IEA EBC Annex 66

Definition and Simulation of Occupant Behavior in Buildings

Operating Agents

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INTRODUCTION

Importance and Urgency

Currently, there is international public concern over the rapid and continual increase in building energy consumption. Occupant behaviour is a key contributor towards the overall building energy consumption. Often a disproportionate amount of attention is directed towards upgrading system or technological efficiency, while ignoring the human dimension. Therefore, the cognition of influences of occupant behavior is insufficient in building systems design and energy retrofit. This limited understanding of occupant behaviour results in inappropriate, overly simplified, assumptions which lead to inaccurate expectations of building energy performance. The traditionally low priority placed on occupant behaviour research, has resulted in large discrepancies in building design optimization, energy diagnosis, performance evaluation, and building energy simulations. The large majority of the existing studies on occupant behaviour embrace a social sciences perspective, lacking in-depth quantitative analysis. The fraction of studies generated from an engineering and/or mathematical angle lack consensus in common language, experimental design and modelling methodologies. As a result, current occupant behaviour models suffer from inconsistencies.

Objectives

The International Energy Agency (IEA), Energy in Buildings and

Figure 1: Participants at the Open Forum for Annex 66 in Hong Kong, China, March 12-14, 2014.

Figure 3: Annex 66 will help bridge the gap between energy related behaviors and building energy efficiency.

Communities (EBC) Programme approved the Annex 66 project at its Executive Committee Meeting in November 2013. The project will establish a standard occupant behavior definition platform and a quantitative simulation methodology to be used to model occupant behavior in buildings. The IEA EBC Annex 66 is the first Annex to focus exclusively on occupant behavior simulation and brings together the leading experts in the field (Figure 1). A top priority of Annex 66 is to establish a robust, universal, scientific framework for occupant behavior quantitative definition and simulation methodologies. Figure 2 shows the interdependence between occupant behaviour and building energy performance. The success of Annex 66 will foster innovation and drive broad, sustained growth towards achieving energy targets.

Annex 66 Targeted Outcomes

(Deliverables, Target Audience, Related Subtasks)

[1] Guideline of behavioural data collection, *Building Energy Researchers, Energy Modelers, Simulation Software Developers,* ***Subtasks A, B, & C.***

[2] Methodologies to develop and validate occupant behavior models, ***Building Energy Researchers, Energy Modelers, Simulation Software Developers, Subtasks A, B, & C.***

[3] Integration and applications of occupant behavior models, ***Building Designers, Energy Saving Evaluators, HVAC Engineers, System Operators, Subtasks D & E.***

Annex 66 Expected Benefits to Industry

Robust energy simulation results:

- More accurate system/equipment sizing
- More robust system for green building assessment
- More reliable data for government to establish relevant policies

Understand the energy impact of different occupant behavior so as to:

- Design more people-centered buildings
- Smarter control of building systems
- Encourage the appropriate action of individuals

Annex 66 Expected Benefits to Stakeholders

- ***Designers:*** The end-users of the models and the software
- ***Developers:*** Benefit from building energy efficiency
- ***Occupants:*** The case(s) to be studied; the end-user of guidelines
- ***Operators:*** The case(s) to be studied; the end-users of the guidelines
- ***Policy makers:*** Learn from the research findings

International Collaborations

Another top priority of Annex 66 is to foster international collaboration to establish a universal, research framework. One focus of Annex 66 is to tackle the current challenges in OB research, with the

