IEA ECBCS Annex 53

Total Energy Use in Buildings – Analysis and Evaluation Methods

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Subtask A: Definition and reporting

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Subtask B: Case studies and Data collection

Leader: Yi Jiang China
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Subtask C: Statistical analysis

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Subtask D: Energy performance evaluation

leader: Philippe André, Belgium
Co-leader: Ad van der Aa, Netherlands

Schedule

This proposed annex was initiated in November 2008. After a preparation phase of one year, it will continue for a period of three years shown on figure 2.

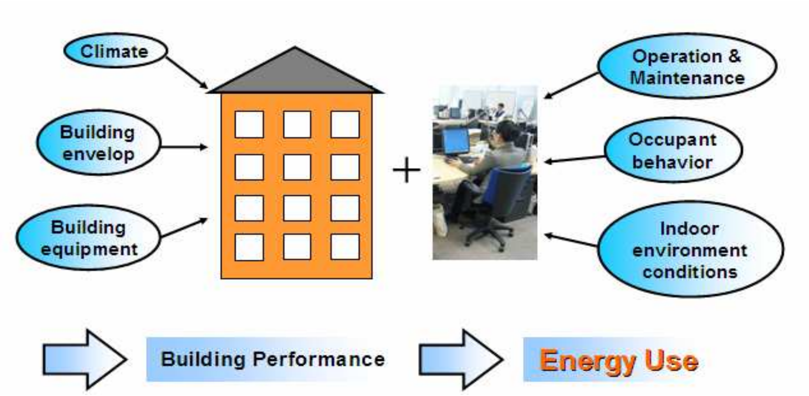

Figure 1. The six factors directly influencing building energy use

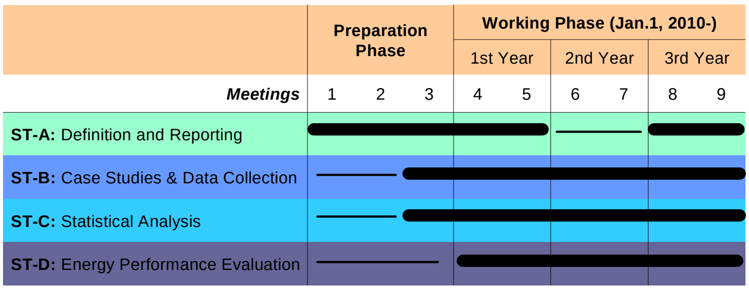

Figure 2. Subtasks and schedule

Photo 1. Participants of first expert meeting of working phase in Vienna (Austria) in April 2010

Introduction

One of the most significant barriers for achieving substantial improvement of building energy efficiency is a lack of knowledge about the factors determining the energy use. For example, Figure 3 illustrates measured energy use of air-conditioners in apartments in a multi-family building in China: It can be seen that even for the same kind of end use, there is a large variation in electricity consumption across the apartments. The reason for this is actual building energy use is a result of the combined effect of various factors. Each influencing factor varies in its impact among the different apartments. Therefore, the combined effect leads to the large differences observed in levels of energy use in each apartment.

To better understand the factors determining the energy use in buildings an ECBCS project, 'Annex 53: Total Energy Use in Buildings - Analysis and Evaluation Methods', is now under way. It was initiated in November 2008 and will last for four years in total.

Well known factors of direct influence are climatic conditions, the building envelope, and building services performance, but energy use also depends on operation and maintenance, occupant behaviour and indoor environmental conditions. Figure 1 indicates schematically the relationship between these factors and energy use. However, current research generally focuses only on the well-known factors, i.e. the building envelope, building services and climate, and does not consider the interaction between building energy use and the other three factors: operation and maintenance, occupant behaviour and indoor environmental conditions. Apart from that, a scientific methodology does not yet exist to clearly and thoroughly account for:

- interactions between the six influencing factors, especially those involving occupants' activities and behaviour, or
- energy use predictions when all of the influencing factors have been taken into account.

Finally, inconsistency in terminology relating to building energy use is also a surprisingly serious problem. This hinders both attempts to understand the influencing factors and the analysis of real energy use.

