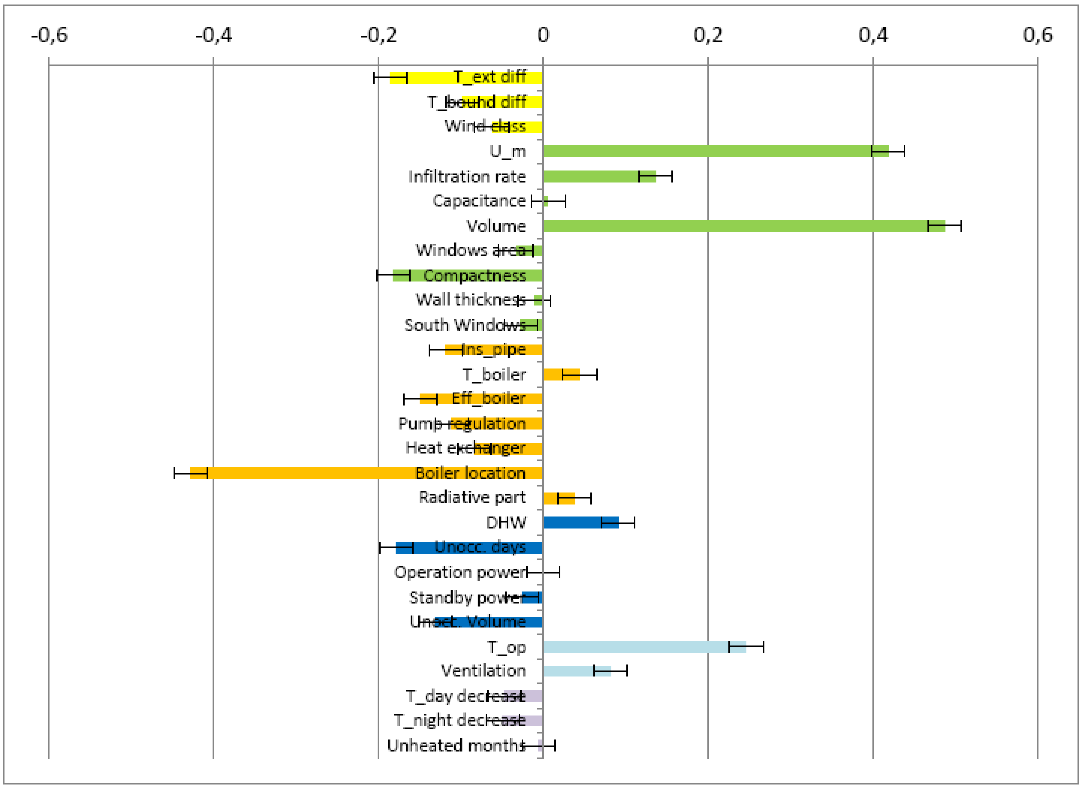


Figure 6.2 Example of results obtained with the Morris statistical method and showing sensitivity of different parameters: the length of the bars shows the impact of the corresponding parameter on the global performance. Impact may be positive (increase of the parameter generates an increase in consumption) or negative (decrease of the parameter generates increased consumption).

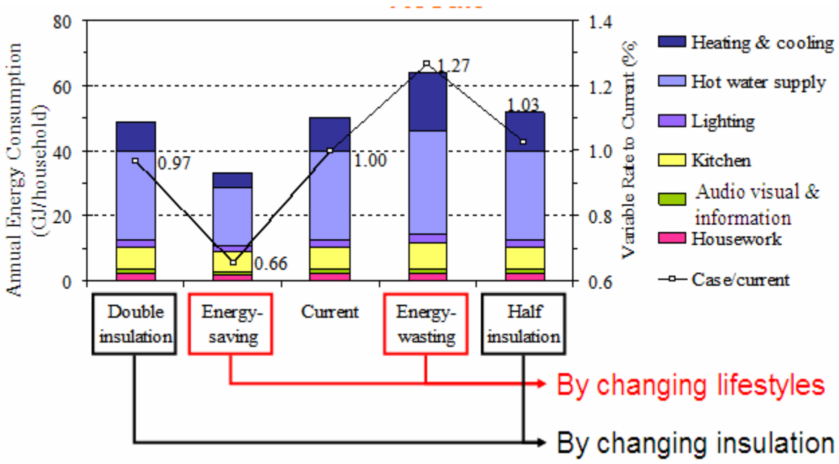


Figure 6.3 Analysis of the effect of lifestyle change on residential energy use in Subtask D.

6.4 Performance indicators

Energy performance indicators usually used in the building sector include energy consumption/m² and energy consumption/occupant. The main goal of indicators is to allow normalization of energy performance according to the different influencing factors (climate, occupant behavior, etc.).

In Annex 53, the role of the building occupant has been recognized as a major one. Consequently, a relevant performance indicator should offer the ability to normalize the model according to occupant behavior. An example of performance presentation that would consider this occupant performance is one where performance would be given for a number (for example three) of users: an energy-conscious user, an average user, and an energy waster user. Each type of user is characterized by coherent behavior regarding actions like set points selection, window opening, heating and cooling system programming. On the other hand, a normalized energy performance would consider a "typical" or "standard" user behavior.

6.5 Simulation Applications

6.5.1 Design of residential buildings

A simulation methodology targeting the design of residential buildings was developed. It is based upon the *a priori* realization of a large number of simulations of typical cases (generic buildings) followed by the identification of a simplified regression model expressing performance in terms of the dominating parameters. An uncertainty can be attributed to each parameter and the final performance is given as a range around a central value.

The objective of this method is to be able to predict a **range** of heating consumption as a function of the uncertainty or the variability of several parameters, in place of a unique heating consumption for a fixed building, climate, and occupant behavior.

A linear regression model created by Matlab generated all of the results of this program. This **linear model** is based on results of TRNSYS simulations, generated from a Monte-Carlo method. The model takes interaction and curvature effects into account. The linear model is implemented in an Excel sheet, shown in Figure 6.4.

