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Reference procedures for obtaining occupancy profiles in residential buildings

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1. Introduction

This report presents the main findings of the activity 4.4 "Reference procedures for obtaining occupancy profiles in residential building" belonging to IEA EBC Annex 66 Subtask A. The activity was conducted with the aim of providing methods to describe occupancy in residential buildings and technical approaches to define occupancy profiles for energy simulations. Occupancy data can be classified into four levels: presence status ("occupied" and "unoccupied"), number of occupants, place in the space and activity. Occupants' profiles can be defined by considering how people occupy the building, how they use the systems (heating, cooling, etc.), and how they interact with devices including windows, blinds, lights, appliances, etc. Occupancy profiles may differ significantly from each other and affect the energy performance of buildings. Their determination is essential as they are necessary inputs to energy building simulation. Based on these considerations, the report is focused on:

1. Investigating the procedures used to obtain occupancy profiles and their limitations;
2. Identifying the problems of data collection methods;
3. Characterizing different types of variables necessary to define representative occupancy profiles.

To achieve the aims above, the following steps were done:

1. Completing a literature review by considering different residential context and doing a classification (by continent, methodology, type of statistical analysis and other);
2. Providing information about methodologies for data collection and processing;
3. Define the variables to be considered in surveys to get occupancy profiles.

2. Review of case studies and methods

Identification of occupancy characteristics in residential buildings presents specific issues. Unlike in laboratory studies, researchers may have limited access to sensors and other equipment used for in situ monitoring. Adjustment or replacement of monitoring equipment can be invasive and time-consuming. Frequent visits may remind occupants that they are being monitored. Thus, occupants and their behavior can be significantly affected by knowledge that they are being monitored (Hawthorne effect). In consequence, in residential buildings, collecting data by applying social surveys is mostly preferred by researchers to reveal occupancy profiles and the reasoning for those.

2.1 Description of the sample of literature reviewed

A body of literature of fifty studies related to occupancy profiles was collected through systematic literature review and snow-ball approach. The selected documents were analyzed and classified according to geographic context, period, sample size, and methods used to collect information and analyze data. The review allowed also to identify which variables are taken into consideration, the sampling strategy, the study design. Most of the works were carried out in Europe (37), some examples were found in Asia (10) and only few works were identified in USA (3). Figure 1 details the countries where the investigations were conducted.

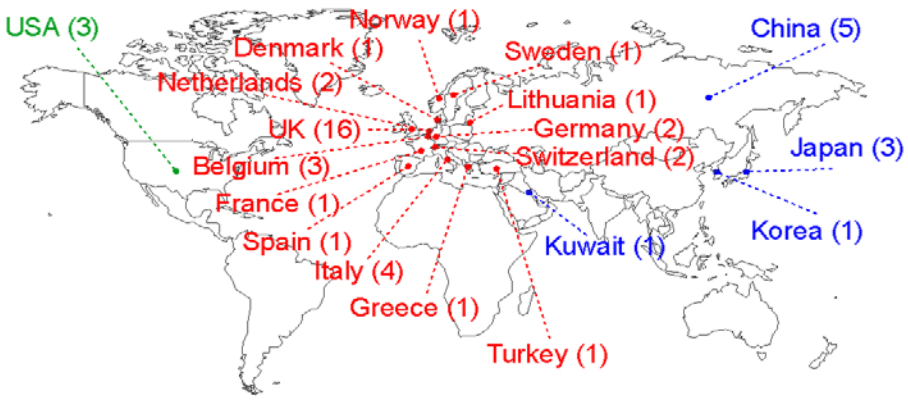

Figure 1. Countries of provenance of the analyzed studies on occupancy profiles.

