Energy in Buildings and
Communities Programme

Annex 66: Definition and Simulation of Occupant Behavior in Buildings

Technical Report:

Surveys to understand current needs, practice and capabilities of occupant modeling in building simulation

November 2017

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Preface

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 29 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes. The mission of the Energy in Buildings and Communities (EBC) 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 IEA-EBC Programme was known as the Energy in Buildings and Community Systems Programme, ECBCS.)

The research and development strategies of the IEA-EBC Programme are derived from research drivers, national programmes within IEA countries, and the IEA Future Buildings Forum Think Tank Workshops. The research and development (R&D) strategies of IEA-EBC aim to exploit technological opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy efficient technologies. The R&D strategies apply to residential, commercial, office buildings and community systems, and will impact the building industry in five focus areas for 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 IEA-EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA-EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA-EBC Executive Committee, with completed projects 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: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System 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: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
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Annex 21: Thermal Modelling (*)
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Annex 33: Advanced Local Energy Planning (*)
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Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for 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: Integration 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 & CO2 Equivalent Emissions for Building Construction (*)
Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements (*)
Annex 59: High Temperature Cooling & Low Temperature Heating in Buildings (*)
Annex 60: New Generation Computational Tools for Building & Community Energy Systems (*)
Annex 61: Business and Technical Concepts for Deep Energy Retrofit of Public Buildings (*)
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Annex 70: Energy Epidemiology: Analysis of Real Building Energy Use at Scale
Annex 71: Building Energy Performance Assessment Based on In-situ Measurements

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 (*)
Working Group - Survey on HVAC Energy Calculation Methodologies for Non-residential Buildings

Introduction to Annex 66

Energy-related occupant behavior in buildings is a key issue for building design optimization, energy diagnosis, performance evaluation, and building energy simulation. Actions such as adjusting the thermostat for comfort, switching lights, opening/closing windows, pulling up/down window blinds, and moving between spaces, can have a significant impact on the real energy use and indoor environmental quality in buildings. Having a deeper understanding of occupant behavior, and quantifying their impact on the use of building technologies and building performance with modeling and simulation tools is crucial to the design and operation of low energy buildings where human-building interactions are the key. 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 and requires a multi-disciplinary approach if it is ever to be fully understood (Figure 1). On one hand, occupant behavior is influenced by external factors such as culture, economy and climate, as well as internal factors such as individual comfort preference, physiology, and psychology; On the other hand, occupant behavior drives occupants' interactions with building systems which strongly influence the building operations and thus energy use/cost and indoor comfort, which in-turn influences occupant behavior thus forming a closed loop.

There are over 20 groups all over the world studying occupant behavior individually. However, existing studies on occupant behavior, mainly from the perspective of sociology, lack in-depth quantitative analysis. Furthermore, 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. Therefore, there is a strong need for researchers to work together on a consistent and standard framework of occupant behavior definition and simulation methodology.