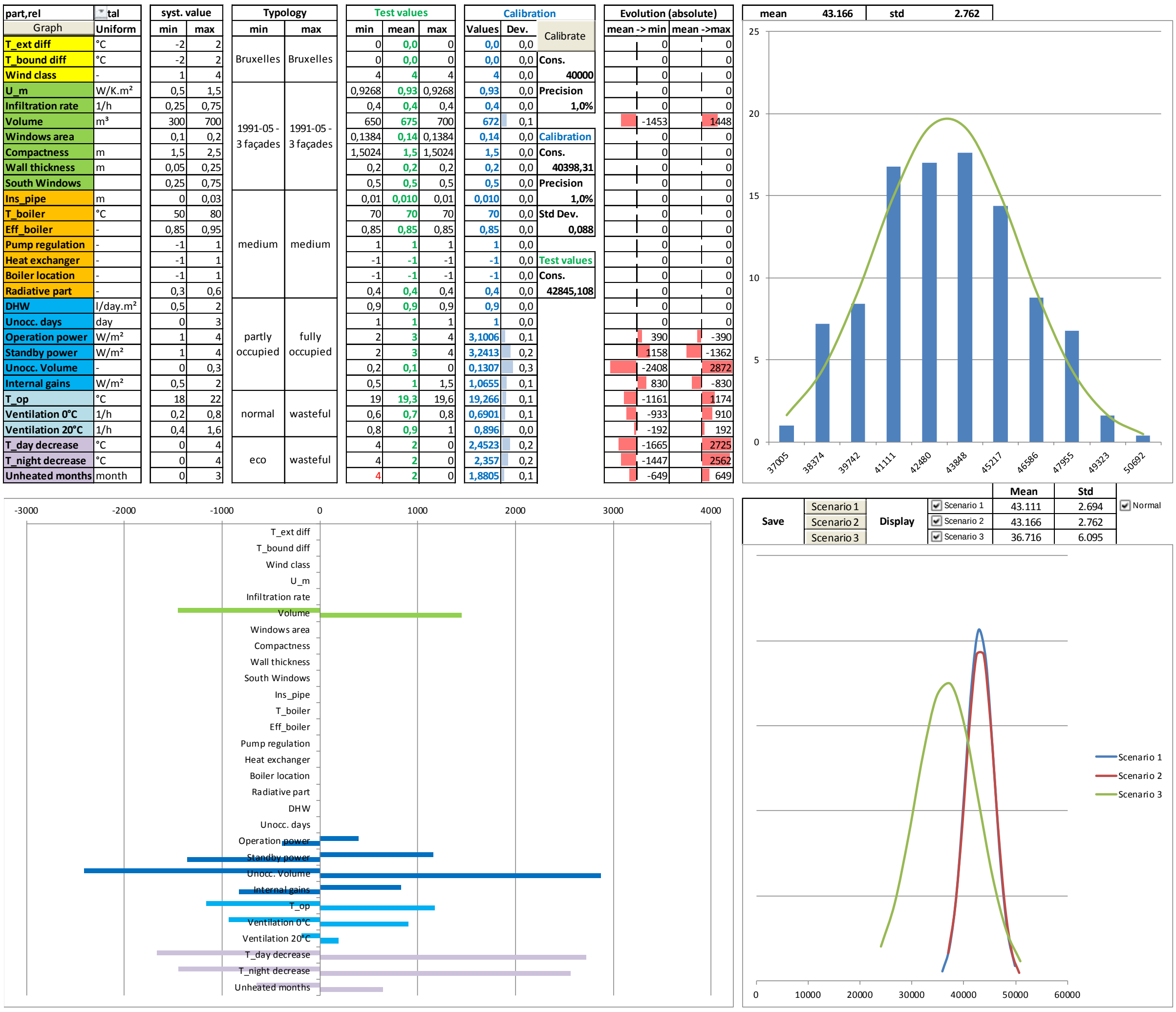


Figure 6.4 General view of the simulation-based evaluation tool developed to analyze residential building design:Upper left: input of parameters bounds and values
Upper right: performance of one design as a statistical distribution curve
Lower left: sensitivity of the performance to each input parameter
Lower right: comparison of three scenarios

As previously mentioned, this method can help a designer to estimate the energy consumption for heating of a unique building with different climates and occupant behaviors.

This program can also be used for an audit where all the parameters are fixed. Indeed, it is impossible to know the exact value for every parameter and it is useful to estimate the consequence of uncertainty in the input on the output. This allows the auditor to detect which parameters really need to be tuned or measured more precisely. When the parameters are precise enough, the auditor can estimate the evolution of the heating consumption with any parameter and, in this way, choose what to do to decrease it. Changes can be made in the occupant behavior parameters or in the building or even the heating system, one by one or all together. This program is also able to auto-tune the parameters if the annual heating consumption is known. It finds the solution that respects the annual consumption and minimizes the standard deviation between the estimated value of the parameters and those of the solution.

6.5.2 Design of tertiary buildings

Historically, building simulation has been integrated into the building design process to give designers a better understanding about how design decisions may influence energy and environmental performance. However, the classical simulation approach consisting of selecting single values for model parameters (usually taken from standards, national regulations, etc.), running dynamic simulation (typically one-hour time step) for a typical year, and getting only one set of “instantaneous” or integrated results (monthly, yearly, etc.) makes the analysis rigid and limited. Such an approach does not give the opportunity to evaluate more than one possible situation.

The addition of a sensitivity analysis makes it possible, by means of identifying the most important design parameters in relation to building performance, to provide a more realistic view of the impact of each parameter.

Monte Carlo simulation is a method based on *performing multiple model evaluations* with probabilistically selected model inputs. The results of these evaluations can be used to determine the *uncertainty* in the model output (prediction) and to perform *sensitivity analysis.*

The goal of performing sensitivity analysis on a simulation model is to determine which parameter(s) is (are) responsible for a majority of the output’s uncertainty.

For this analysis a simplified variance based method has been implemented (Ruiz et al. 2012). In general terms, variance based methods use the variance (squared value of standard deviation) as a measure of uncertainty. In this method, the total amount of the output’s variance is decomposed, in relative terms, according to the contribution of the different input parameters. Figure 6.5 illustrates the entire analysis methodology.

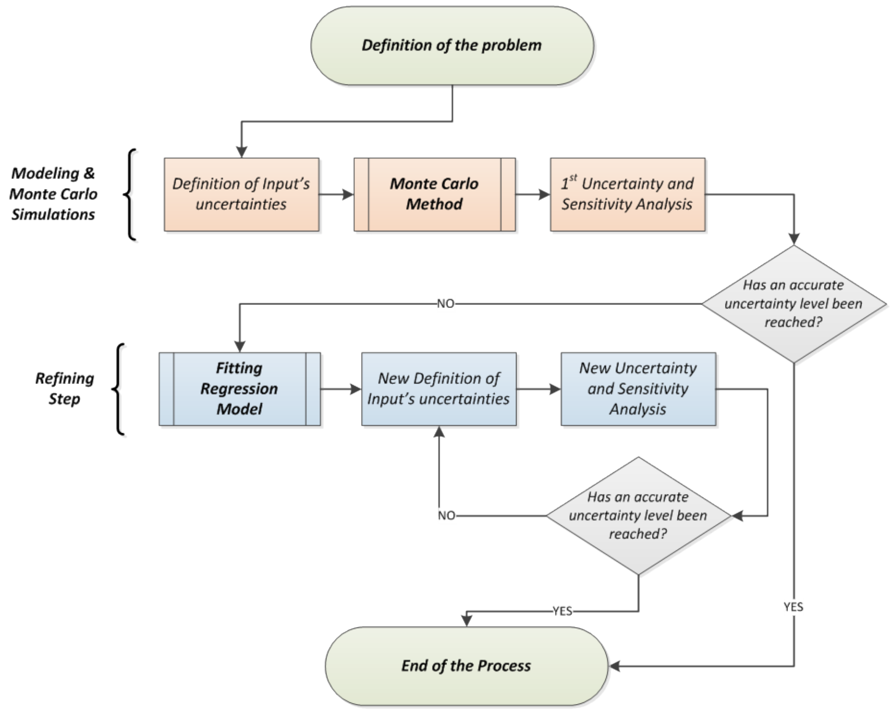


Figure 6.5 Proposed methodology combining sensitivity analysis and disaggregation of output variance.

The Monte Carlo method generates a set of outputs over which uncertainty and sensitivity analyses are performed. If a satisfactory accuracy level is not reached, the same set of inputs and outputs is used for creating a simplified regression model over which "theoretical" uncertainty and sensitivity analyses are carried out.

The method includes the following steps:

- Definition of the problem
- Running Monte Carlo simulations, including first uncertainty and sensitivity analysis
- Calculation of a simple regression model which makes further calculations easier and faster
- Exploitation of the regression model to analyze different scenarios

6.5.3 Performance verification of office buildings

It is commonly admitted that using a building simulation model to assist in analyze the energy use of an existing building requires the model to closely represent the building's actual behavior. When facing a problem like this, calibration cannot be avoided.

