EBC
Energy in Buildings and Communities Programme

IEA EBC Annex 66

Definition and Simulation of Occupant Behavior in Buildings

Operating Agents

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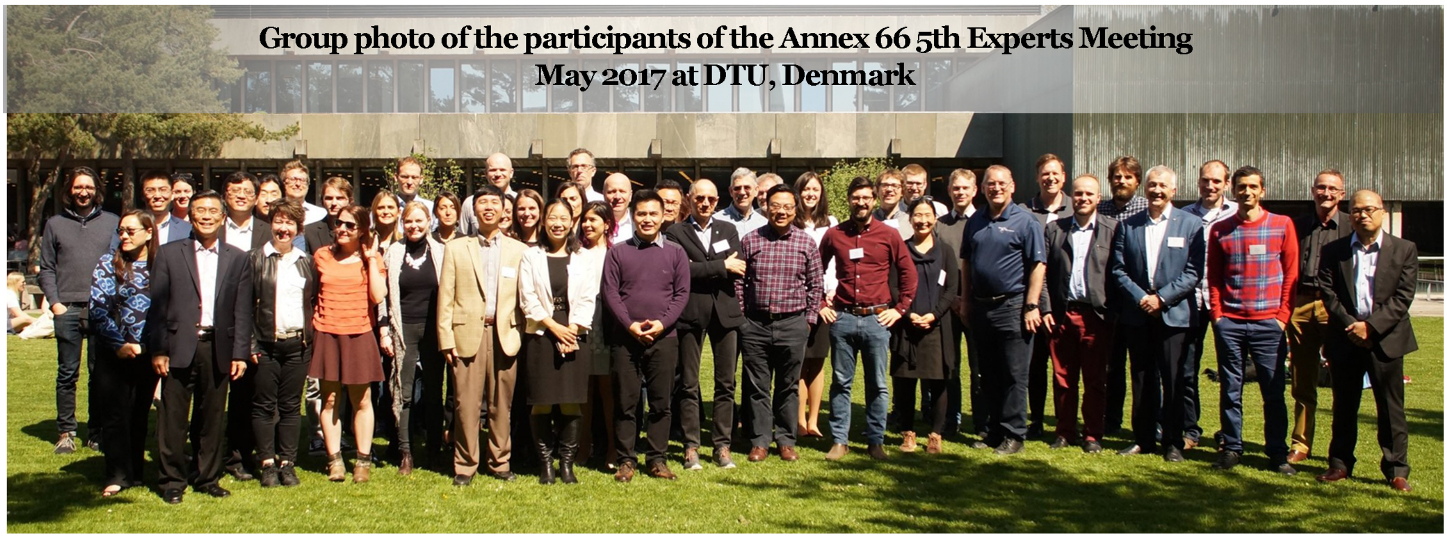
Annex 66 Overview

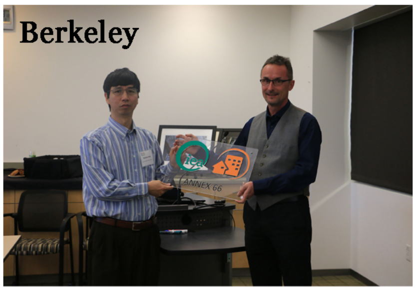
Energy related occupant behavior in buildings is a key issue for building design optimization, energy diagnosis, performance evaluation, and building energy simulation due to its significant impact on real energy use and indoor environmental quality in buildings. However, the influence of occupant behavior is under-recognized or over-simplified in the design, construction, operation, and retrofit of buildings. Occupant behavior is complex, stochastic and multi-disciplinary. Having a deep understanding of occupant behavior and being able to model and quantify its impact on use of building technologies and energy performance of buildings is crucial to design and operation of low energy buildings. Existing studies on occupant behavior, mainly from the perspective of sociology, lack in-depth quantitative analysis. There are over 20 groups all over the world studying occupant behavior individually. The occupant behavior models developed by different researchers are often inconsistent, with a lack of consensus in common language, in good experimental design and in modeling methodologies. Due to the complexity and the great district discrepancy of occupant behavior, it is prerequisite for researchers to work together to define and simulate occupant behavior in a consistent and standard way. The Annex aims to set up a standard occupant behavior definition platform, establish a quantitative simulation methodology to model occupant behavior in buildings, and understand the influence of occupant behavior on building energy use and the indoor environment. We hope to provide scientific description and clear understanding of energy related occupant behavior in buildings, as well as research methodologies and simulation tools to bridge the gap between occupant behavior and the built environment, thus to assist building design, operation, and energy technologies evaluation through the close co-operation of researchers all over the world.