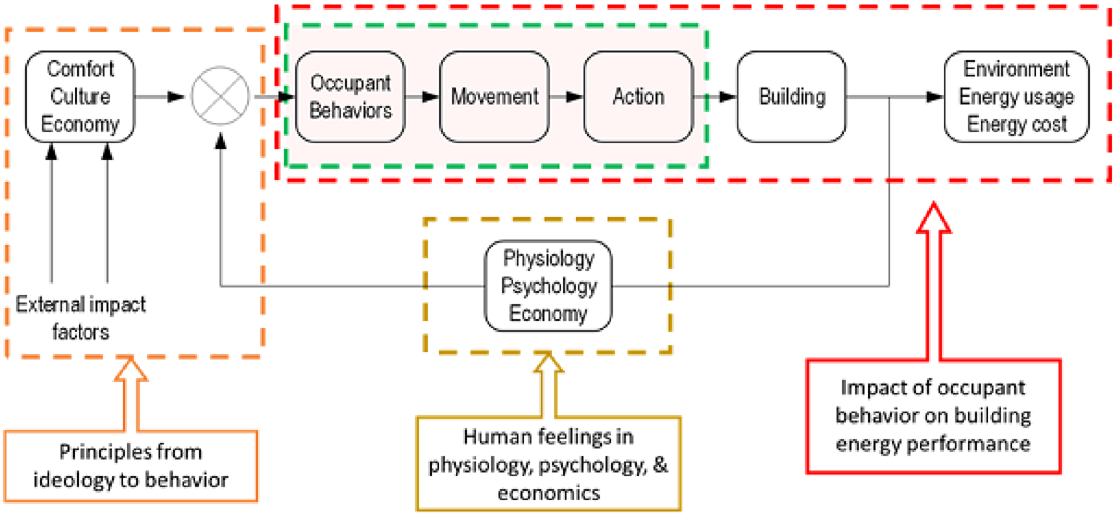

Figure 1: Relationship between occupants and buildings

The Annex 66 project was approved unanimously at the 74th Executive Committee Meeting of the International Energy Agency's Energy in Buildings and Communities Programme, held on 14th November 2013 in Dublin, Ireland. Operating Agents are Dr. Da Yan of Tsinghua University and Dr. Tianzhen Hong of Lawrence Berkeley National Laboratory. The Annex aims to (1) set up a standard occupant behavior definition platform, (2) establish a quantitative simulation methodology to model occupant behavior in buildings, and (3) understand the influence of occupant behavior on building energy use and the indoor environment. The project has five subtasks:

Subtask A - Occupant movement and presence models. Simulating occupant movement and presence is fundamental to occupant behavior research. The main objective of the subtask is to provide a standard definition and simulation methodology to represent how an occupant presents in his/her office and moves between spaces.

Subtask B - Occupant action models in residential buildings. Occupant action behavior in residential buildings affects building performance significantly. This subtask aims to provide a standard description for occupant action behavior simulation, systematic measurement approach, and modeling and validation methodology for residential buildings.

Subtask C - Occupant action models in commercial buildings. Some specific challenges of occupant behavior modeling exist in commercial buildings, where occupant behavior is of high spatial and functionality diversity. This subtask aims to provide a standard description for occupant action behavior simulation, systematic measurement approach, and modeling and validation methodology for commercial buildings.

Subtask D – Development of new occupant behavior definition and modeling tools, and integrating them with building performance simulation programs. This subtask will enable applications by researchers, practitioners, and policy makers and promote third-party software development and integration. A framework for XML schema and a software module with occupant behavior models will be the main outcome of this subtask.

Subtask E - Applications in building design and operations. This subtask will provide case studies to demonstrate applications of the new occupant behavior modeling tools. The occupant behavior modeling tools can be used by building designers, energy saving evaluators, building operators, and energy policy makers. Case studies will verify the applicability of the developed modeling tools by comparing the measured and simulated results.

17 countries and 123 participants from universities, research institutes, software companies, design consultants, operation managers, and system control companies participated in this Annex. All parties expressed an interest in developing a robust understanding of energy-related occupant behavior in buildings, via international collaboration on developing research methodologies and simulation tools that can bridge the gap between occupant behavior and the built environment. The Preparation Phase started in November 2013 and continued through November 2014. The Working Phase started in December 2014 and lasted for two and a half years. The Reporting Phase took place from July 2017 to May 2018.

Summary

This report summarizes two surveys that were performed: (1) a survey to understand current practice and attitudes of current building simulation users regarding occupant modeling and (2) a survey of currently available occupant modeling functionality in building performance simulation (BPS) tools.

In order to guide research and development efforts, researchers, policy makers, and software developers with regards to occupant modeling, the first survey was developed to form a better understanding of current practice and acceptance of occupant modeling. This report provides a summary of the results, analysis, and discussion of the results of a 36-question international survey on current occupant modeling practice and attitudes in building performance simulation. In total, 274 valid responses were collected from BPS users (practitioners, educators, and researchers) from 37 countries. The results indicate that most assumptions that simulation users make about occupants vary widely and are considerably simpler than what has been observed in reality. Most participants cited lack of time or understanding as their primary reason for not delving deeply into occupant modeling, but responded that they are receptive to further training.

The second survey assessed the occupant modeling functionality of nine BPS programs, four of which were among the top 10 most commonly used tools identified by the first survey. Data was gathered from users and/or developers of these tools with substantial experience, or directly from the parent company in the case of some of the commercial tools. Functionality was assessed in terms of six distinct areas: occupant movement/presence, lighting operation, window operation, HVAC operation, other internal heat gains resulting from occupant actions (e.g., small power, DHW), and others (e.g., blinds). Stochastic and deterministic functionality was strongly differentiated in the questions. Results broadly suggested that while deterministic functionality was fairly consistent among BPS tools, built-in stochastic models are less common and much less consistent. Capability to implement user-defined models (including stochastic models) is widespread, though the input methods vary widely which compromises model interoperability.