The earliest study dates back to 1979 in USA, very recent investigations are also available. Most of the studies have been developed after 2000, on all continents. In particular an increasing attention to this topic is registered in latest years in Europe, where 60% of the studies are dated after 2010. In most of the analyzed cases (42.5%), data are collected through questionnaires administered in different ways (face-to-face, mailed, telephone, self-completed). In 34% of the cases, field measurements or time use data are employed. Some studies (15%) report mixed techniques for data collection, and about 8.5% refer to literature review for the definition of occupancy profiles. Data acquisition by field measurements is typically used for limited case studies while the application of time use data involves large samples. In the works elaborated before 2010s, the most commonly used analysis techniques are correlation, regression, and clustering. Markov models appear widely used after 2010s. Generally, cluster analysis is applied to large samples (hundreds or thousands investigated units), other statistical elaborations, such as regression or Markov chain, are used for diverse sample sizes (from less than ten to more thousands).

2.2 Methods of occupancy data collection

There are two main categories of data collection methods: social surveys and monitoring surveys. Social surveys collect subjective data and can capture causal inference (why and how people do things) and socio-demographic information. Monitoring surveys capture the actual type, duration and frequency of occupancy patterns. Reference studies for each data collection method can be found in [1] and [2].

a) Social Surveys

Method	Advantages	Limitations
Interview: private meeting to discuss a topic (face to face or not). Structured (fixed questions) to unstructured (guided interview)	Respondents are not limited in their answers Interviewers can confirm that respondents understand the questions and provide clarification when needed	Possible bias due to 'interviewer effect' Difficult to replicate
Focus group: group meeting between participants and moderator to discuss a topic	Flexible, content led by respondents	Possible bias due to 'moderator effect' and 'group effect' Difficult to replicate
Diary: self-completed questionnaires with structured entries, Time Use Survey (TUS)	Comparable and replicable when same diary structure is utilised (e.g. HETUS across Europe)	Requires commitment from participant Filling the diary may interfere with the activities
Questionnaire: structured questions and answers	High replicability Multiple means of communication: meeting, phone call, email, post Minimal interviewer intervention	No opportunity for follow-up questions Possible subsampling problems with post and email Limited answers
Observations: researcher observes participants on-site or passively through monitoring device, e.g. camera	Does not depend on people's report, activities are directly observed. High flexibility in the content captured	Possible bias due to 'Hawthorne effect' Relative to observer; two observers could consider the relevancy of events differently

b) Monitoring surveys

Method	Advantages	Limitations
Passive infra-red (PIR): detection of heat waves from warm objects. PIR sensors detect motion.	Affordable, available, easy to install and maintain Ease of data analysis	Does not allow differentiating between multiple occupants Can produce false negatives when occupant is still or false positives by pets
Carbon dioxide sensor (CO_2): capture of changes in carbon dioxide concentration levels	Affordable and easy to deploy	Requires mains power Measurements can be affected by ventilation practices and

Method	Advantages	Limitations
		infiltration rates
Energy meters: inference of occupancy from electricity consumption	Non-intrusive Already installed technology	Limited to houses with smart meters only Requires high granularity
Device-free Localisation (DfL): detection of changes in a radio frequency signal environment due to absorption from occupants' bodies	Non-intrusive, no tag needed Allows tracking individual movement Not limited by structural elements	Requires precise positioning of components Possible interferences from other sources
Wearable loggers: geolocation sensing as GPS or inertial navigation	Already installed technology (e.g. occupant's mobile phone)	Possible bias due to 'Hawthorne effect' Privacy issues
Wearable loggers with stationary sensors: combination of wearable tags and beacons of Bluetooth, wireless or ultrasound networks	Precise detection	Participants have to wear/carry tags Requires challenging set-up and maintenance

2.3 Data analysis methods

Reference studies for each data analysis method can be found in [2].