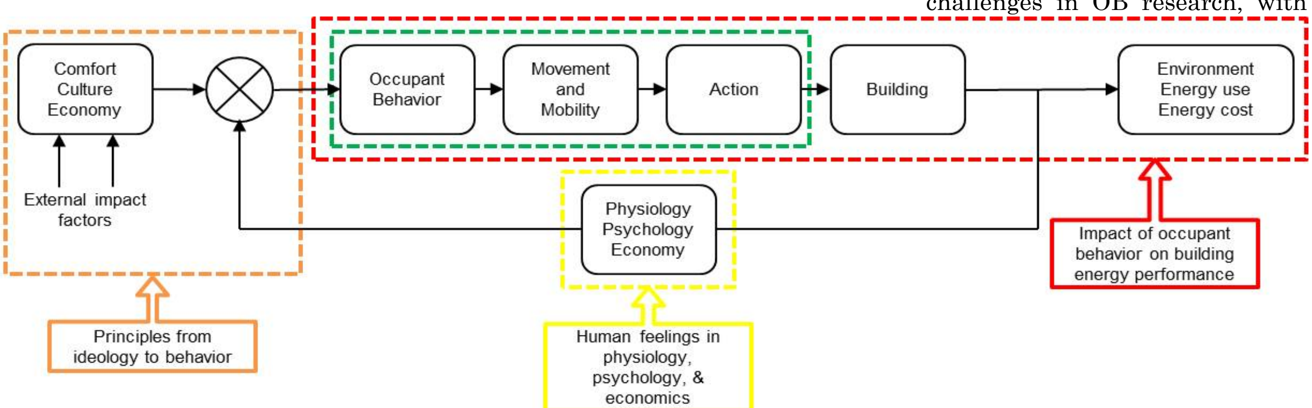


Figure 2: The interdependence between occupant behaviour and building energy performance.

spirit that the framework will be universally adopted, the models will be integrated into a coherent whole and efforts will be channelled where most needed. International cooperation becomes extremely important for both knowledge discovery and data sharing, to move the research field forward. The efforts of the international coalition assembled for Annex 66 will help bridge the gap between energy related behaviors and building energy efficiency (Figure 3).

Subtasks

To facilitate comparative studies and provide researchers with a deeper understanding of occupant behavior on energy use and the indoor environment, five subtasks were created. Three parallel subtasks focus on occupancy (presence and movement), residential building occupants, and commercial building occupants modelling. The three subtasks have also joined forces to establish (1) standard protocols for occupant monitoring (e.g., sensing and experimental design) modelling approaches and (2) a database of high quality monitored occupant behavior data. The combined efforts of subtasks A to E, will cultivate solutions to real world problems in building design, operations, and controls. The subtasks, leaders and co-leaders are described as follows:

Subtask A: *Occupant movement and presence models in buildings*

<u>Leader:</u> Andreas Wagner, Germany
<u>Co-leader:</u> Bing Dong, USA

This subtask aims at providing a description and simulation methodology for different personnel presence and movement. One further objective is to provide information on data collection with regard to movement and presence in buildings. Four main areas will be considered including: 1) presence, 2) number of people in a room, 3) number of people for a whole floor/building, 4) movement between rooms. In line with these items, different detection and tracking methods will be developed to obtain data for modeling.

Scope of Subtask A:

[1] Literature review on the state of the art, also taking into account work in other domains dealing with simulation of occupant's presence and movement

[2] Description of sensor technology and data collection methods providing useful data for modeling occupant's presence and movement

[3] Collection of monitoring data for a general Annex 66 data base

[4] Description of modeling techniques, models and model validation for occupant's presence and movement

[5] Collection and provision of models for a general Annex 66 repository

As a cross-sectional activity, the participants in Subtask A will construct a guideline on data collection within the whole context of occupant behavior.

Activities/Deliverables of Subtask A:

- Build up a matrix in order to structure important questions about occupant's presence and movement and to clarify the hierarchy of topics;
- Conduct a literature review on modeling techniques with particular focus on models from other domains;
- Investigate the possibility of creating a head-to-head comparison framework for occupant behavior models;
- Specify and provide test data sets for modeling competition within the whole annex;
- Structure the guideline on data collection for occupancy presence and movement.

Subtask B: *Occupant action models in residential buildings*

<u>Leader:</u> Darren Robinson, UK
<u>Co-leader:</u> Henrik Madsen, Denmark

This subtask will address the apparent lack of consistency in experimental design and modelling methodologies. Additionally the lack of availability of high quality data and access to algorithms or source code, will be addressed. This subtask will coordinate efforts to lessen the severity of the above inconsistencies, with the spirit that models are supposed to be integrated into a coherent whole. Avoiding replication and channeling efforts where most needed, will be essential.