1. Survey 1: International survey on current occupant modeling approaches in building performance simulation

1.1 Introduction

While research on occupant modeling in buildings has experienced a surge of research interest and activity in the past decade, it is unclear whether building simulation practice has kept pace. While we expect most building performance simulation (BPS) users to be interested in constructing accurate models – including with respect to occupants – a predominant building model purpose is for code and standard compliance, for which standard schedules tend to be used. BPS users tend to work in a fast-paced environment and are sometimes pressured to obtain greater predicted energy savings from BPS tools. One of the known ways to achieve predicted energy savings is to adjust occupant modeling assumptions.

In order to gain a better understanding of BPS users common practice, attitudes, and knowledge about occupant modeling, we conducted a survey of BPS users. The objectives of the study were to understand BPS users':

- current assumptions relative to occupant observations in the domains of occupancy, equipment use, operable window and window shading device use, lighting use, and thermostats
- willingness to use more rigorous occupant modeling approaches
- appetite for uncertainty quantification and representation
- willingness to learn more about occupant modeling through training and other education

Ultimately, the information from this survey is critical for software developers, occupant behavior researchers, educators, and building code developers. This report provides a summary of the survey and survey results. The results can be read in greater detail in the Journal of Building Performance Simulation[1].

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[1] O'Brien, W., Gaetani, I., Gilani, S., Carlucci, S., Hoes, P., Hensen. J. International survey on current occupant modeling approaches in building performance simulation. Journal of Building Performance Simulation. 10(5-6): 653-571. http://dx.doi.org/10.1080/19401493.2016.1243731.

1.2 Methodology

To cover major research and all major disciplines and geographical regions, a survey was iteratively developed with approximately 20 IEA EBC Annex 66 members. Key sections of the survey include: background information (e.g., experience level and tool use), modeling assumptions made about the aforementioned occupant domains, attitudes and future practice, and barriers to using advanced occupant models (e.g., resulting uncertainty of stochastic models). The survey was carefully constructed to be versatile to cover all expected respondents (e.g., different professions from numerous countries), while also obtaining specific results that could be compared to the literature. For instance, we were specifically interested to understand how various occupant behaviors are modeled compared to extensive monitoring studies in the literature. Most of the survey's 36 questions were multiple-choice, while others were the short answer (e.g., to further justify their selected multiple-choice answers).

After the survey was piloted, approved by Carleton University's research ethics board, and presented to Annex 66 experts, it was implemented on Google Forms (a free survey platform). Over a five-week period, starting in September 2015, the survey was completed by 274 BPS users from 37 countries. Survey recruitment took place through BPS-related email lists, LinkedIn, and the International Building Performance Simulation Association (IBPSA) newsletter. It is thought that there are at least 5000 BPS users worldwide, on the basis that this is the approximate number of IBPSA members. To encourage participation of the survey, approximately a dozen prizes valued at up to $100 were offered to randomly drawn participants. The target population - non-researchers – were the predominant participant group with 206 individual responses. However, responses from researchers were preserved to enable the results of various user group categories are comparable. The full survey is presented in the appendix of this report and in the journal article.

The sample size of 274 compares favorably to other surveys that have been performed about BPS users or tools. There is some notable bias to the survey results, though the results are expected to still be valuable. Namely, the English-only survey was primarily answered by English-speaking participants. Several of the recruitment email lists were tool specific (e.g., for eQUEST and EnergyPlus); thus users of those tools are overrepresented. Finally, we expect that the participants are more diligent than the average BPS users, since they took the time to respond to this fairly lengthy survey.

1.3 Results

This report summarizes key findings from the survey. About 44% of participants responded that occupant behavior is the single biggest source of discrepancy between modeled and measured building performance. When separated by experts and non-experts (less than five years of BPS experience), this result still held relatively consistent. However, only a slight majority (56%) of participants responded that they agree or somewhat agree that occupants use more energy than predicted in BPS.

When asked about their knowledge of occupant behavior modeling, 47% of participants stated “moderate”, while very few claimed to have no or an authoritative level, as shown in Figure 2.