Kaplan et al. (1990) defines calibration as the process of adjusting the parameters of a model through several iterations until it agrees with recorded data within some predefined criteria. The definition of these criteria is a complex issue and, to date, it is impossible to determine how close a tolerance needs to be to fulfill the calibration objective.

A calibration procedure has been proposed in order to get the maximum benefit from the use of a computerized building model:

- Confirm the user's knowledge of the building
- Identify Energy Conservation Opportunities (ECOs)
- Document the baseline conditions

Focus is given to the development of a calibration procedure dedicated to the steps of the energy efficiency process requiring energy performance diagnosis of the existing situation, i.e.:

- Energy end use breakdown and analysis at inspection and audit stages;
- ECOs evaluation and post-retrofit performance monitoring and verification (M & V);
- Whole-building level on-going/continuous commissioning.

The main feature of this systematic evidence-based calibration methodology is to integrate a simple sensitivity analysis into the calibration process in order to perform a better measuring and/or estimation of those parameters that are responsible for the largest consumptions.

The whole calibration methodology is illustrated in Figure 6.6. At each step of the calibration process, it is proposed to characterize the quality of the calibrated model by means of:

- Classical statistical indexes (Mean bias error and coefficient of variation of the root mean squared error) computed on a monthly basis for gas/fuel, peak electricity, and off peak electricity consumptions and,
- Visual comparison of available recorded data (e.g. power measurements) and corresponding predicted values.

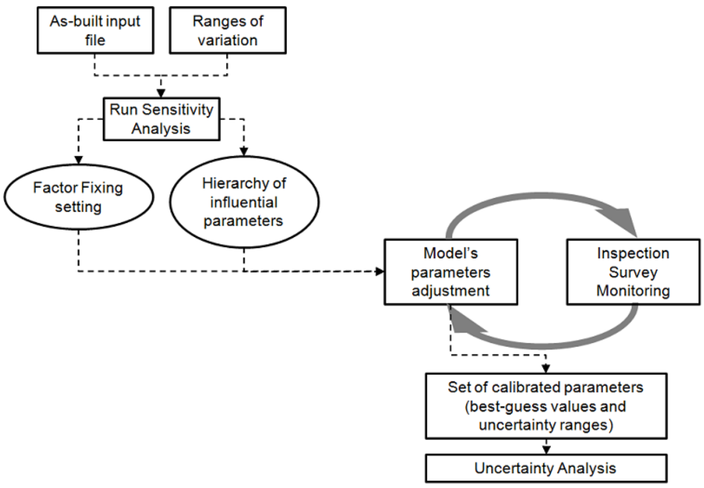


Figure 6.6 Main steps of the evidence-based calibration methodology.

6.5.4 Development of a smart counting method

A new smart counting method has been developed in order to better understand, by means of a simulation model, the impact of the occupant on the total energy consumption and also to have an impact on the occupant's behavior to make it more efficient.

The *first idea* proposed hereafter is to support the energy recording currently available by a dynamic simulation of the building (and of its HVAC system) in such a way to allow some "smart counting" of the energy consumption.

A new approach consists of using indoor temperatures recorded inside different building zones and integrated energy demands as simulation input and output variables. This is the contrary to what is usually done: in most current simulations, control laws and set points are imposed, in such a way as to reproduce as well as possible (but with questionable accuracy) the real behavior of the (building and HVAC) system.

With the new approach, one can be sure that the indoor temperatures are fully realistic, because being imposed *as recorded;* focus can then be given on the most important result: the energy consumption.

A *second idea* is briefly suggested hereafter: correlating integrated energy and water consumptions between themselves.

Water consumption seems to reflect rather well the occupancy rate of the building and therefore also the heating demand "intensity" for a given set of weather conditions (i.e. a given seasonal period).

The method includes the following steps:

- Develop a simulation model for the case study
- Record data (energy and water consumption, indoor temperatures, weather data) during a few days
- Simulate this short time period using measured temperatures as inputs in order to eliminate control uncertainty
- Compare measurements and simulations which shows a smart counting on such a short period may be applied to warn the occupant about any abnormal energy consumption
- Analyze a longer period (typically one month) to confirm the feasibility of the counting method (see Figure 6.7)
- Calculate correlations between energy and water consumption since water consumption may be used as a good indicator for occupancy.

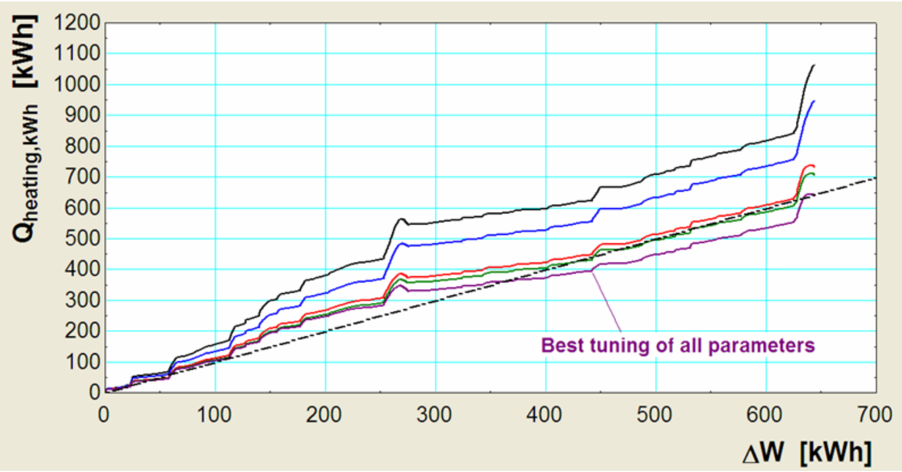


Figure 6.7 Simulated heating demand as function of the electricity consumption.

As a conclusion, a more significant building signature could be established by correlating its energy consumption with *two* independent variables: the water consumption and the outdoor temperature. In order to make this signature easy to read, the three variables considered would have to be integrated over time.

6.5.5 Maintenance of buildings

Maintenance practices for HVAC systems can be categorized into three levels depending on maintenance effort and coverage: 1) proactive, the performance-monitored maintenance representing good practice; 2) preventive, scheduled maintenance representing the average practice (business as usual); and 3) reactive, unplanned or no maintenance representing poor practice. Table 6.2 shows the three practices of HVAC maintenance and their implications for equipment operating efficiency and energy use, equipment life, short term maintenance cost, and life cycle cost including maintenance cost, energy cost, and equipment replacement or repair cost.

A few common HVAC maintenance issues are reviewed and selected for the initial modeling and simulations (including sensor calibration, filter replacement, heat exchanger treatment, mechanical repair and refrigerant charge). These issues are investigated using detailed simulation models. Each maintenance issue is modeled and simulated with EnergyPlus, and finally the combination of all issues is simulated.

The results shown in Figure 6.8 demonstrated the energy penalty introduced by the reactive maintenance practice for HVAC systems. The percentages are derived by comparing the total source/primary energy use of HVAC systems for the reactive maintenance practice to those of the good practice (Base case - ASHRAE).

Table 6.2 Three types of HVAC maintenance practices.