Method		Common application
Descriptive statistics	Analysis of data, description and summary of main features	Energy meter data Monitored occupancy data from single sensors or networks
Inferential statistics	Generalisations about a population from a sample	Energy meter data Monitored occupancy data from single sensors or networks
Modelling	**Schedules** as binary daily occupancy profiles	Social surveys
	Deterministic models: to establish causal relationships to occupant behaviour	Monitored occupancy data from single sensors or networks Social surveys
	Non-probabilistic and stochastic models including Markov chain models based on a random transition between states	Extensively used with Time Use Surveys where state probabilities are derived from diaries
	Time series analysis: statistical analysis accounting for trends and seasonality. Forecasting model. Includes: Auto-Regression, Moving Averages, Hidden Markov Model	Energy meter data Monitored occupancy data from single sensors or networks Occupancy forecasting in BMS
	Agent-based: modelling of behaviour at individual level; each person is an autonomous agent with own behaviour, social norms, etc. that interacts with each other in a dynamic environment	Data from both monitoring and social surveys can be used for model calibration and validation
	Machine learning: algorithms that can learn from data without specific instructions. They can be supervised (Decision-tree, Support Vector Machine-SVM, k-nearest neighbours) or unsupervised (hierarchical clustering, neural networks)	Monitoring sensors networks Energy meter data Social surveys
Data mining	Identification of patterns in large datasets (factorial analysis, multidimensional scaling, cluster analysis, etc.)	Energy meter data Monitored occupancy data from single sensors or networks

2.4 How to define occupancy profiles

Social and monitoring surveys can be used to define or validate occupancy profiles. Occupancy profiles may be defined through Time-Use Survey (TUS) data. For example, Aerts et al. [3] described a methodology to obtain occupancy profiles based on the 2005 Belgian time-use survey with the aim of using it for user behavior modeling in building energy simulation. The authors of the study developed seven user profiles reflecting realistic user behavior in homes. Similarly, Richardson et al. [4] defined occupancy profiles for UK households by using TUS data describing people habits. The developed models indicate the number of occupants in the house at a given time to have information on the sharing of energy use. Wilke et al. [5] used French time-use survey data to calibrate stochastic models and to predict activity chains.

In [6] different procedures for obtaining occupancy profiles are reviewed focusing on residential building stock located in Italy. Three occupancy profiles are derived from different methods: (1) interview of residents, (2) national standards application and (3) Harmonised European Time Use Survey for Italy. Then, different modes of use of a representative dwelling are tested by varying density of occupancy, ventilation, lighting, domestic hot water and heating operation. Another study by [7] considers nZEB definition and national census information to determine a method for creating housing occupancy patterns by using free database. Finally, another study in Turkey [8] conducted social surveys in 4 residential complexes situated in 4 large cities of Turkey each of which is in a different climatic region but has similar design and construction system. In addition, monitoring survey was undertaken in one of the four residential complexes. The results showed that presence at home and window opening strategy are the most sensitive parameters on heating load and comfort levels both under winter and summer conditions.

3. Identification and classification of variables related to occupancy profiles

Occupancy profiles are determined by diverse driving factors such as household characteristics, cultural traditions, social and economic variables. On the other hand, occupant's preferences and attitudes affect the use of equipment and air conditioning systems and influence the building energy consumption. In general, it is possible to individuate two types of variables:

Variables Type_1 – Variables that influence occupancy profiles

- **Socio-demographic variables** are determinants of occupancy in dwellings as in 'when' people are in their homes [2]. Variables include household composition and employment status. Adults overs 60 years of age and families with small children tend to spend more time in their homes during weekdays and weekends. Regarding employment, work status (working full time, part-time, retired) and industry (working schedules) shape occupant's schedules throughout the week.
- **Environmental and physiological variables** influence occupancy patterns (time and/or space) and comfort level preferences [9]. Occupants' comfort depends on environmental characteristics (climate and building typology), psychological characteristics are related to age, gender and expectations derived from past experiences.

Variable Type_2 – Variables influenced by occupancy profiles

- **Presence variables**: energy consumption in households is heavily dependent on how the building is used. In particular, the type of activity, the hours of presence of the occupants in the different rooms and the density of occupancy should be considered for the estimation of sensible and latent heat associated with people and, consequently, in the convective/radiative loads that weights on the energy balance of the internal environment.
- **Comfort variables:** parameters that control the environmental conditions in homes (air temperature, heating and cooling systems operating, ventilation, etc.).
- **Tools variables:** use of the amenities in homes, including the use of electrical equipment, cooking and the demand for hot water.