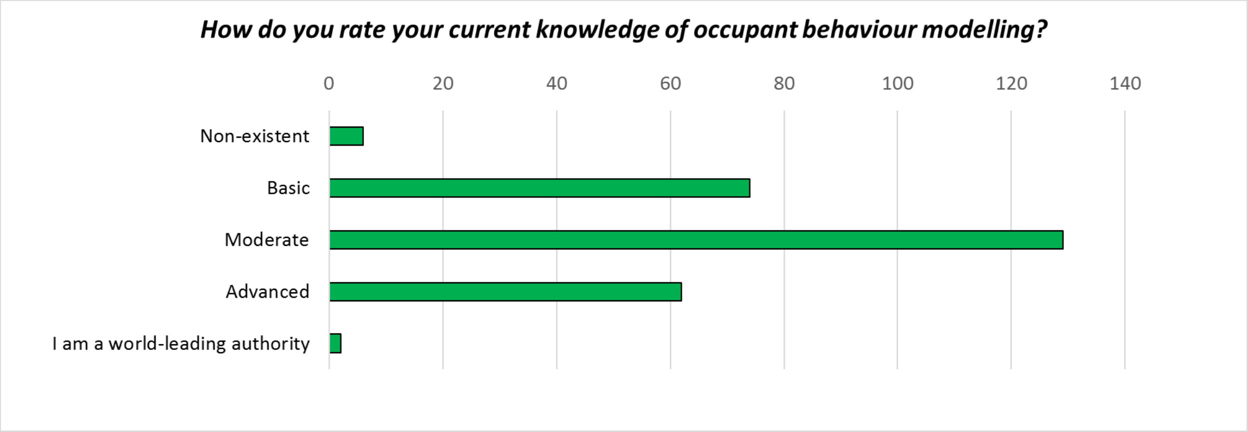


Figure 2: Participants rated knowledge of occupant behavior modeling.

Many participants (58%) feel that properly modeling occupants is necessary and that it is not an adequate justification to model them inaccurately merely because the assumptions are consistent throughout all simulated design variants (Figure 3). This is in contrast to most code compliance modeling approaches, which use relatively simple but consistent occupant modeling assumptions across the reference and proposed building designs.

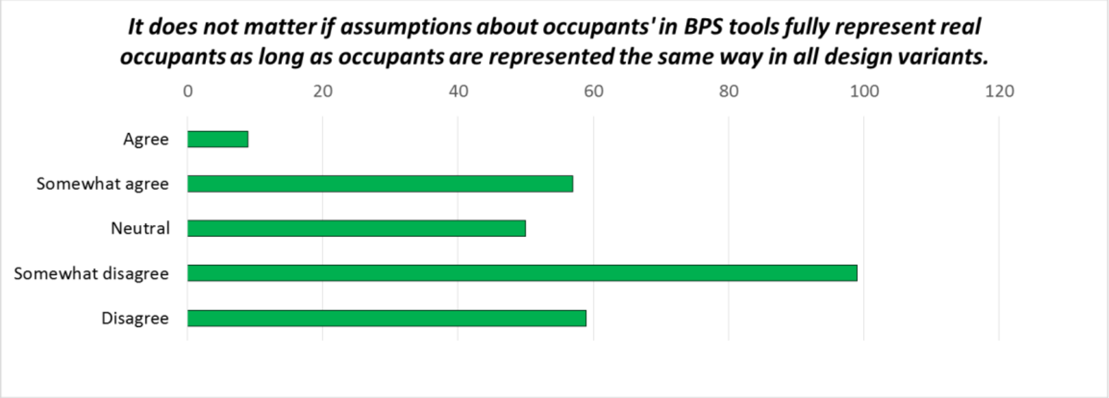


Figure 3: Participants’ attitudes about occupant modeling approaches

Participants tend to be moderately confident in the assumptions they make about occupants. Of the six occupant-related domains we asked about, participants were least confident about modeling blinds and most confident about modeling thermostat use. The mean response about confidence levels is near-neutral (neither confident nor unconfident) (Figure 4). Many of the participants named domestic water consumption, occupant clothing level, and metabolic rate assumptions as important domains that the survey should have included and that should be better addressed in BPS. In general, these tend to be domains that are not well modeled by BPS tools.