Maintenance Practice	Description	Equipment Efficiency	Operating Energy	Equipment Life	Short-Term Costs	Life Cycle Costs
Reactive (Bad)	Deferred or no maintenance, "run to fail".	Low	High	Short	Low	High
Preventive (Average)	Scheduled maintenance, periodic inspection, cleaning, and adjustment.	Medium	Medium	Medium	Medium	Medium
Predictive (Good)	Use periodic measurements to detect evidence that equipment is deteriorating and to avoid failing.	High	**Low**	Long	High	**Low**

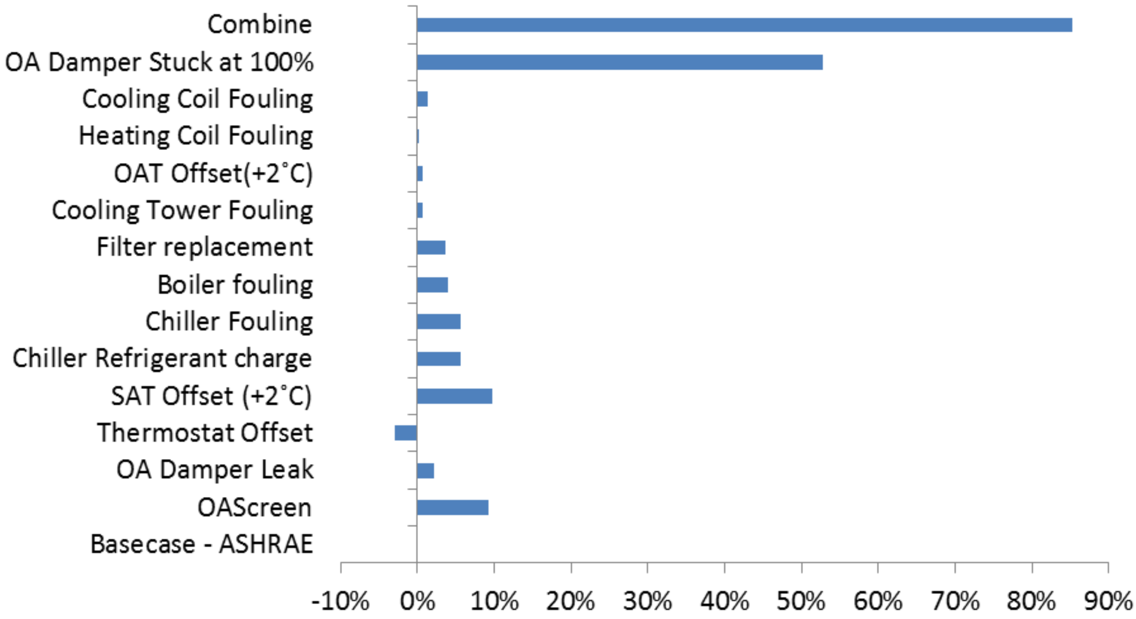


Figure 6.8 The impacts of poor HVAC maintenance on HVAC source energy consumption for a large office building in Chicago, USA.

6.6 Conclusions

In order to get a better benefit from the use of simulation models to analyze total energy use in buildings, a number of specific methodologies were developed considering different phases of the building life cycle. These methodologies complement the use of simulation tools with resources like sensitivity analysis, uncertainty analysis, and model calibration in order to get more reliable results and to adapt the presentation of the results to the specific user of the simulation tools. A more realistic consideration of the impact of the user of the building is also pointed out by the methodologies.

6.7 References

[1] André, Ph.; Lebrun, J. *Bringing Simulation to Application*, IEA Annex 30 Final Report, April 1999.

[2] Aparecida Silva, Cl.; Hannay J.; Lebrun, J. *Contribution to the development of smart counting methods.* IEA Annex 53 Subtask D report, December 2012.

[3] Hasegawa et al. *Energy Conservation Effect of Occupants' Behavior in Residential Buildings*. Presentation at the IEA 53 Copenhagen Meeting, April 2011.

[4] Hong, T.; Lin, R. *An in-depth Look at Key Driving Factors to Energy Use of Office Buildings in the US.* Presentation at the IEA 53 Berkeley meeting, September 2011.

[5] Hong, T.; Wang, L. *Modeling and Simulation of HVAC Faulty Operations and Performance Degradation due to Maintenance Issue.* IEA Annex 53 Subtask D report, October 2012.

[6] Nonaka, T. *Definition of Typologies for (Japanese) Detached House*. Presentation at the IEA 53 Copenhagen meeting, April 2011.

[7] Hoes, H. *Optimizing building designs using a robustness indicator based on user behavior.* Presentation at the IEA 53 Copenhagen meeting, April 2011.

[8] Pignon, N.; André, Ph. *Method used for the analysis of the heating consumption in residential buildings.* IEA 53 Subtask D report, September 2012.

[9] Pignon, N.; André, Ph. *Final report of Ulg/BEMS contribution to IEA Annex 53 Subtask D.* December 2012.

[10] Ruiz, R.; Bertagnolio; S. Lemort, V. *Building and HVAC typologies representative in Europe*. Presentation at the IEA 53 Copenhagen meeting, April 2011.

[11] Ruiz, R.; Bertagnolio, S.; Lemort, V. *How can sensitivity analysis support building design process? A proposed methodology.* IEA Annex 53 Subtask D report, September 2012.

[12] Ruiz, R.; Bertagnolio, S.; Lemort, V. *How calibrated whole-building simulation models can support energy analysis for existing buildings? A proposed methodology*. IEA Annex 53 Subtask D report, October 2012.

[13] Task Force: *Total energy use in residential buildings – the modeling and simulation of occupant behavior*. IEA Annex 53 Final report, December 2012.

7. Publicity

7.1 Newsletter

1) The first newsletter was published at the end of 2010.
2) The second newsletter was published at the end of October 2011.
3) The third newsletter was published in November 2012.

IEA ECBCS Annex 53

Total Energy Use in Buildings – Analysis and Evaluation Methods

Operating Agent: Hiroshi Yoshino, Tohoku University, Japan

Newsletter No.3 September 2012 http://www.ecbcsa53.org

Subtask A: Definition and Reporting
Leader: Mark Levine, U.S.
Co-leader: Hiroshi Yoshino, Japan

Subtask B: Case Studies and Data Collection
Leader: Yi Jiang, China
Co-leader: Jorma Pietiläine, Finland

Subtask C: Statistical Analysis
Leader: Stefano Paolo Corgnati, Italy
Co-leader: Christian Ghiaus, France

Subtask D: Energy Performance Evaluation
Leader: Philippe André, Belgium
Co-leader: Ad van der Aa, The Netherlands

Occupant Behaviour Task Force
Co-leaders: Ad van der Aa, The Netherlands and Bjarne Olesen, Denmark

Fig. 1: Six influencing factors on building energy use

Schedule

This Annex 53 was initiated in November 2008. After the one-year preparation phase, the Annex will continue for three and half consecutive years.

Introduction

One of the most significant barriers preventing the improvement of building energy efficiency is a lack of knowledge about the actual factors that determine total energy use. The well-known factors that have a direct influence include climate, building envelope, and building equipment, indoor environmental conditions, but energy use also depends on operation and maintenance, occupant behaviour which is still unknown, as shown in Fig. 1. The current project is intended to improve the understanding of how these six factors together can, and also to what extent influence on the building energy use. It also aims to bring these factors into the building energy field, and to conduct work related to the real world more closely. Hence, we will have a better understanding of how to robustly predict the total energy use in buildings, thus enabling the improved

Fig. 2: 5th meeting, Rotterdam, The Netherlands, April 26-27, 2012 (37 Participants, 14 Countries)

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7.2 Conferences and workshops

1) ISHVAC 2009 Workshop, Nanjing, China, Nov. 8, 2009
A workshop titled “Mission of IEA/ECBCS/Annex 53 Total Energy use in Buildings -Analysis and evaluation methods-” was held in the International Symposium of HVAC, Nov.8, 2009.
The six speakers presented the mission of Annex 53, purpose and status of each subtask and examples of research followed by discussion with around 40 participants.