Scope of Subtask B:

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

Activities and Deliverables:

- Data collection methodology for residential occupant behaviors including consistent experimental design;
- Implementation of a central repository for occupant behaviour data
- Modelling methodology for occupant behaviour in residential buildings
- Methodology for residential occupant behaviour methodology
- Implementation of occupant behaviour models in *EnergyPlus*

Subtask C: Occupant action models in commercial buildings

Leader: Ardeshir Mahdavi, Austria
Co-leader: Liam O'Brien, Canada

Some specific challenges of occupant behavior modeling exist in commercial buildings, where occupant behavior is of high spatial and functionality diversity. A commercial building is regulated by complex environmental control systems, and the control degrees of freedom between occupants and building or system managers are at diverse levels. Occupants in commercial buildings often interact out of social issues of mutual influence and negotiation.

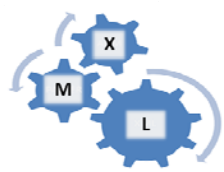
Scope of Subtask C:

[1] Empirical observations of occupant behavior to collect data by monitoring equipment;
[2] Development of mathematical/statistical modelling methods;
[3] Evaluation of the occupant behavior models by comparison with empirical observations.
[4] Applications in real cases as guidelines for field survey and simulation.

Activities and Deliverables:

• Explore the potential of energy metering and indoor environmental monitoring toward comparative evaluation of various occupancy models
• Provide a structured description of simulation applications in practice (should be approached in conjunction with Subtasks D and E). Toward this end, consider at the outset two broad application scenarios:
(a) Use of models in simulation-supported building and systems design and retrofit
(b) Use of models (in conjunction with or independent of simulation) to support building systems control (e.g., model-predictive control)

• Review literature to identify appropriate (statistical) indicators for the performance of occupancy models
(a) Consider the definition model deployment boundaries
(b) Consider the definition of minimum model performance levels
• Document best practices in occupancy model testing and evaluation.
• Define model robustness criteria



Subtask D: Integration of occupant behavior models with BEM programs

Leader: Tianzhen Hong, USA
Co-Leader: TBD

This subtask aims to better understand and fill in the gaps of modeling occupant behavior in building simulations using software programs like EnergyPlus and DeST. The subtask will develop a behavior framework obXML and software module obModels to integrate the behavior models developed from Subtasks A, B and C, enable applications in Subtask E and promote third-party software development and integration. The behavior software module can be used in three different ways: 1) run stand-alone to produce user profiles (schedules or settings), which are used as inputs for occupancy or actions without feedback; 2) direct code integration via function calls to dynamic link libraries (DLLs); 3) co-simulation via functional mock-up interface (FMI) to allow simultaneous simulations between the behavior module and the BEM programs.

Scope of Subtask D:

[1] Develop a framework and an XML schema to describe energy-related occupant behavior in buildings, which provides a standard language for occupant behavior;
[2] Develop a software architecture and module to integrate the occupant behavior models developed in Subtasks A, B and C;
[3] Produce a Software Developer Guide for third party software developers;
[4] Integrate the behavior Schema and software Module with BEM programs;
[5] Demonstrate the use of the Schema and software Module through examples.

Activities and Deliverables:

Table 1 provides a summary of the planned activities and deliverables for Subtask D.

A survey was administered with the main objective to that results would be to help guide the research and outcomes of Subtask D. Main findings from 27 respondents are: (1) energy,

Table 1: Planned main activities of Subtask D.