Group photo of the participants of the Annex 66 5th Experts Meeting May 2017 at DTU, Denmark

Expert Meetings

- **2013 - 08 Paris** — **Expert Meeting for New ANNEX**
- **2014 - 03 Hong Kong** — **1st Expert Meeting Preparation Phase**
- **2014 - 08 Nottingham** — **2nd Expert Meeting Preparation Phase**
- **2015 - 04 Berkeley** — **1st Expert Meeting of Working Phase**
- **2015 - 08 Karlsruhe** — **2nd Expert Meeting of Working Phase**
- **2016 - 03 Vienna** — **3rd Expert Meeting of Working Phase**
- **2016 - 08 Ottawa** — **4th Expert Meeting of Working Phase**
- **2017 - 05 Copenhagen** — **5th Expert Meeting of Working Phase**
- **2017 - 09 Beijing** — **6th Expert Meeting of Working Phase**



There are nine in-person experts meetings, including one international workshop to develop the concept of Annex 66, two meetings during the preparation phase and six meetings during the working phase. Regularly, there are two meetings each year for the four year period. The first experts meeting in the working phase was held in Berkeley, USA, to officially kick off the research activities. The last meeting was held in Beijing, China, which summarized the key research activities and outcomes of Annex 66.

The overall progress of Annex 66 and research activities under each subtask were reported and discussed in detail at each experts meeting. Also discussed were management and out-reach of Annex 66, seminars, workshops, web site updates, newsletter, deliverables and final report preparation.

Expert Meetings

- 2013 - 08 Paris

- 2014 - 03 Hong Kong

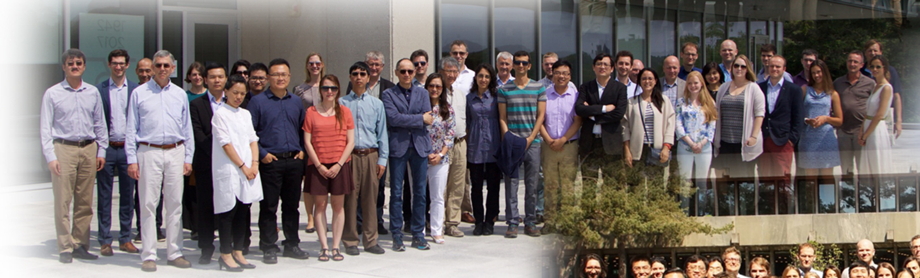
- 2014 - 08 Nottingham

- 2015 - 04 Berkeley

- 2015 - 08 Kalsruhe

- 2016 - 03 Vienna

- 2016 - 08 Ottawa



- 2017 - 05 Copenhagen

- 2017 - 09 Beijing

Symposium, Forum and Workshop

Besides Experts' meeting, there are a series of symposium, forum and workshops focusing on occupant behavior research organized by Annex 66 participants at international conferences, such as ASHRAE Conference, ACEEE, CLIMA, ACEEE and ISHVAC. Here is the list of those activities.