2) REHVA Workshop at CLIMA2010, Antalya, Turkey , May 10, 2010
A wworkshop titled “Total energy use in residential buildings and influential factors - Measurement and analytical methods-” was held in the CLIMA, May 10, 2010.
The five speakers presented research related to residential energy use for the Annex followed by discussion with around 35 participants. New information and suggestions on residential energy use and occupant behavior were obtained.

3) Forum at IAQVEC 2010, Syracuse, USA, Aug 18, 2010
A fforum titled “Total Energy Use in Buildings and Influential Factors” was held in IAQVEC 2010, Syracuse, USA, August 18, 2010.
The five speakers gave presentations to 40 participants. A report by Stefano is available on the Annex 53 Home Page.

4) Session at PALEC2010 Conference, Rhodes Island, Greece, Sept. 30, 2010
Session 14: IEA/ECBCS/Annex 53 Total Energy Use in Buildings – Analysis and Evaluation Methods was held at PALEC2010 Conference, Rhodes Island, Greece, Sept. 30, 2010.
Four papers related to Annex 53 were presented as well as four papers on energy use and indoor environment were given at the session. There were fourteen participants listening to the presentations and discussion. One of attendants from Spain showed interests in participation in the Annex.

5) International Seminar on “Occupant behavior, total energy use in buildings and energy efficient methods providing an optimal indoor environment”
The seminar was held in Copenhagen, Denmark, April 27, 2011, which was hosted by Prof. Bjarne Olesen. There were 20 papers presented with 40 participants. Prof. Fergus Nicol was invited to present the paper titled “Human behavior in Offices”.

6) ROOMVENT 2011 Workshop
The workshop of “IEA/ECBCS Annex 53 Total Energy Use in Buildings - Analysis and evaluation methods, Occupant behavior related to ventilation and energy use” was held at ROOMVENT 2011 Conference held in Trondheim, Norway on June 21, 2011.
There were 5 presentations, followed by discussions on occupant behavior related to ventilation energy consumption.

7) ISHVAC2011 Special session, Shanghai, Nov. 2011
Special session of “Total energy use in buildings and influencing factors” was held at ISHVAC2011 in Shanghai, Nov.2011. There were six papers presented, followed by discussion on the factors that influence energy use. There were 30 participants at this event.

8) One day forum “ Total energy use in buildings”, Rotterdam, April 2012
A one day forum about the latest research on total energy use in buildings was held in Rotterdam, April 2012 just before the expert meeting. Twelve papers were presented on not only the status of Annex 53 activities but also the present and future status of the energy use of buildings in the Netherlands. There was more than 70 participants and fruitful discussion on occupant behavior impact energy use.

9) IBPC2012 Special ssession, Kyoto, May. 2012
Four papers related to Annex 53 activities were presented. Prior to that, the Operating Agent presented an introduction of Annex 53.

10) International Joint Forum, Yokohama, Japan, October 4th, 2012
The title of the forum was “Analysis and evaluation of total energy use in buildings and development and application of energy use database”, organized by Annex 53 and Database of Energy Consumption of Commercial Buildings Committee, Japan Sustainable Building Consortium. There were 13 presentations and 90 participants.

11) CLIMA 2013 Workshop, Prague, Czech Republic, June 18th, 2013
IEA/EBC Annex 53 Total Energy Use in Buildings - Analysis and evaluation methods -, Outcomes of the Annex and future research subject related to occupants’ behavior.

7.3 **List of Publications**

[1] Zhun (Jerry) Yu, Fariborz Haghighat, et al., *A Methodology For Identifying And Improving Occupant Behavior In Residential Buildings*, Energy, Volume 36, Issue 11, 6596-6608, November 2011.

[2] Natasa Djuric, Vojislav Novakovic, *Identifying important variables of energy use in low energy office building by using multivariate analysis*, Energy and Buildings, In Press, Accepted Manuscript, Available online 25 October 2011, doi: 10.1016/j

[3] Ehsan Asadi, Manuel Gameiro da Silva, et al., *Indoor air .quality audit implementation in a hotel building in Portugal*, Building and Environment, Jan 2011

[4] Ehsan Asadi, Manuel Gameiro da Silva, et al., *Multi-Objective Optimization Retrofit strategies: A model and an application*, Energy and Buildings, 2011.

[5] Azra Korjenic, Thomas Bednar, *Impact of lifestyle on energy demand of a single family house*, Building Simulation, Vol. 4, No. 2, 89-95, June 2011.

[6] Chuang Wang, Da yan, YiJiang, *A novel approach for building occupancy simulation*, Building Simulation, Vol. 4, No. 2, 149-167, June 2011.

[7] Zhun (Jerry) Yu, Fariborz Haghighat, Hiroshi Yoshino, et al., *A decision tree method for building energy demand modeling*, Energy and Buildings, Vol. 42,pp.1637-1646, 2010

[8] M C Gameiro da Silva, *A wireless network web-based monitoring solution for indoor environmental quality and energy performance assessment of an office building in Portugal*, Rehva Journal, European Journal of Heating, Ventilation and Air-Conditioning Technology, Volume 48, Issue 2, 51-52, March 2011.

[9] Markus Dorn, Naomi Morishita, Azra Korjenic, and Thomas Bednar, *The combined impact of thermal renovations and user behavior on predicting residential heating energy use*, Proceedings of IBPC 2012 Conference, ID 405, 2012.

[10] Hoes, P., Trcka, M.,Hensen, J.L.M., B. Hoekstra Bonnema, *Optimizing building designs using a robustness indicator with respect to user behavior*, Proceedings Building Simulation 2011, 2011.

[11] Hoes, P., Trcka, M., Hensen, J.L.M., B. Hoekstra Bonnema, *Exploring the optimal thermal mass to investigate the potential of a novel low-energy house concept*, Proceedings 10th International Conference for Enhanced Building Operations

[12] S.P. Corgnati, V. Fabi, M. Filippi, N. Tala, *Statistical analysis methods to investigate energy use in buildings*, 3rd International Conference Palenc2010, Rhodes Island, Greece 29September-01 October 2010, Vol. 1, 1-12, 2010.

[13] I. Ballarini, S.P. Corgnati , V. Corrado, N Tala, *Definition of building typologies for energy investigations on residential sector by tabulaiee-project, application to Italian case studies,* Proceedings of RoomVent 2011 , Trondheim 19-22 June 2011, pp. 8, 2011,ISBN: 9788251928120.

[14] I. Ballarini, S.P. Corgnati , V. Corrado, N Tala, *Improving energy modeling of large building stock through the development of archetype buildings*, Proceedings of 12th International Conference of the International Building Performance Simulation Association, Sydney,Australia,14-16 November 2011, Author and contributor

[15] Fabi V., Corgnati S.P.,Andersen R.V., FilippiM., Olesen B.W., *Effect of occupant behavior related influencing factors on final energy end uses in buildings*, Proceedings of Climamed11, Madrid, June 2-3 2011.

[16] Fabi V., Andersen R.V.,Corgnati S.P., Filippi M.,Olesen B.W., *Description of occupant behavior in building energy simulation: state-of-art and concepts for their improvement*, Proceedings of 12th International Conference of the International Building Performance Simulation Association. Sydney, Australia, 14-16 November 2011.