No.	Activities	Output	Potential Contributors
1	Review and select OB models	A report	Subtask D participants: LBNL, Tsinghua, University of Nottingham, Plymouth, TUE, CMU, USC, USDOE, etc.
2	OB framework development	XML schema and description	
3	OB software module design	Design document	
4	OB software module development	Source code	
5	OB software module testing	Test plan and results	DesignBuilder, Bentley Systems
6	OB software module guide for developers and users	Guide for developers and users	Subtask D participants
7	Enhancement to BEM tools	New version of BEM tools	LBNL – EnergyPlus; Tsinghua - DeST
8	Assist Subtask E on applications	Case studies	All D & E participants
9	Final report	Contribution to the Annex final report	

thermal comfort, IAQ and visual comfort are main goals of behavior modeling, (2) 15% said very difficult in using current BEM tools to model occupant behavior, 54% said it can be done but difficult, 31% said they need to write custom code, (3) there are four ways of modeling behavior, 28% of participants precalculate user profiles using other tools then feed the profiles into BEM tools, 23% use embedded behavior models in the BEM tools, 26% use custom code inside BEM tools, and 15% use co-simulation between BEM tools and behavior software tools, (4) most (96%) agreed interoperability of behavior models across BEM programs is poor, needs conversion or impossible, (5) all agreed that behavior models are not currently documented well or clearly, (6) 26% of participants used agent-based modeling for occupant behavior, and (7) more than a dozen most challenging issues were identified.

Subtask E: *Applications in building design and operations*

Leader: Khee Poh Lam, USA
Co-leader: Cary Chan, Hong Kong
Subtask E aims to deploy and demonstrate the use of methods and tools developed in Annex 66, to improve building design, operations, and energy performance by case studies (either simulation and/or combined with empirical field studies). The expected output of this subtask is to establish a set of behavior guidelines exemplified with case studies to illustrate the impact of occupant behavior on building design and operations. Figure 4 shows the framework and integration of parts occurring in Subtask E.

Scope

[1] Understand the needs in the industry and current research in academia
[2] Standardize the model input/output requirements and occupant model performance evaluation
[3] Use case studies to apply the models and software tools in real buildings and to validate software applications
[4] Provide feedback on software user-friendliness and effectiveness
[5] Develop guidelines for simulating occupant behavior in buildings
[6] Promote the outcomes in industry

Activities and Deliverables:

A literature review on the input/output of various types of occupant behavior was conducted. An industry survey based on the literature review and industry experience will be completed by the end of 2014.

As a cross-sectional activity, Subtask E will work with Subtask A, B, and C to standardize various occupant behavior model input/output requirements.

General Deliverables include:
• Case studies: Case studies to apply the models and software tools in real buildings.

• Guidelines: Occupant behavior guidelines for design, construction and operations.

Meetings and Seminars

The first Open Forum and Experts Meeting was held on March 12 to 14, 2014 in Taikoo Place in Hong Kong. The purpose of this meeting was to solidify the objectives of the Annex and to develop a detailed work plan. In total, 39 researchers and industry professionals from 13 countries