Name	Date	City	Country
Seminar at ASHRAE Conference	2014-06	Seattle	USA
Workshop on human behavior	2014-08	Berkeley	USA
Forum on occupant behavior simulation, ASIM conference	2014-11	Nagoya	Japan
Seminar at ASHRAE Conference	2015-01	Chicago	USA
Workshop on understanding Comfort, Attitudes and Behaviours	2015-04	Windsor	UK
CLIMA 2016	2015-05	Aalborg	Denmark
International Building Physics Conference	2015-06	Torino	Italy
Seminar at ASHRAE Annual Conference	2015-06	Atlanta	USA
ISHVAC-COBEE	2015-07	Tianjin	China
ACEEE Summer Study on Energy Efficiency in Buildings	2015-08	Pacific Grove	USA
International Symposium on Sustainable Human-Building Ecosystems	2015-10	CMU	USA
Cold Climate Conference	2015-10	Dalian	China
International Conference on Industrial Ventilation	2015-10	Shanghai	China
Seminar at ASHRAE Conference	2016-01	Orlando	USA
Occupant Behavior Modeling Tools Webinar	2016-01	Berkeley	USA
BEHAVE 2016	2016-09	Coimbra	Portugal
ASHRAE Building Performance Simulation Conference	2016-09	Atlanta	USA
ASIM 2016 (IBPSA-Asia Conference)	2016-11	Jeju Island	South Korea
Seminar at ASHRAE Annual Conference	2017-01	Las Vegas	USA
Cold Cilmate HVAC 2018	2017-03	Kiruna	Sweden
Symposium on Occupant Behaviour and Adaptive Thermal Comfort	2017-05	Lyngby	Denmark
Modelling and Simulation of Building Occupants	2017-05	Ottawa	Canada
World Sustainable Built Environment Conference	2017-06	Hong Kong	China
Seminar at ASHRAE Annual Conference	2017-06	Long Beach	USA
IBPSA Building Simulation Conference	2017-08	San Francisco	USA
The second International Symposium on Sustainable Human-Building Ecosystems	2017-09	Beijing	China
ISHVAC International Symposium on HVAC	2017-10	Jinan	China

Subtask A:
Occupant movement and presence models in buildings

Leader: Andreas Wagner, Karlsruhe Institute of Technology, Germany
Bing Dong, The University of Texas at San Antonio, USA

INTRODUCTION

Simulating occupant movement and presence is a fundamental part of occupant behavior research. The influencing factors include various types of spaces, time and events. The common method used currently is the inverse function method. As occupants move stochastically, models are often probabilistic. They can be categorized according to the problems to address:

1) Number of occupants at the building level;
2) Occupied status at the space level;
3) Number of occupants at the space level;
4) Location of an individual at the occupant level.

The main objective of the subtask was to provide comprehensive information on existing work in this field including existing and available data sets, occupant presence models used for simulation so far, and technology for collecting data (see figure 1).

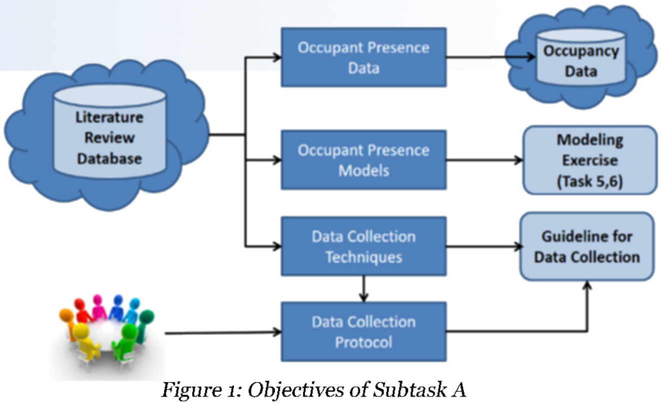


Figure 1: Objectives of Subtask A

ACHIEVEMENT

Based on an extensive literature review an EndNote database was set up which contains more than 450 papers. It is accessible at annex66.org. Further, a special issue on Occupant Behavior in Buildings was edited for Energy and Buildings, An International Journal in 2016; out of approx. 40 submissions 17 papers have been finally selected and published.