The current project is intended to improve the understanding of how the six factors together influence building energy use, especially occupant behaviour. It also aims to bring these factors into the building energy field, and to conduct work more closely related to the real world. Hence, we will have a better understanding of how to robustly predict total energy use in buildings, thus enabling the improved assessment of energy–saving measures, policies and techniques by this project.

Research Objectives

Taking into account the above concerns, the main project objectives are, for dwellings and offices, to develop and demonstrate:

- The approach to describe occupant behaviour quantitatively, and to then set up a model for occupant behaviour;
- New methodologies to analyze total building energy use and to then investigate the factors that influence total energy use, especially occupant behaviour;
- Methodologies and techniques for monitoring total building energy use, including hardware & software platforms
- How monitored data can be used to provide meaningful indicators of building energy performance
- Methodologies to predict total energy use in buildings and to assess the
- impacts of energy saving policies and techniques including the influence of occupant behaviour

To realise these objectives, four distinct areas of research have been established within the project:

- Definitions and reporting
- Case studies and data collection
- Statistical analysis
- Energy performance evaluation

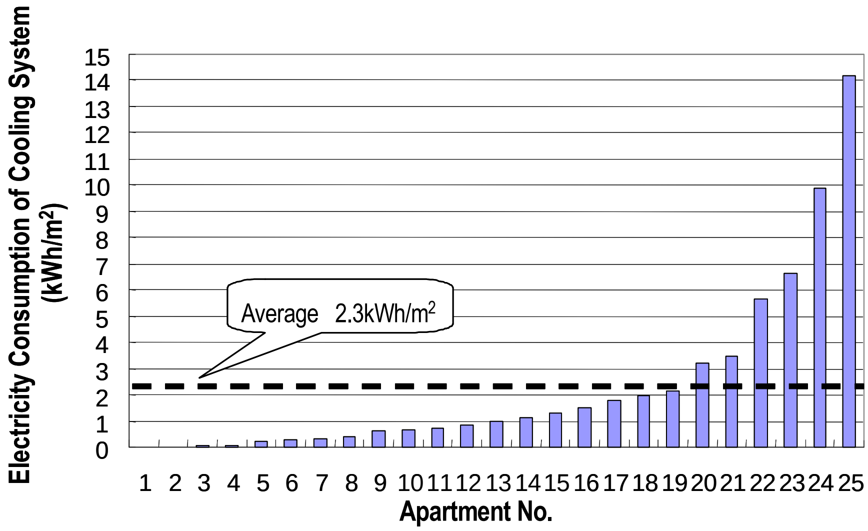

Figure 3. Household electricity use for split-unit air-conditioners in Beijing, China, measured in 2006 (Yi Jiang & Qingpeng Wei)

Subtask A: Definition and Reporting

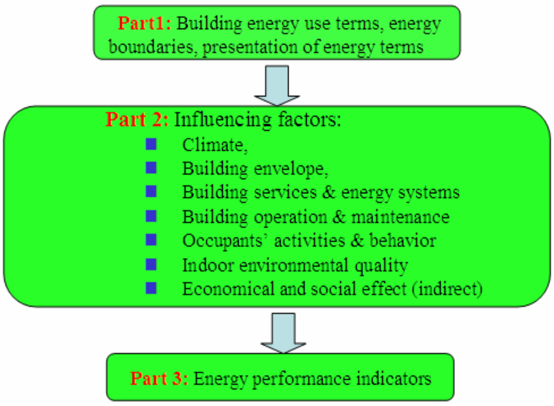

Figure 4. The list of item definitions

Making consistent definitions related to building energy use terms, influencing factors of energy use, and other related items, which finally becomes the fundamental platform in our achieving understanding of energy use in buildings, is the main goal achieved in Subtask A.

Three work items are proposed to be studied in ST_A:

1) Work item A1: State-of-the-art review: State-of-the-art review was made on building energy use terms, energy boundaries, conversion factors, buildings energy performance, influence factors, so that the uniform definitions can be made in the following work.