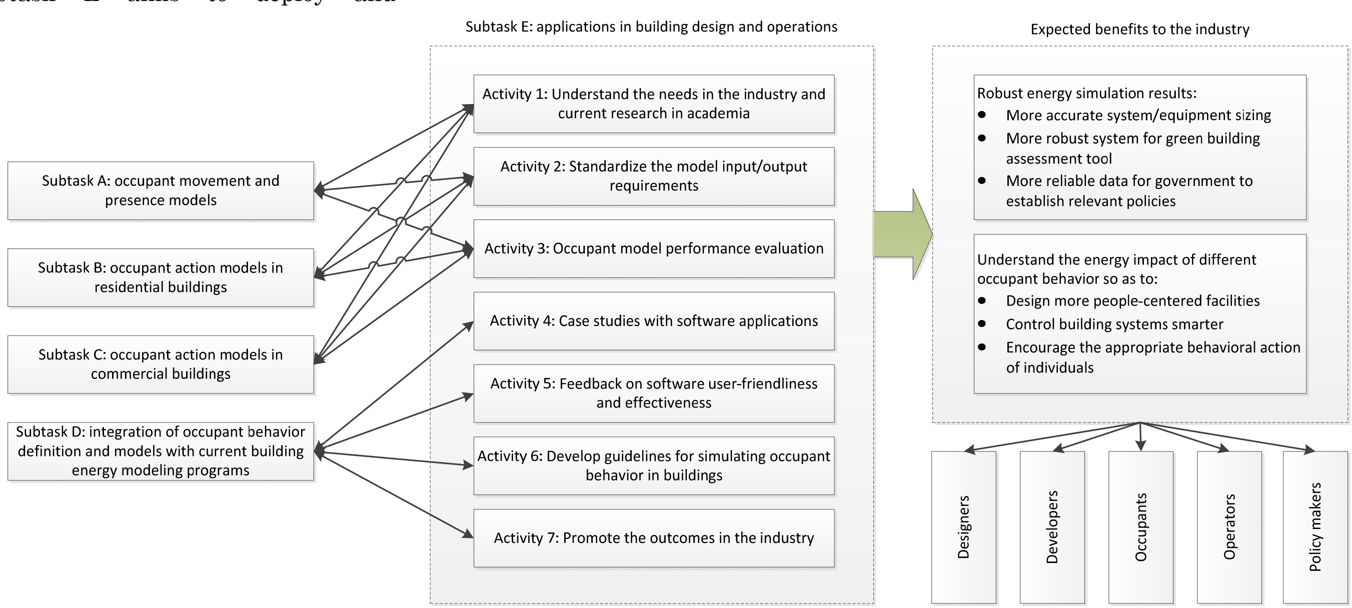


Figure 4: Framework of IEA Annex 66 Subtask E and the integration of Subtasks A, B, C, D.

attended the three-day meeting.

The second Open Forum and Experts Meeting was held on August 4 to 6, 2014 in Nottingham, United Kingdom (Figure 5).

The third Open Forum and Experts Meeting will take place at Lawrence Berkeley National Laboratory, California, USA on March 30 to April 1, 2015.

Based on the discussions at the two preparation meetings in Hong Kong and Nottingham, a questionnaire was designed to survey the status, experience, and challenges of modeling occupant behavior using current building energy modeling programs. More than a dozen of the most challenging issues in modeling occupant behavior were identified, such as:

- ✓ The translation between quantitative (simulation) and qualitative information (behavior) is difficult
- ✓ Complex decision making dynamics between many occupants in large open plan places are hard to model
- ✓ It is difficult to gather enough occupant data, covering various building types, organization cultures, diverse population, and changing work styles due to technology
- ✓ There are too few tools available to develop models
- ✓ Implementation with existing simulation software is very difficult considering divesity ofclimates, populations, buildings, designs
- ✓ There is uncertainty about appropraite level of resolution of behavioral modelling depending on the aim of the investigation
- ✓ There are few comparitive studies, causing difficulty in model selection
- ✓ There's a lack of sound/established methodologies for modeling behavior
- ✓ Occupant behavior model validation procedures are not established
- ✓ Convincing industry that occupant behavior has a significant enough design impact to deserve effort and investigation.

Newsletter Questionnaire

(Q)In one sentence, what is the single biggest challenge of the occupant behavior research field?

"Getting to the realization that from a building point of view, we are not really interested in 'behavior' – we need to refocus on occupant presence and actions only, and stop pretending we can/want to model the factors that cause these." Pieter De Wilde

"Only two words are necessary: 'the occupant'. To be more precise the occupants' inter- and intra-individual differences and variations in behavioral actions together with a low frequency of interactions to be observed, which necessitates big campaigns in order to gain data suitable for analyses." Marcel Schweiker

"To me, synthesizing the findings of the occupant behaviour research with building performance simulation practice is a great challenge." Burak Gunay

"The challenge is the lack of standard method to collect high quality data and of the availability of model algorithms." Yiwen Jian

"Respecting privacy while developing new sensing technologies for the many types of occupant behaviors." Mikkel Kjaergaard

"Effective communication and knowledge sharing between the different disciplines involved (e.g. between social scientists and engineers)." Clair Das Bhaumik

Where do you envision the field of occupant behavior research in 10 years?