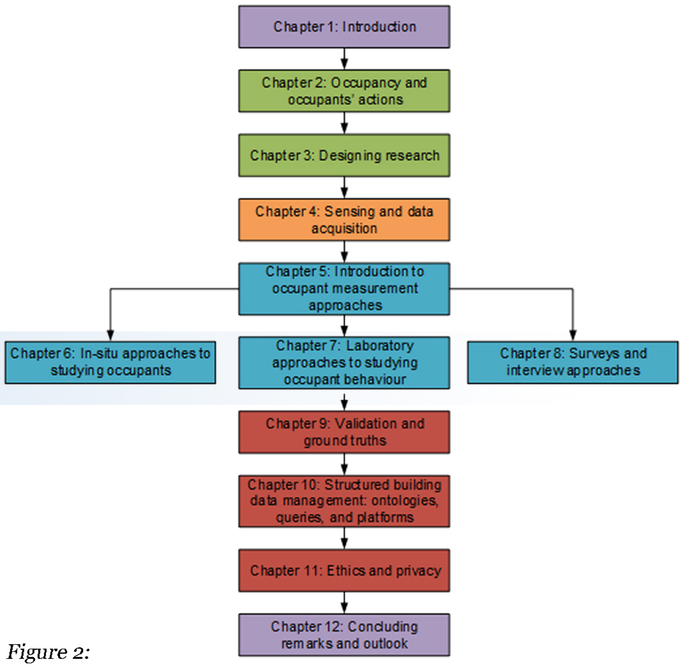


Figure 2:
Structure of the book 'Exploring Occupant Behavior in Buildings'

Three activities within Subtask A led to journal papers:
The collection and evaluation of information on existing occupancy presence data and models;
An assessment of modeling methods for presence and movements;
An analysis of methods and approaches for reference procedures for obtaining occupancy profiles in residential buildings.

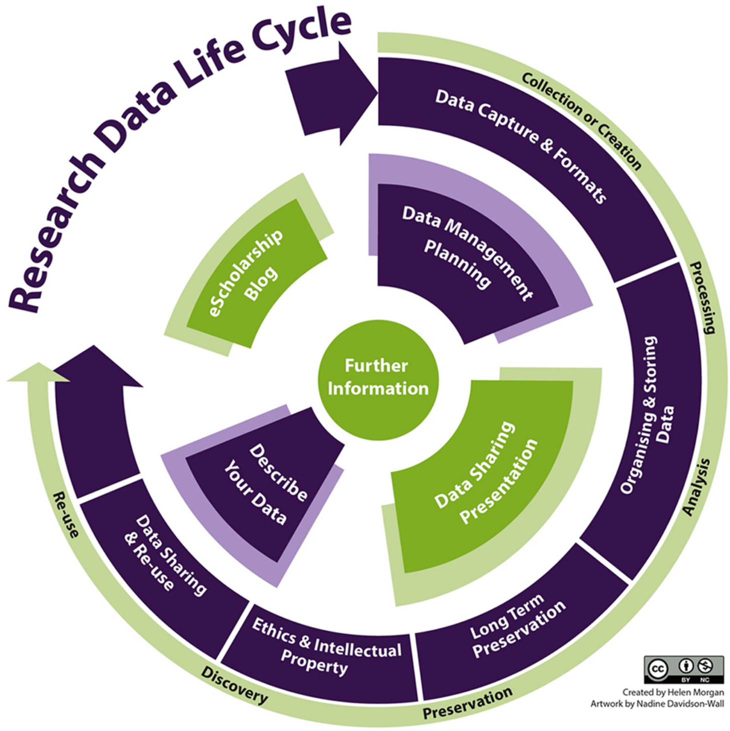
The main activity of Subtask A was on data collection techniques as existing studies and models used for simulation show that mostly no consistent approach had been followed in the past in order to gain comparable data sets. Therefore, substantial information on monitoring occupant behavior should be provided. This included state-of-the-art and new emerging sensing and data acquisition technologies, different experimental approaches (in situ measurements and surveys in real-life buildings, laboratory experiments) – including consistent protocols – and data management. The results were summarized in one of the chapters of the book 'Exploring Occupant Behavior in Buildings' (see figure 2).

Finally, the two Subtask leaders were strongly involved (together with Liam O'Brien, Carleton University, Canada) in editing the above mentioned book on 'Exploring Occupant Behavior in Buildings' which will be published by Springer within the next months. Figure 2 shows the structure of the book.

Subtask B:
Occupant action models in residential buildings

Leader: David Shipworth, University College London, UK
Henrik Madsen, Technical University of Denmark, Denmark

From reviewing projects and papers, it seems we lack consistency in experimental design and availability of high quality data and in modelling methodologies and availability of model algorithms or source code. Coordination of efforts to ensure the above, avoiding replication and channeling effort where most needed are necessary. Models are supposed to be integrated into a coherent whole.