2) Work item A2: Definition of energy boundaries, building energy use terms (energy consumption for different end users, et. al), and conversion factors

3) Work item A3: Definition of influence factors and energy performance indicators, and making report format for the scientific expression of the above items with uniform definitions and correct application in other subtasks.

Figure 4 lists the six categories of influence factors on building energy use which need to be developed in Annex 53, as well as the indirect factor of economical and social effect.

As item definitions will be used for the different researches of case studies, statistical analysis and simulations in Annex 53 and different researches serve different purpose, they consequently have the different requirements for the categories of items and complexity of the definitions. Therefore, the agreement was made that three levels of database should be made from the simple version to complex version, in order to develop specific item definitions in each database and serve each kind of research. The instructions on how to develop the different database were also fully discussed in the first expert meeting on April 28-30, 2010, Austria. On this base, a draft of three level data base was completed in the second expert meeting on September 26-28, 2010, Greece. Table 1 shows the three database typologies and the covered categories of influence factors. Different database include different categories of influence factors, and specific items are also defined in each category of influence factors. For example, Level A database includes the IF1-3. Both Levels B and C cover IF1-6, but the items in the categories of influence factors should be defined more complicated in Level C than those in Level B.

The acceptable minimum level depends on the goal and on the subject of the analysis, but typically:

- For analyses on very large building stocks, level A can be acceptable
- For analyses on individual buildings, level B is considered as the minimum level.

It was stressed that the purpose of the data base is not to prescribe a database for studies to use; instead, its goal is to able to compare the data used in different studies (e.g., completeness of the data).

The draft of the three level data base was circulated to all the participants for comments. Future work awaits results of subtasks B and C: comparison of actual data used in research on single buildings and statistical samples of buildings with the database.

Table 1. Three database typologies and the categories of influence factors defined in each database

Database Typology	Categories of influencing factors			
	I	II	III	+(optional)
Level A (simple)	IF1. Climate IF2. Building envelope IF3. building service and systems			
Level B (intermediate)	IF1. (Outdoor) Climate IF2. Building envelope IF3. building service and systems	IF4. Operation & Maintenance IF5. indoor thermal environment	IF6. occupants' activities and behavior	IF7. Social and economical aspects
Level C (complex)	IF1. (Outdoor) Climate IF2. Building envelope IF3. building service and systems	IF4. Operation & Maintenance IF5. indoor thermal environment	IF6. occupants' activities and behavior	IF7. Social and economical aspects

Subtask B: Case study and Data collection

Subtask B is divided into two subtasks namely Subtask B1 and Subtask B2.

Subtask B1: Case study

Work Items (WI)

The WI in Subtask B1 includes two parts:
1) Collection, review and selection of case studies for analysis
2) Documentation and analysis of case studies and of collected data

According to the review, the cases of existed building rather than new construction will be studied with different occupants' behaviors (OB). Typical buildings with measured energy data are proper as cases for study. Therefore, four different types of buildings with 3 to 5 cases for each type are decided to be collected and documented in this subtask. They are:

- R: residential buildings
  - R1: Detached house (single house)
  - R2: Multi-family apartments
- O: Office buildings
  - O1: Small-scaled office buildings
  - O2: Large-scaled high-rise office buildings

Current progress

- What kinds of buildings fit our research requirement of case studies is figured out.
- Collection of typical case studies of different kinds of buildings in different countries.
- Different participant countries are providing their own case studies for the analyses
- Developing template for case study buildings.