[17] WenKuei Chang, Tianzhen Hong, *Statistical Analysis and Modeling of Occupancy Patterns in Open-Plan Offices using Measured Lighting-Switch Data*, Building Simulation, March 2013.

[18] Liping Wang, Tianzhen Hong, *Modeling and Simulation of HVAC Faulty Operations and Performance Degradation due to Maintenance Issues*, Proceedings of the 2012 Asim Conference, Shanghai, 2012.

[19] HungWen Lin, Tianzhen Hong, *An In-Depth Analysis of Space Heating Energy Use in Office Buildings*, Proceedings of the 2012 ACEEE Summer Conference for Building Energy Efficiency, 2012.

[20] Tianzhen Hong, HungWen Lin, *Occupant Behavior: Impact on Energy Use of Private Offices*, Proceedings of the 2012 Asim Conference, Shanghai, 2012.

[21] Xin Zhou, Da Yan, Xiaoxin Ren, Tianzhen Hong, *Data analysis and modeling of lighting energy use in large office buildings*, submitted to Building Research and Information, 2012.

[22] Tianzhen Hong, WenKuei Chang, Hungwen Lin, *A Fresh Look at Weather Impact on Peak Electricity Demand and Energy Use of Buildings Using 30-Year Actual Weather Data*, Submitted to Applied Energy, 2012.

[23] Hungwen Lin, Tianzhen Hong, *On Variations of Space-heating Energy Use in Office Buildings*, Submitted to Applied Energy, 2012.

[24] Christoph Harreither, Bernd Nusser, Thomas Bednar, *Decision Support Method for Flat Roofs using Probabilistic Tools to calculate Life Cycle Costs and Energy Efficiency*, IBPC2012 conference, ID:404"

[25] Fabi V., Andersen R.V., Corgnati S.P., Filippi M., Olesen B.W., *Main physical environmental occupant behaviour drivers with regard to natural ventilation*, Building Physics Conference2012 , Kyoto Japan, May 28-31 2012."

[26] Stefano Paolo Cognatti and Manuel Gameiro da Silva, *Indoor Climate Quality Assessment, ed.*, REHVA Guidebook no. 14 May 2011"

[27] Manuel Carlos Gameiro da Silva, *Indoor Environment and Energy Efficiency in Schools, Part I Principles, ed.*, REHVA Guidebook no. 13 May 2010"

[28] M. C. Gameiro da Silva, A. Paulino, M. Bento, M. Góis, G. Botte, R. Valentim, J Gomes, R. Fonseca, *A Wireless Network Web Based Monitoring Solution For Indoor Environmental Quality and Energy Performance Assessment of Buildings*, Clima 2010-10th REHVA World Conference, 9-12 May 2010, Antalia, Turkey, ISBN 978-975-6907-16-6"

[29] P. Gonçalves, A. Gaspar, M. Gameiro da Silva, *Comparative Exergy and Energy Performance Analysis of a Separated and Combined Heat and Power System for a Student Housing Building*, 2nd International Conference in Microgeneration and Related Technologies in Buildings: Microgen `II, Univ of Strathclyde, Glasglow, 4-6 April 2011"

[30] Manuel Gameiro da Silva, José Joaquim Costa, Ernesto Peixeiro Ramos, *On the definition of ventilation requirements in IAQ standards – A method based on emission rates of pollutants*, Climamed 2011, 11th Mediterranean Congress of Climatization, 2-3 June 2011, Madrid"

[31] Manuel Gameiro da Silva, José J. Costa , Adélio Gaspar, António Paulino, Miguel Bento, Gustavo Botte, *The influence of wind on the infiltration rate in web-based monitored building*, Roomvent 2011, 12th International conference on Air Distribution in Rooms, 19-22 June 2011, Trondheim, Norway"

[32] He XIAO, Q.WEI, Yi JIANG, *The reality and statistical distribution of energy consumption in office buildings in China*, Energy and Buildings, ENB 3700, 2011.3 Accepted

[33] Christian Ghiaus, *Causality issue in the heat balance method for calculating the design heating and cooling load*, Energy, Volume 50, 1 February 2013, Pages 292-301

[34] Fabi V., Andersen RV., Corgnati SP., Olesen BW. , *Occupants' window opening behaviour: A literature review of factors influencing occupant behaviour and model*, Building and Environment (2012), pp. 188-198 DOI information: 10.1016/j.buildenv.2012.07.009.

[35] Fabi V., Andersen RV., Corgnati SP., Olesen BW. , *A methodology for modelling energy-related human behaviour: Application to window opening behaviour in residential buildings*, Building Simulation Journal, 2013, DOI information: 10.1007/s12273-013-0119-6.

[36] Fabi, V., Andersen RV., Corgnati SP. , *Influence of Occupant's Heating set-point preferences on Indoor Environmental Quality and Heating Demand in Residential Buildings*, HVAC&R Research Journal DOI information:10.1080/10789669.2013.789372.

[37] Zhun (Jerry) Yu, Fariborz Haghighat, Hiroshi Yoshino, et al., *A systematic procedure to study the influence of occupant behavior on building energy consumption*, Energy and Buildings. 43(6) (2011) pp. 1409-1417.

[38] Zhun (Jerry) Yu, Fariborz Haghighat, et al., *A novel methodology for knowledge discovery through mining all associations between building operational data*, Energy and Buildings. 47(4) (2012) pp.430-440

[39] Zhun (Jerry) Yu, Fariborz Haghighat, et al., *Extracting knowledge from building-related data — A data mining framework*, Building Simulation: an International Journal. 6(2) (2013), pp. 207-222

[40] Natasa Djuric, Vojislav Novakovic, Frode Frydenlund, *Improved measurements for better decision on heat recovery solutions with heat pumps*, International Journal of Refrigeration 35 (6) (2012), pp. 1558-1569

[41] Natasa Djuric, Vojislav Novakovic, Frode Frydenlund, *Electricity use in low energy office buildings*, Rehva Journal, European Journal of Heating, Ventilation and Air-Conditioning Technology, Volume 49.(1) p. 30-34, 2012

[42] Chen Peng, Da Yan, Ruhong Wu, Chuang Wang, Xin Zhou, Yi Jiang , *Quantitative description and simulation of human behavior in residential buildings*, Building Simulation (2012) 5: 85–94

[43] S. Danov, J. Carbonell, J. Cipriano, J. Martí-Herrero, *Approaches to evaluate building energy performance from daily consumption data considering dynamic and solar gain effects*, Energy and Buildings 57 (2013) 110–118

[44] Ruiz R., Bertagnolio S. & Lemort V., *Global Sensitivity Analysis applied to Total Energy Use in Buildings*, Proceedings of the 2nd International High Performance Buildings Conference at Purdue, West Lafayatte, USA., 2012

[45] Aparecida Silva, Cl., Hannay, J. and Lebrun, J., *Thermal simulation and monitoring of a dwelling*, ISHVAC 2011, Shanghai, November 2011

[46] Aparecida Silva, Cl., Hannay, J. and Lebrun, J., *A new way of comparing simulation with measurements in residential heating*, Clima 2013, Prague, June 2013

[47] Ad van der Aa, Henk Polinder, Peter Op ‘t Veld, *Driving forces of energy-related behavior in residential buildings*, Clima 2013, Prague, June 2013

8. Meetings and participants

8.1 Period of the Annex project and meetings

8.1.1 Preparation phase: Jan.1, 2009-Dec. 31, 2009

12) 1st Meeting, Liege, Belgium, Feb. 9-10, 2009,
    29 participants, 11 countries