The scope of this subtask is as follows:

- Residential occupant modelling social network of who is doing what and how;
- State of the art in residential occupant modelling, following the path from presence, activities, behavior to comfort with thorough analysis;
- Field survey and data management protocol for a good model;
- Modelling strategies and validation techniques for a good model;
- Use of the above to coordinate filling of gaps between simulation and measurement;
- Lighthouse contributions of new models and their applications during the Annex lifetime for partner survey of existing and forthcoming linked projects.

ACHIEVEMENT

- **Guidebook on stochastic modeling**
  A guidebook on stochastic modeling of occupant behavior was produced.
  It is an introduction to the techniques most frequently used for modeling occupant behavior (OB). Here, the main emphasis will be on methods for modeling serially independent data, but it will be stressed that in the case of serially correlated data (time series data) it might be of outermost importance to consider methods which enable a description of time correlated data. Additionally, an overview over some important model selection tools is given. Subsequently, some of the major modeling results in literature and the progress made in Annex 66 will be briefly outlined. These results are divided into sections each corresponding to one facade of OB such as presence, window opening, window shading, lighting, thermostat and appliance use. Finally, a section is dedicated to the modeling of occupants' diversity.

- **Summer School**
  A Summer School on "Dynamic Calculation Methods For Building Energy Assessment," was successfully held at the Danish Technology University (DTU) on July 19 to 25, 2015. The main purpose of the summer school was to train the students in a methodology for evaluation of measured data. Statistical modeling methods for using such time series data are discussed to assess valuable information about the energy performance of a building or the building element. Invited lecturers include Hans Bloem (JRC, Ispra), María José Jiménez (CIEMAT), Henrik Madsen, Peder Bacher (DTU), Paul Strachan (Strathclyde University).

Subtask C:
Occupant action models in commercial buildings

Leader: Ardeshir Mahdavi, Vienna University of Technology, Austria
William O'Brien, Carleton University, Canada

INTRODUCTION

A commercial building is typically operated via complex environmental control systems, and the control degrees of freedom between occupants and building or system managers can substantially vary from building to building. Moreover, occupants in commercial buildings often work in shared spatial settings and interact within a social field that requires collaboration and negotiation. Thus, modelling occupants' behavior in commercial buildings involves some specific challenges given the complexity and diversity of the respective processes.

In this context, in order to enhance the reliability and usability of occupant presence and behavior models, the Subtask C researchers conducted a number of activities as follows: review of different modeling approaches for occupant behavior in buildings; approaches to address occupants' behavior diversity in model development; recommendations for evaluation of building occupants' presence and behavior models; documentation of best practices in occupancy model testing and evaluation.

ACHIEVEMENT

The following list summarizes selected important achievements of Annex 66 STC.

- **Special issue in Journal of Building Performance Simulation titled Fundamentals of occupant behaviour research:** In addition to a large number of publications in a variety of high impact scientific journals, subtask C members acted as guest editors (and authors of a number of contributions) to provide a comprehensive collection of contemporary fundamental contributions to the field of building occupant modelling and simulation. The special issue, which is to appear in Fall 2017 follows a structure that consists of three major stages of occupant research, including data collection, modelling, and simulation. 10 of the expected 16 articles in the special issue were written by Annex 66 members.
- **Contributions to the Springer's book "Exploring Occupant Behavior in Buildings: Methods and Challenges":** Edited by A. Wagner, W. O'Brien, and B. Dong, book which will be available in December 2017 cover the multi-faceted topic of occupant behavior research. The research efforts conducted in STC formed a number of chapters in the book. In one chapter, Mahdavi et al. introduced an ontology for the representation and incorporation of multiple layers of building and occupancy-related data in pertinent computational applications such as building performance simulation. This chapter focused on a number of necessary high-level efforts and developments to better realize the versatile potential of building monitoring in supporting the building design, delivery, and operation processes. O'Brien co-authored several chapters on occupant data collection and particularly on in situ methods.
- **Exploring the diversity in occupancy and energy-related behavior:** A topic of particular growing interest to numerous occupant modelling researchers is characterizing inter-occupant diversity. Previous modelling approaches have tended to aggregate data from all occupants within a monitoring study. In response, O'Brien, Gunay, Tahmasebi, and Mahdavi wrote a paper on occupancy modelling and demonstrated that aggregating data from all occupants prior to modelling tends to suppress diversity predictions relative to observations. This has significant implications with regards to the spread of energy prediction results (e.g., for robust design applications).
- **Contribution to the Annex 66 Final report:** In the course of last months, STC members specifically focused on preparing one of the chapters in Annex 66 final report. This chapter formulated a number of relevant conditions and requirements with regard to the evaluation of occupant behavior models. It also presents a demonstrative model evaluation study involving a number of recently proposed window operation models.