Figure 2. Variables categorization and reciprocal influences.

Both 'comfort' and 'tools' variables are strongly linked to the "type of user" and to the "management" of the house by the occupants. Heating/cooling demands are derived from set point temperature and occupancy profile, while ventilation is related to window operation. The figure below illustrates the framework of the variables in building simulation and modelling that are dependent upon occupancy profiles.

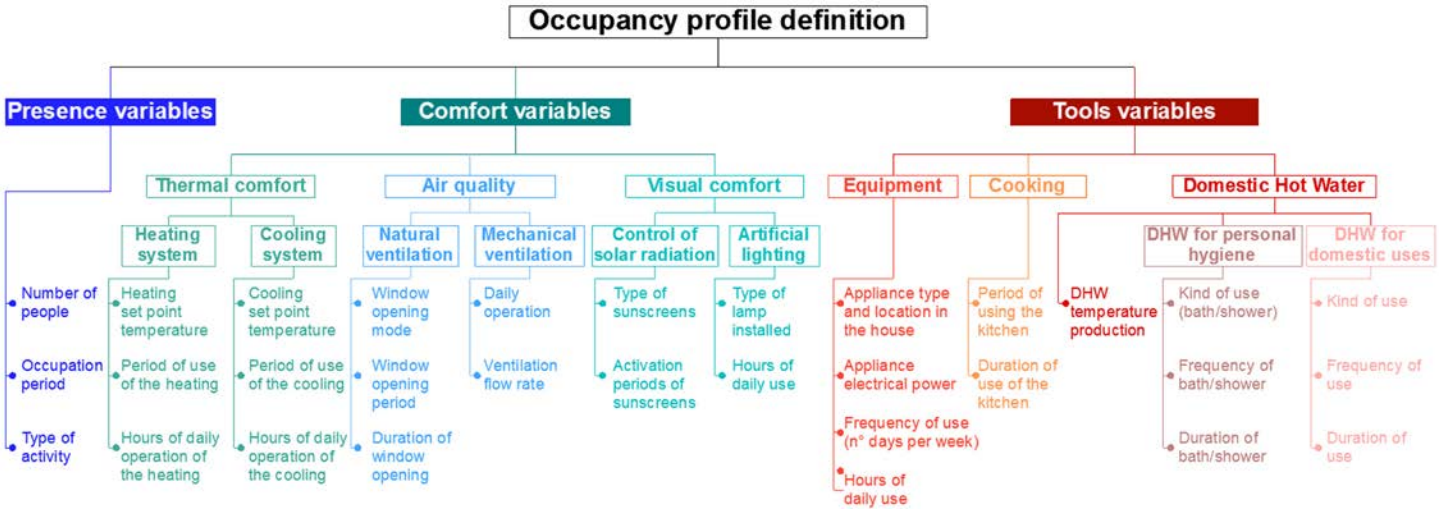

Figure 3. Variables categorization for input in energy building simulation and modeling.

4. Conclusions

This report draws out different methods for defining occupancy profiles and highlighted the advantages and disadvantages of each approach by considering an extensive literature review. Also, the variables related to occupancy, which are necessary input for energy simulation, are defined. In situ monitoring and social surveys are used as data collection methods, in some cases these are coupled. Monitoring sensors are able to track occupancy characteristics in real time but can be invasive and require an adequate observation period. The most common method is interview surveys, but this method can be time consuming and not replicable. A viable alternative might be the use of existing datasets; but most currently available datasets are not sufficiently detailed. Therefore, targeted

surveys should be developed in order to create exploitable datasets for this specific purpose. Analyses at local level are needed since the habits and behaviors of users vary depending on the geographical area. Finally, this report underlines the necessity to include National survey questions about the occupancy and the use of houses. Generally, this information is poor and fragmented.

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