13) 2nd Meeting, Turin, Italy, May 11-12, 2009,
    30 participants, 14 countries

14) 3rd Meeting, Nanjing, China, Nov. 5-6, 2009,
    25 participants, 10 Countries

8.1.2 Working phase: Jan.1, 2010-Mar.31, 2013

15) 1st meeting, Vienna, Austria, April 28-30, 2010
    29 participants, 11 countries

16) 2nd meeting, Rhodes Island, Greece, Sept. 26-28, 2010
    22 participants, 12 countries

17) 3rd meeting, Copenhagen, Denmark, April 27-28, 2011
    35 participants, 14 countries

18) 4th meeting, Berkeley, USA, Sept. 19-21, 2011
    32 participants, 14 countries

19) 5th meeting, Rotterdam, The Netherlands, April 26-27, 2012
    37 participants, 14 countries

20) 6th meeting, Yokohama, Japan, October 4-6, 2012
    30 participants, 13 countries

21) 7th Meeting, Turin, Italy, February 28 - March 1
    27 participants, 13 countries

8.2 The Operating Agent and Subtask Leaders

Operating agent: Hiroshi Yoshino (Japan)

Subtask A:
Leader: Mark D. Levine (U.S), Co-leader: Hiroshi Yoshino (Japan)

Subtask B:

Leader: Yi Jiang (China), Co-leader: Jorma Pietilainen (Finland)

Subtask C:
Leader: Stefano Paolo Corgnati (Italy), Co-leader: Chirstian Giaus (France)

Subtask D:
Leader: Philippe Andre (Belgium), Co-leader: Ad van der Aa (The Netherlands)

Task Force:
Co-leaders: Ad van der Aa (The Netherlands), Bjarne Olesen (Denmark)

8.3 List of participants

Austria:
Azra Korjenic, Vienna University of Technology
Thomas Bednar, Vienna University of Technology
Naomi Morishita, Vienna University of Technology
Kerstin Seif, Vienna University of Technology
Markus Dörn, Vienna University of Technology
Markus Leeb, Vienna University of Technology

Belgium:
Hide Breesch, KaHo Sint-Lieven Ghent Lieven)
Jean Lebrun, JCJ Energetics
Johan Coolen, Factor4
Philippe Andre, Université de Liège
Stéphane Bertagnolio, Université de Liège
Aparecida Silva Cleide, JCJ Energetics
Jules Hannay, JCJ Energetics
Nicolas Pignon, Université de Liège
Vincent Lemort, Université de Liège
Roberto Ruiz, Université de Liège
Gabrielle Masy, Haute Ecole de la Province de Liège

Canada:
Fariborz Haghighat, Concordia University
Zhun (Jerry) Yu, Concordia University
Benjamin Fung, Concordia University

China:
Chuang Wang, Tsinghua University
Xiao He, Tsinghua University
Qingpeng Wei, Tsinghua University
Da Yan, Tsinghua University
Xiu Yang, Tsinghua University
Yi Jiang, Tsinghua University

Chen Peng, Tsinghua University
Yingxin Zhu, Tsinghua University
Zhe Li, Tsinghua University
Danial Chan, The Hong Kong Polytechnic University
Cary Chan, Swire Poperties, HK
Jianying Qin, Swire Poperties, HK
Lina Yang, The University of Hong Kong
Yuguo Li, The University of Hong Kong
Zhiwen Luo, The University of Hong Kong
Shuqin Chen, Tongji University

Denmark:
Henrik Brohus, Aalborg University
Per Heiselberg, Aalborg University
Tine S. Larsen, Aalborg University
Bjarne Olesen, Technical University of Denmark
Rune V. Andersen, Technical University of Denmark

Finland:
Jorma Pietiläinen, VTT Technical Research Centre of Finland
Olli Seppänen, Helsinki University of Technology
Guangyu Cao, VTT Technical Research Centre of Finland
Timo Kauppinen, VTT - Technical Research Centre of Finland

France :
Christian Ghiaus, CETHIL, INSA Lyon
Mohamed El Mankibi, ENTPE

Germany:
Marcel Schweiker, Karlsruhe Institute of Technology
Thomas Gropp, Karlsruhe Institute of Technology
Andreas Wagner, Karlsruhe Institute of Technology
Karin Schakib-Ekbatan, Karlsruhe Institute of Technology

Italy:
Stefano Paolo Corgnati, Politecnico di Torino
Marco Filippi, Politecnico di Torino
Valentina Fabi, Politecnico di Torino
Simona D'Oca, Politecnico di Torino
Francesco Causone, Politecnico di Torino
Novella Tala, Politecnico di Torino
Vincenzo Corrado, Politecnico di Torino
Alfonso Capozzoli, Politecnico di Torino

Japan:
Hiroshi Yoshino, Tohoku University
Tianchi Hu, Tohoku University
Takashi Inoue, Tokyo University of Science
Takao Sawachi, Building Research institute
Toshiharu Ikaga, Keio University
Toshihiro Nonaka, LIXIL Corporation
Shigeki Nishizawa, National Institute for Land and Infrastructure Management
Hisashi Miura, National Institute for Land and Infrastructure Management
Masato Tanaka, Osaka Gas Co.,Ltd.
Mingjie Zheng, Sanko Air Conditioning Co.,Ltd.
Tomohiro Yabu, Daikin Industries,Ltd. Sakai Plant
Shigehiro Ichinose, Chubu Electric Power Co.,Inc
Takehito Imanari, Tokyo Gas Co.,Ltd.
Shinji Okuda, Tohoku Electric Power Co., Inc.
Hideharu Niwa, Nikken Sekkei Research Institute
Youji Nagaoka, Institute for Building Environment and Energy Conservation
Keiko Senbon, Institute for Building Environment and Energy Conservation
Shigeru Tokita, Public Buildings Association
Masaya Okumiya, Nagoya University
Toshikazu Suzuki, Public Buildings Association
Ting Shi, Building Research Center, Vanke, China
Shiho Kawada, Tokyo Electric Power Company, Incorporated
Sayuri Nishiya, Tokyo Electric Power Company, Incorporated
Sawako Nakamura, Kajima Corporation
Ayako Miura, Taikisha Ltd.

The Netherlands:
Ad van der Aa, Cauberg-Huygen Consulting Engineers
Henk Polinder, Cauberg-Huygen Consulting Engineers
Wouter Borsboom, TNO Built Environment and Geosciences
Jan L.M. Hensen, Eindhoven University of technology
Maija Trcka, Eindhoven University of technology
Pieter-Jan Hoes, Eindhoven University of technology

Norway:
Eline Skard, The Research Council of Norway
Natasa Nord, Norwegian University of Science and Technology
Vojislav Novakovic, Norwegian University of Science and Technology

Portugal:
Eduardo Maldonado, University of Porto
Paulo Santos, Portuguese Energy Agency
Dinis Rodrigues, Portuguese Energy Agency
Manuel Gameiro, University of Coimbra

Spain:
Stoyan Danov, International Centre for Numerical Methods in Eng.
Jordi Carbonell, International Centre for Numerical Methods in Eng.
Xavier Cipriano, International Centre for Numerical Methods in Eng.
Jordi Cipriano, International Centre for Numerical Methods in Eng.