Available cases

Collection of typical case studies of different kinds of buildings in different countries has been done shown as following:

Study on Cases

There are several steps to do in order to realize the goal this Subtask:

- Document each case including OB
- Study the approach for unification of energy data
- Study the OB influence through comparison between cases
- Study the OB influence through simulation of each cases
- From the view point of OB, figure out what type of building should be built to reach the goal of low energy

The undergoing actions include:

- Collecting the documents on cases, and circulate to participants.
- Preliminary assessment on it by using the documents for simulation
- Propose the sub-items of energy use in office buildings
- Review/study to select the most important issues related to the sub-items of energy use

1) Detached house in Japan

2) Detached house in Belgium

3) Multi-family apartments in Austria

4) Large-scaled high-rise office building in China

5) Small-scaled office building in Italy

6) Small-scaled office building in Belgium

Photo 2. Selected buildings for case study

Subtask B2: Data collection

Monitoring is fundamental when aiming at better knowledge and understanding of the energy behaviour of buildings. Until now deficiencies of energy metering and consumption data has been an obstacle for comprehensive analysis and verification of the real energy performance of buildings. Situation is changing however and at the moment the new automated meter reading technology (AMR) combined with modern ICT is rapidly taking place. Thousands of so called smart meter systems comprising an electronic box and a communications link are under installation all over the world.

The smart meter measures electronically the consumption in short intervals (with hourly or higher resolution), and can communicate this information to another devices or systems. These systems will provide energy users and other factors timely information about their domestic energy consumption. Based on this kind of data the energy supplier, customer or the service provider can view how much and when energy is used and where might be the biggest saving potentials for example. Ongoing smart meter rollouts will offer new possibilities for the development of monitoring systems, which will offer accurate and real-time information for various stakeholders. Smart meters can unleash data about the fluctuating price of electricity throughout the day, enabling consumers that have energy management tools to shift energy consumption to the time of day when power is cheapest. For utilities, that can mean better management of the power grid and eliminate the need to build out expensive power generating systems. The structure of typical smart meter based monitoring system with it´s components is described in the figure below taken from the U.S. Department of Energy´s Guidance for Electric Metering for Federal Buildings /1/.

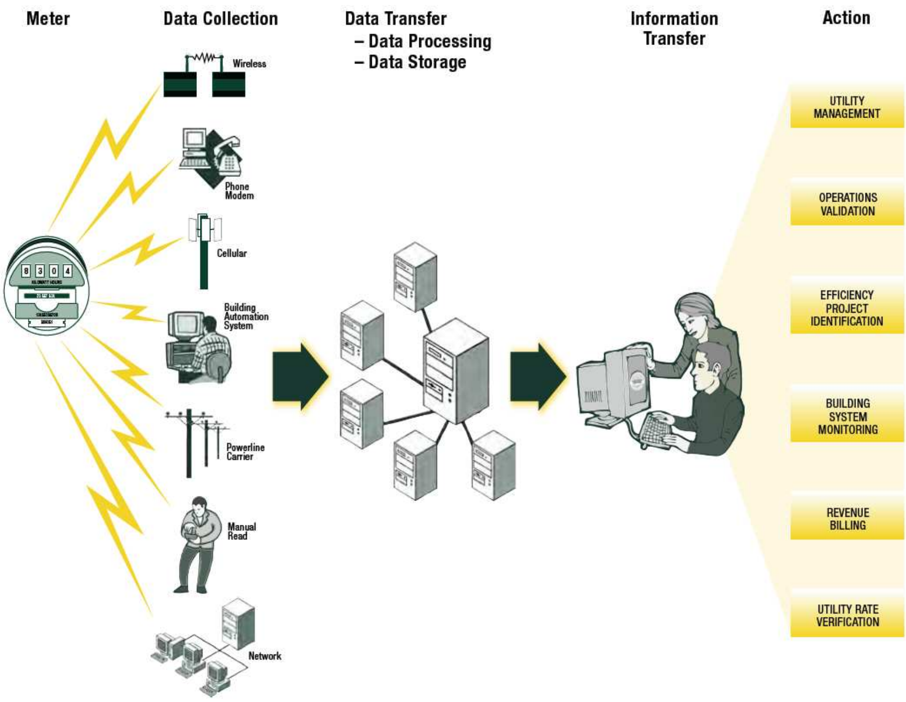

Figure 5. Structure of typical smart meter based monitoring system

In addition to energy and water consumption also the main influencing factors discussed earlier should be monitored. Data about outdoor and indoor conditions and occupation should be available on the same frequency (time periods) in order to analyze the interaction with energy consumption. If building automation systems are available they can offer this kind of data but most often the influence of human behaviour (occupants, operators) is difficult to separate from other factors or there is no data available for these kinds of analyses. New (wireless) sensor technologies might offer solutions for certain needs but installation and maintenance costs can reduce their utilisation.