Subtask D: Development and integration of occupant behavior modeling tools for building performance simulation

Leader: Tianzhen Hong, Lawrence Berkeley National Laboratory, USA
Andrew Cowie, University of Strathclyde, UK

INTRODUCTION

Subtask D aims to develop quantitative description and models of occupant behavior in order to analyze, evaluate and understand the impact of occupant behavior on building energy consumption, as well as helping to reduce discrepancies between the simulated and measured energy use in buildings, by developing new behavior modeling tools and integrating them with BPS programs.

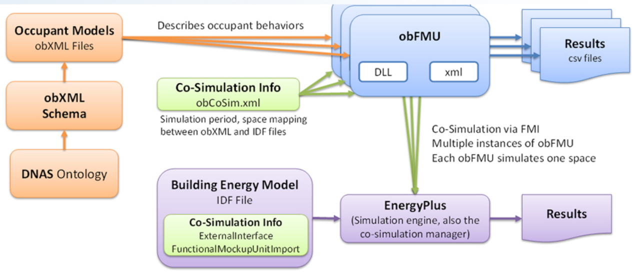


Figure 1: The co-simulation workflow of obFMU with EnergyPlus

There are five research activities:
(1) Activity 7.1 – Survey and review of occupant behavior modeling with current BPS programs, (2) Activity 7.2 - Standard representation of occupant behavior models, (3) Activity 7.3 – Development of a software module with occupancy and occupant action models, (4) Activity 7.4 - Integration of occupancy and occupant action models with BPS programs, and (5) Activity 7.5 – A case study comparing occupant behavior modeling tools with various BPS programs.

ACHIEVEMENT

• **Activity 7.1:** We wrote a paper detailing the results of our survey, which was published and presented at the 2017 IBPSA Building Simulation conference in August in San Francisco.

• **Activity 7.2:** We developed the DNAS ontology to represent occupant behavior in buildings, and developed an XML schema obXML to describe occupant behavior models, which enables model exchange between BPS programs and user applications. We reviewed the literature and selected 52 occupant behavior models to be included in an obXML model library.

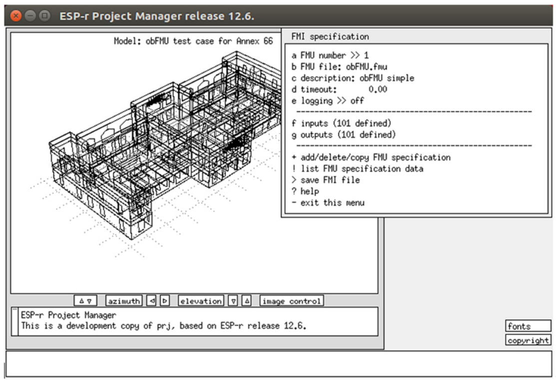


Figure 2: Screenshot of Activity 7.5 case study building in ESP-r, showing the obFMU linkage interface.

• **Activity 7.3:** We developed an occupant behavior functional mockup unit (FMU), obFMU, which enables its co-simulation with BPS programs implementing the functional mockup interface (FMI). A web-based application, Occupancy Simulator, was developed to simulate the stochastic occupant presence and movement in buildings, which generates hourly or sub-hourly occupant schedules for building performance simulation.

• **Activity 7.4:** We have successfully linked obFMU with EnergyPlus and ESP-r. A release version of ESP-r that includes this functionality is in the final stages of being made available to the public. There has also been interest from other programs (e.g., IDA-ICE) to link with obFMU.

• **Activity 7.5:** We have developed a case study to demonstrate and compare the obFMU linkages with EnergyPlus, ESP-r and TRNSYS. Results indicate that obFMU performs consistently among these implementations.