"The routine application of multi-agent simulation of occupants' behaviors in a building energy simulation framework, assisted through clear definitions of models' scope of applicability." Darren Robinson

"Maturity of the field of occupant behaviour modelling to the level of other BPS inputs such as climate data and material properties." Liam O'Brien

"Stronger consideration of qualitative aspects and context and the interplay of parameters; Occupant's awareness on their potential to help improve building performance." Astrid Roetzel

"In 10 years, every terminal unit (light, heat, air, plug) will be addressable and end user controllable with central knowledge and expertise (and occasionally override)." CMU team

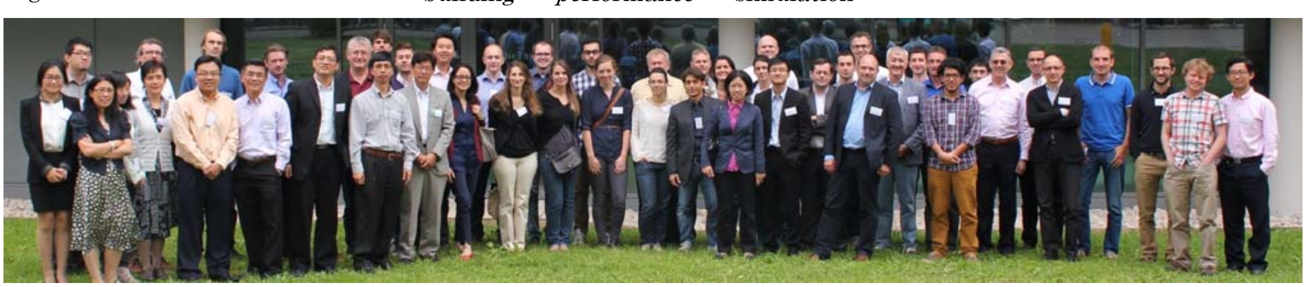


Figure 5: Group picture from the second Open Forum and Experts Meeting was held on August 4-6, 2014 in Nottingham, United Kingdom.

"Based on the developed standardized methods for data collection, modeling, validation, and tools, evaluate OB impact on energy and IEQ in buildings to improve building design and operations. Link sensing, network, and controls to provide informed decision for stakeholders including occupants, operators, managers, owners, and policy makers." Tianzhen Hong

"Modeling, measurement and validation to make occupancy behavior study robust" Bing Dong

What is the most bizarre/interesting/illogical occupant behavior you have studied or observed?

"So I met a guy a while ago who lived in a house with single glazing - not uncommon for older UK homes. There was of course quite a lot of condensation. Normal strategies might include raising the surface temperature (better glazing, trace heating), better ventilation, reducing moisture production... This guy's solution was to train his cat to lick up the condensate. It was a double-whammy: he didn't need to water his cat in winter!" Darren Robinson

"When we asked occupants of a commercial building what they did to conserve energy that day one answered that they did not eat meat. It is not exactly illogical, but we certainly didn't expect such a response when asked about their work-related energy consumption!" John Taylor

"I close the window and door, turn on room air conditioner, and take on a heavy jacket in this September in Beijing, just to block the outside mosquitoes into my office rooms and to freeze the mosquitoes inside my room to death." Yiwen Jian

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Factsheet

Official Participating Countries

United States, China, Austria, Canada, Denmark, Italy, Netherlands, Norway, Poland, United Kingdom, Spain

Preparation Phase

Started in November 2013

First Meeting:

Hong Kong, March 12-14, 2014

Second Meeting:

UK, August 4-6, 2014

Working Phase

Planned to start in November 2014 and continue for 3 years.

First meeting in Berkeley, USA.

March 30 – April 1, 2015

More information

www.annex66.org

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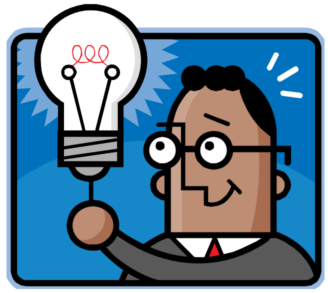

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