In Subtask B2 the state of art of new measurement and data collection systems and technologies will be reviewed, analysed and reported in order to identify the main features and characteristics of various measurement strategies for on-line data collection and monitoring systems. Also real systems will be demonstrated based on the various existing applications in participating countries. Some of them will be compared and evaluated and a common platform demonstrating the capabilities of online monitoring will be set up as described in the figure 6.

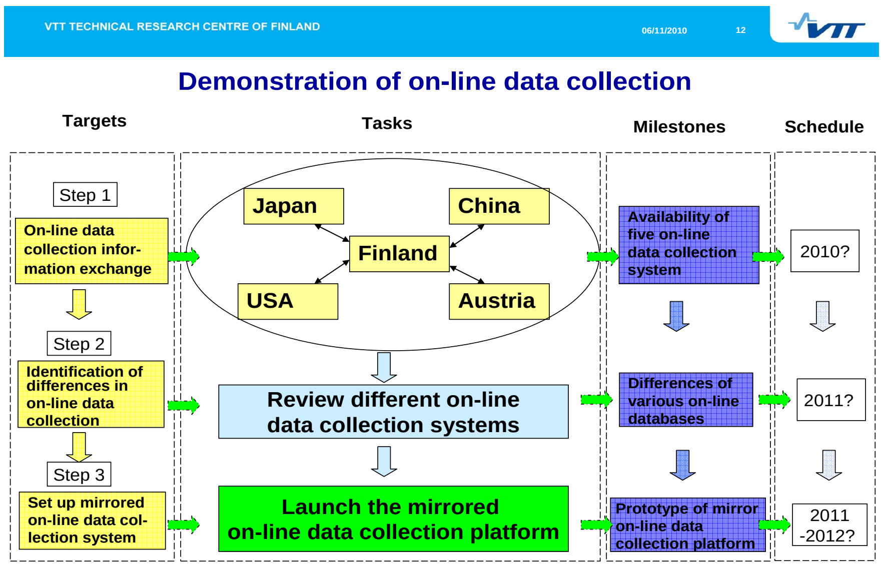

Figure 6. Data collection

Ref. /1/: *Guidance for Electric Metering for Federal Buildings, U.S. Department of Energy, Federal Energy Management Programme, 2006*

Subtask C: Statistical Analysis

Goal

The aim of ST-C is to investigate and highlight potentialities, possibilities and limitations of statistical tools for a better realistic description of building energy end uses and for a robust prediction of future energy consumptions through data-driven calculation methods. Moreover, a key goal of ST-C is to show up which are the most relevant factors influencing the building final energy end uses: among these factors, a specific focus is dedicated to occupant behavior. Both residential and office buildings are examined.

Structure

The structure of ST-C is shown in the following Figure 7.