• All of these activities have been summarized in Subtask D's contribution to the final Annex 66 report. The developed tools are available for free download and use at behavior.lbl.gov and OccupancySimulator.lbl.gov.

• We have reached out to the building simulation community through events such as an Annex 66 panel discussion at BS2017, open webinars, and ASHRAE MTG.OBB seminars. This includes discussion of synergy between obXML and BIM (e.g., gbXML). About a dozen journal articles and conference papers were published based on the outcomes from Subtask D.

Subtask E:
Applications in building design and operations

Leader: Khee Poh Lam, National University of Singapore, Singapore
Cary Chan, Hong Kong Green Building Council, Hong Kong
Clinton Andrews, Rutgers University, USA

INTRODUCTION

The goals of this subtask are to characterize the range of application contexts for occupant behavior modeling, develop guidance regarding the most appropriate fit of tools to specific applications, and assemble succinct case studies of these applications. A dedicated and diverse team of researchers and practitioners assembled to carry out the work of the applications subtask. It included participants from Australia, Canada, China, Germany, Hungary, Italy, Korea, The Netherlands, Singapore, and the United States. Disciplines represented were architecture, architectural engineering, civil engineering, mechanical engineering, sociology, and urban planning. Sectors represented were universi- ties, national laboratories, professional consulting, and design practice.

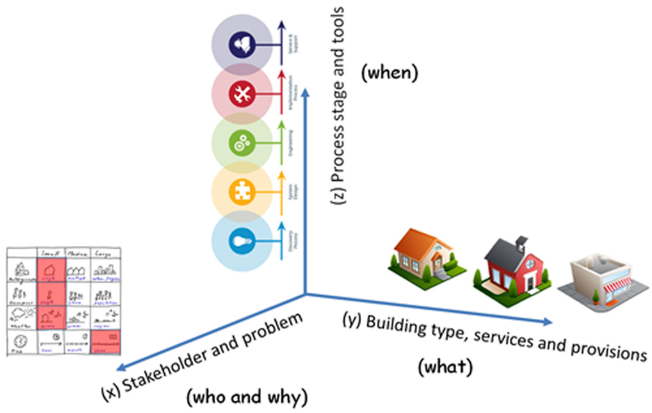


Figure 1:

Three dimensions defining main objectives of the energy modeling

ACHIEVEMENT

Subtask members produced very useful guidance on major application categories, summarized in Figure 1. Three dimensions emerge as the most important: the stakeholder and their problem (Who? Why?); the building type, services, and provisions (What?); and the process stage and relevant tools (When?).

Contributors delivered 30 case studies that illustrate key insights from the experience of applying occupant behavior simulation modeling to specific problems. The cases are summarized in Figure 2. A key finding is an appreciation that the degree of occupant influence on energy consumption varies according to the degree of automation, interior layout and personalization of spaces, relation between internal and external thermal loads, and occupant schedules. A second key finding is that the degree of precision needed about occupant influences on energy consumption varies significantly over the phases of a building's life, suggesting that practitioners should use the simplest tool that serves their specific needs.

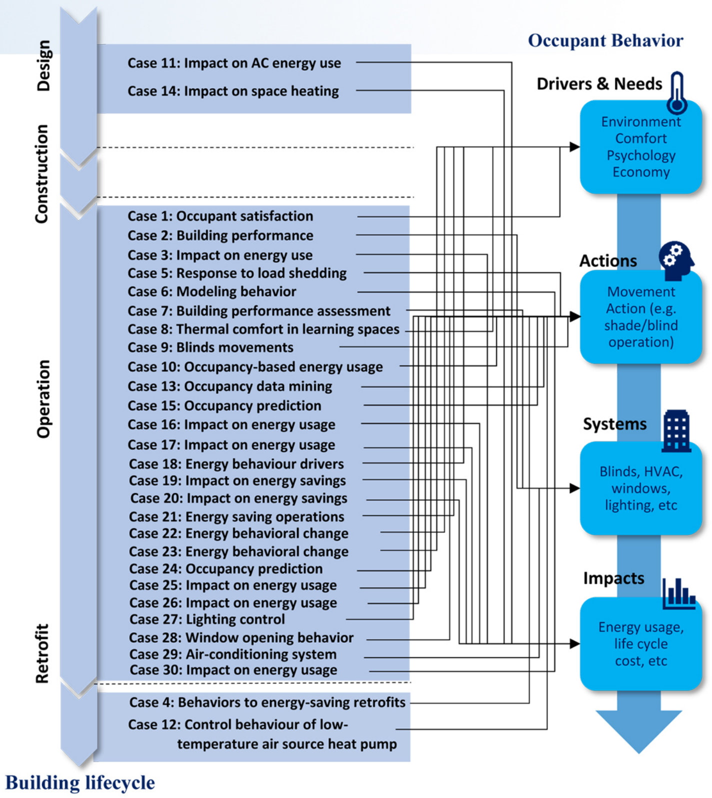
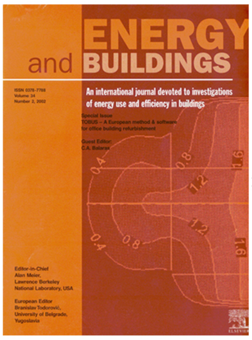