The United States:
Jessica Granderson, Lawrence Berkeley National Lab
Tianzhen Hong, Lawrence Berkeley National Lab
Mark Levine, Lawrence Berkeley National Lab
Kathryn Newhouse, Lawrence Berkeley National Lab
Adam Hinge, Sustainable Energy Partnerships

9. List of authors and contributors

Chapter 0, 7 - 10:

Authors:
- Hiroshi Yoshino, Japan

Chapter 1: Definition of terms relating to energy use and influencing factors

Authors:
- Mark Levine, The United States
- Shuqin Chen, China
- Kathryn Newhouse, Adam Hinge, The United States
- Hiroshi Yoshino, Japan

Contributors:
- Yi Jiang, Qingpeng Wei, Xiu Yang, Da Yan, China
- Tianzhen Hong, The United States
- Philippe Andre, Belgium
- Stefano Corgnati, Italy
- Jan L.M. Hensen, Ad van der Aa, The Netherlands

Chapter 2: Definitions of energy-related occupant behavior and modelling

Authors:
- Henk Polinder, Ad van der Aa, The Netherlands
- Marcel Schweiker, Karin Schakib-Ekbatan, Andreas Wagner, Germany
- Valentina Fabi, Stefano Corgnati, Italy
- Rune Andersen, Per Heiselberg, Bjarne Olesen, Denmark
- Naomi Morishita, Thomas Bednar, Austria
- Chuang Wang, Da Yan, China

Chapter 3: Case Studies of total energy use for analysis and evaluation

Authors:
- Yi Jang, Qingpeng Wei, Xiao He, Chuang Wang, Da Yan, China

Contributors:
- Azra Korjenic, Markus Dörn, Naomi Morishita, Thomas Bednar, Austria
- Roberto Ruiz, Stéphane Bertagnolio, Vincent Lemort, Philippe Andre, Cleide Aparecida Silva, Jules Hannay, Jean Lebrun, Belgium

- Yingxin Zhu, Cary Chan, Jean Qin, China
- Vincenzo Corrado, Italy
- Hiroshi Yoshino, Shigehiro Ichinose, Ting Shi, Ayako Miura, Japan
- Natasa Nord, Norway

Chapter 4: Analysis of data collection systems for the management of a building energy system

Authors:
- Guangyu Cao, Jorma Pietiläinen, Finland

Contributors:
- Yi Jiang, Qinpeng Wei, Jianjun Xia, China
- Jorma Pietiläinen, Guangyu Cao, Finland
- Hiroshi Yoshino, Japan
- Marcel Schweiker, Thomas Gropp, Germany
- Stoyan Danov, Jordi Carbonell, Spain
- Tianzhen Hong, Jessica Granderson, Xiufeng Pang, The United States
- Natasa Nord, Norway

Chapter 5: Statistical analysis of total energy use

Authors:
- Stefano Corgnati, Marco Filippi, Alfonso Capozzoli, Novella Talà, Valentina Fabi, Italy
- Thomas Bednar, Austria
- Yi Jang, China
- Hiroshi Yoshino, Japan
- Stoyan Danov, Spain
- Natasa Nord, Norway
- Marcel Schweiker, Germany
- Christian Ghiaus, France

Contributors:
- Tianchi Hu, Sawako Nakamura, Ayako Miura, Japan
- Naomi Moroshita, Austria
- Karin Schakib-Ekbatan, Germany
- Simona D’Oca, Vincenzo Corrado, Fiorella Lauro, Italy
- Fariborz Haghighat, Zhun Yu, Canada
- Tianzhen Hong, The United States
- Qingpeng Wei, Xiao He, Shuqin Chen, China

Chapter 6: Energy performance evaluation

Authors:

- Philippe Andre, Belgium

Contributors:

- Nicolas Pignon, Roberto Ruiz, Jean Lebrun, Belgium
- Tianzhen Hong, Liping Wang, The United States

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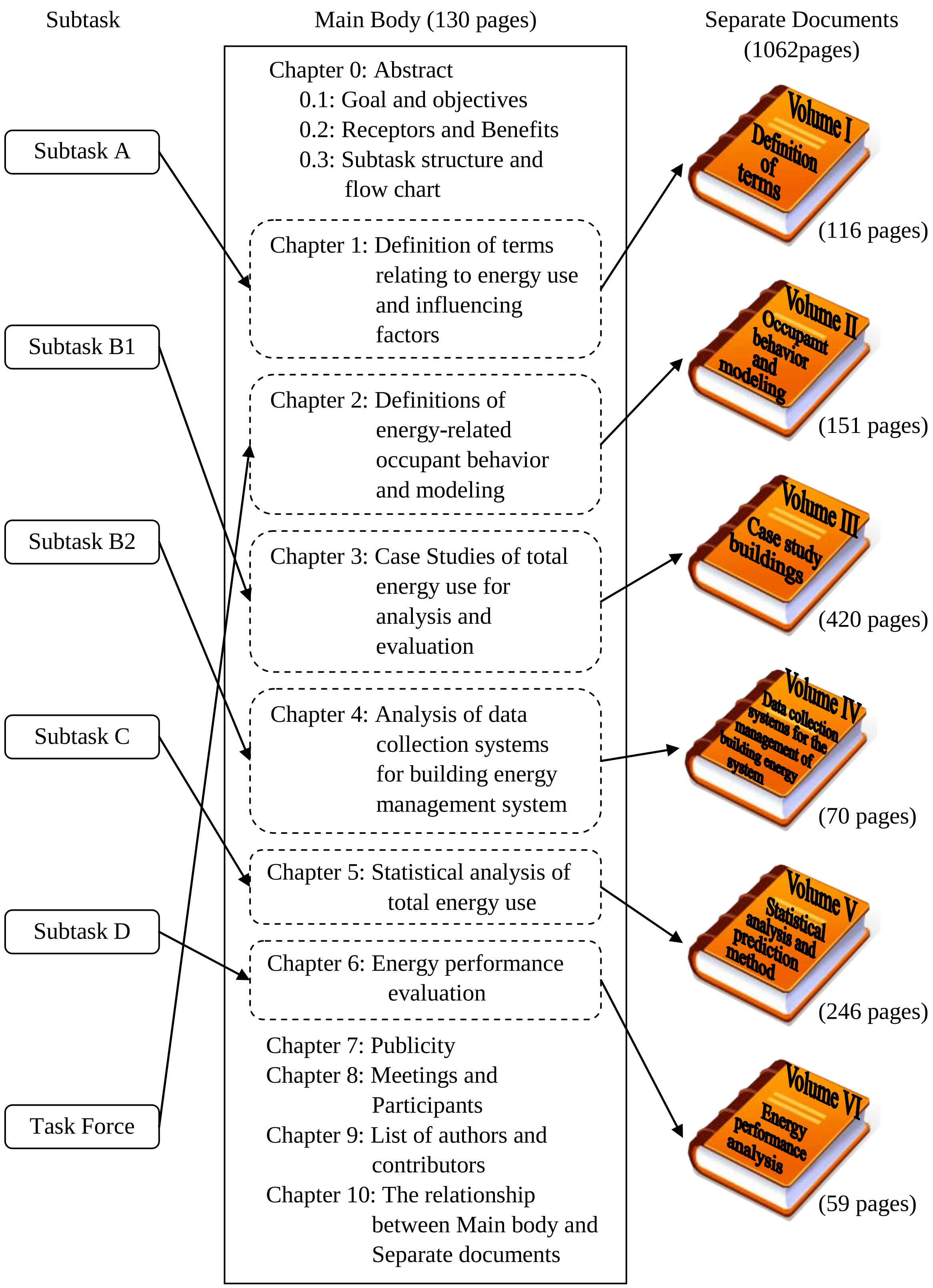

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Participating countries in EBC:
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