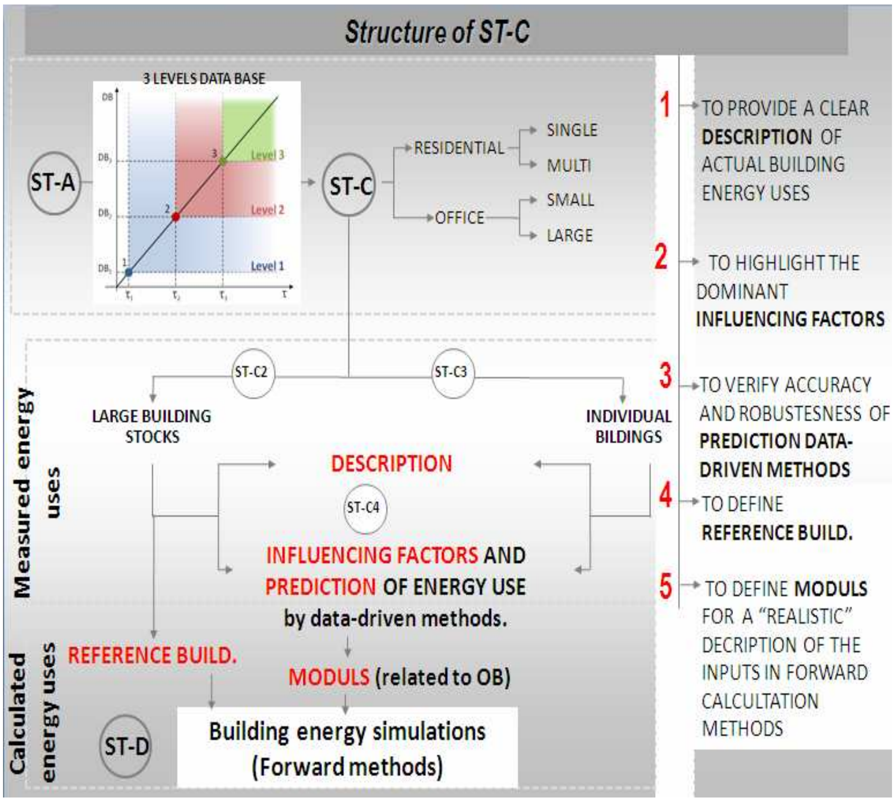

Figure 7. Research structure of ST-C

Looking at the upper left of the figure, the deep connection between ST-A and ST-C is evident: in order to developed statistical analyses a structured database has to be available. The proposal of a 3 level database has been shared with ST-A, after the discussion on the results of a dedicated carried out literature reviewing activity (this topic is one of the key issue of Work Item 1 of ST-C). The 3 level database structure refers both to the frequency of energy consumption (annual, monthly, daily/hourly) and to the categories of influencing factors. To apply statistical tools and data-driven methods, the availability of a clearly structured database, with a well defined format and item definition, is fundamental: unfortunately, the importance of this matter is too often underestimated. Both for large building stocks and for individual buildings, statistical tools can be mainly used: to statistically describe the characteristics of object of the study, to point out the dominant factors influencing energy consumptions and to predict future total energy uses.

When statistical analyses are used to predict, the performed literature review showed that large building stocks are the main subject of the investigation and the studies are mainly performed applying regression methods or neural network methods.

Moreover, statistical tools can be applied to define specific "moduls" for a better description of input parameters in forward methods. Therefore, a "modul" is a statistically based input applied to a direct (forward) calculation method, determined in order to provide a more "realistic" description of the phenomenon. In Annex 53, a special emphasis will be given to moduls describing influencing factors related to occupant behavior.

Activities

The ongoing activities can be divided, according to ST-C structure, with reference to the subject of the analysis:

- Large Building Stocks
- Individual Buildings.

Common questions have to be faced: Fixed the goal of the analysis, what are the more appropriate inverse methods according to the Database Level? What are the dominant influencing factors?

In order to deal with these questions for large building stock, selected benchmark databases will be shared among the partners. First the structures of these databases will be analyzed and the quality of the data will be checked. Then, they will be used and investigated by the different countries, applying different data-driven methods: hypothesis and results, potentialities and limitations will be compared.

With reference to the study of data-driven methods applied to individual buildings, the first action will be to check what are the databases available for individual building investigations. At the same time, the possible relationship with ST-B/Case Study will be verified. When the reference databases will be selected, the analysis of the potentialities of the different inverse methods will be examined.

Subtask D: Energy Performance Evolution

In order to analyze energy flows in buildings and to be able predict them with enough reliability, simulation models can provide an important added value. Such models are developed for a while to compute different aspects of building energy performance: thermal losses through the envelope, HVAC system operation and efficiency, thermal bridges, control features.