Figure 2: Distribution of case studies along the building life cycle

Future work is needed (1) to develop a more complete framework for classifying applications of occupant behavior modeling, (2) offer more consideration of how to change occupant and operator behavior in buildings, (3) provide a practical design guide for cases when modeling is not a feasible strategy, (4) formulate a decision-support framework for practical model users, and a means to incorporate qualitative insights on occupant behavior in buildings not captured in formal simulation models.

Special Issues



Advances in Building Energy Modeling and Simulation

- **Guest Editor: Tianzhen Hong**
- This special issue arose from recent advances in methods, tools and applications of the field, especially from the IEA EBC Annex 66, Definition and Simulation of Occupant Behavior in Buildings. This special issue provides 15 high quality articles on important topics.

Occupancy Behavior in Building

- **Guest Editors: Andreas Wagner, Bing Dong**
- There is a strong need for more accurate approaches of modeling occupant behavior to support planners and building managers during the design phase and building operation. This topic has been addressed in this special issue encouraging researchers to submit contributions in the field.

Fundamentals of Occupant Behaviour Research

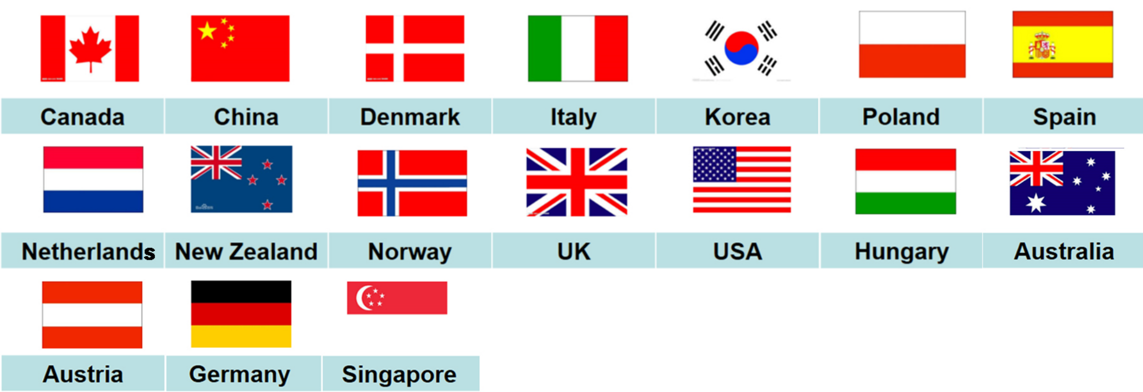
- **Guest Editors: William O'Brien, Burak Gunay, Farhang Tahmasebi, Ardeshir Mahdavi**
- This special issue focus on contemporary fundamental contributions to the field of building occupant modelling and simulation, while the structure that consists of three major stages of occupant research, including: data collection, modelling, and simulation.

Applications of Occupant Behavior Modeling

- **Guest Editors: Clinton J. Andrews, Bing Dong**
- Papers on applications of building simulation to building design, controls, operations, retrofits, equipment design, and public policy are sought for this special issue. By the time the dust cleared in the peer review process, there are 17 strong papers that covered most of these application areas.

National Participation

17 Official National Participants



Publications (Journal Article 2014-2017)

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Award

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