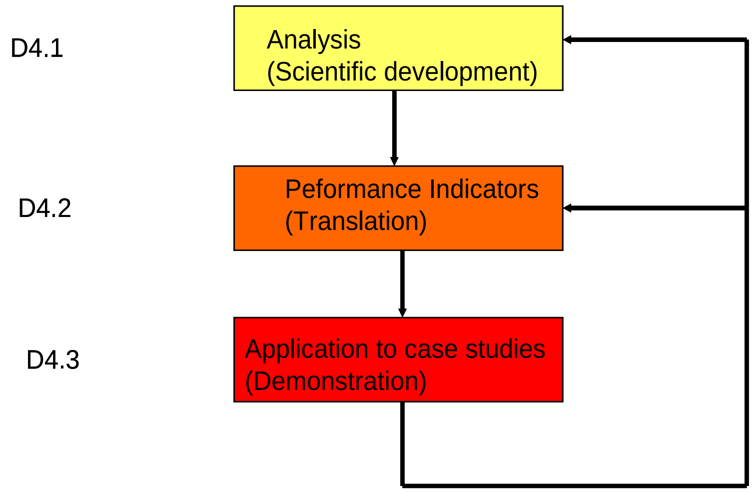

Figure 8. Logical diagram of IEA 53 Subtask D

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

In that perspective, the first step is, by running simulation models on different building cases, to identify the cause-effects relationships between the influence factors and the energy performance of buildings. Typical building cases 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 a second step, new indicators will be proposed to better catch, in a standardized way allowing comparison between two different cases, the building performance.

In a third second step, models will be applied to real cases (the case studies of the Annex) in order to characterize the energy flows in those cases and to provide a quantified method to assess the efficiency (in terms of energy savings) of different Energy Conservation Measures, applied either on the building envelope or on the HVAC system; including its control. This requires an important step to be performed, which consists in calibrating the simulation models to the cases, by comparing with measured performance and adapting some of the sensible model parameters. With a calibrated simulation models, the energy savings can be predicted with a better accuracy and reliability. This prediction considers all factors showing an influence on the performance, including human factors and occupant's behaviour. In order to deliberately point out this influence, it is anticipated that the results will be presented as performance range around an average value (corresponding to the "average user").

When applied to the typical cases in each national context, this methodology allows to perform an extrapolation of the impact of some Energy Conservation Measures to a country or a Region and there from to provide a quantified and objective basis to the energy policies in this country.

Figure 9 shows an example of a simulation study of the influence of envelope insulation and occupants' energy saving actions on residential energy use: A two-storey 153 m^2 detached house with four occupants in Sendai, Japan, was selected as the simulation subject. The simulation results show that lifestyle greatly influence energy use. Changes in lifestyle are then seen to have a large energy saving potential, while the energy saving effect of envelope insulation is not so distinct.

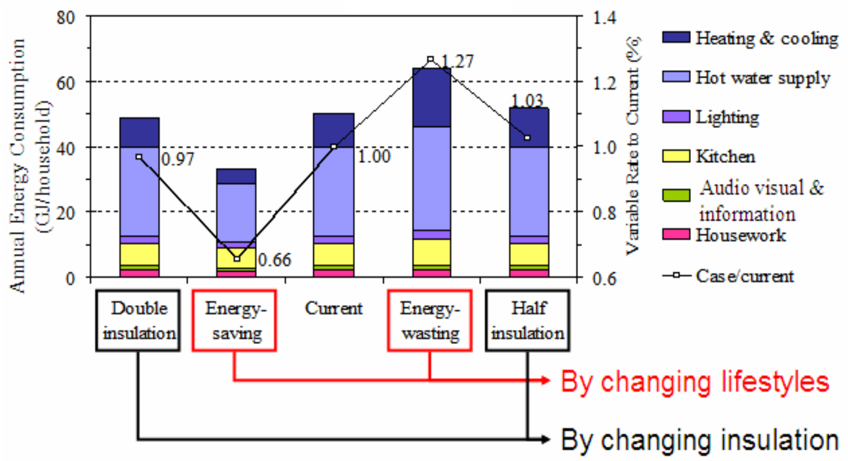

Figure 9. Analysis of the effect of lifestyle change on residential energy use in ST_D

Annex53

Total Energy Use in Buildings - Analysis and Evaluation Methods

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