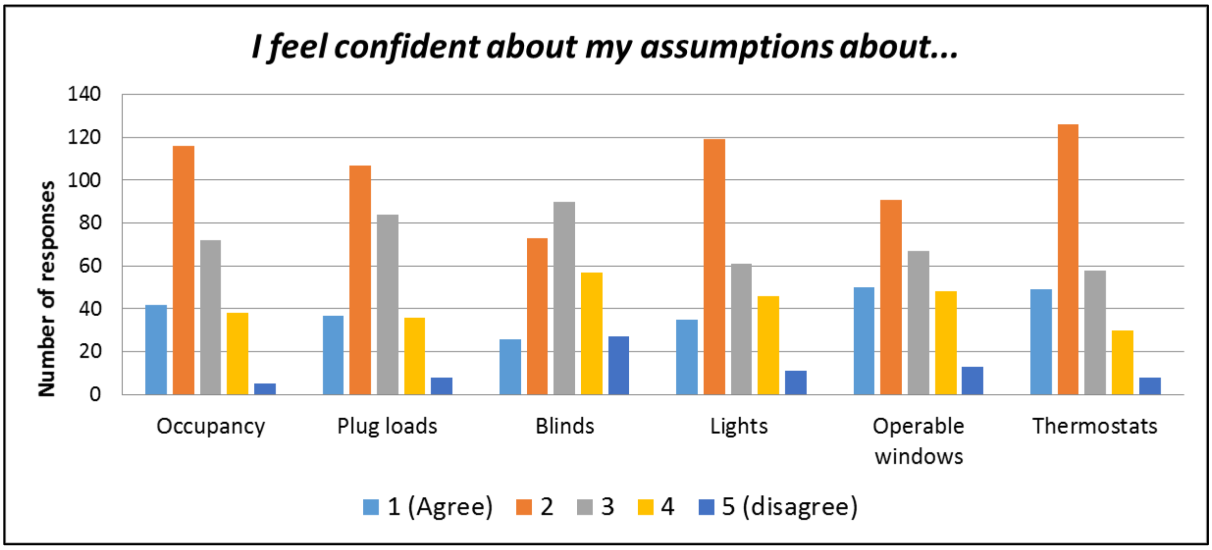


Figure 4: Confidence of surveyed simulation users for six occupant modeling domains

Survey participants were asked how they model a number of common occupant-controlled buildings systems (lights, window blinds, plug-in equipment, windows, and thermostats). For example, in the domain of window blinds, the literature has found that many factors play into occupants’ use of window blinds, but that their action tends to be very infrequent (often on the order of weekly or monthly) and blinds were often left mostly closed and were triggered by some glare event. However, the participants’ reported assumptions (Figure 5) indicate that they assume occupants systematically open and close blinds to control solar gains or based on indoor temperature, or that the blinds are always open/non-existent. These results indicate that modelers may overestimate the extent to which blinds are open and actively used. This has impacts on daylighting performance and heating and cooling loads. Similar discrepancies between participant-reported modeling assumptions and the literature were found for the other domains. A similar comparison was made for the other domains shown in Figure 4, with very similar results. In general, modelers tend to make simple and often-optimistic assumptions about occupants. For instance, more than half of participants responded that they use default schedules from BPS tools or assume the building is always occupied during operating hours.

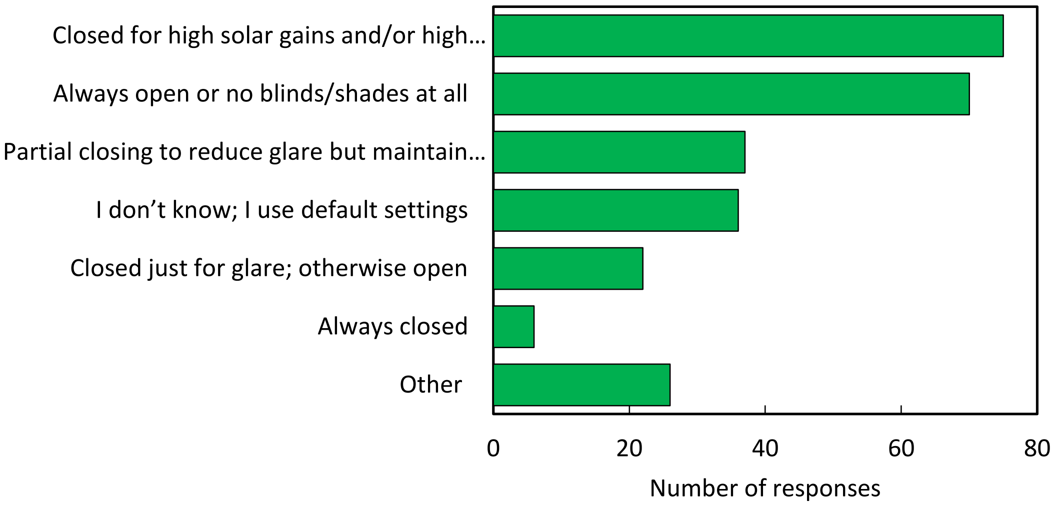


Figure 5: Participants' assumptions about window shades position

Quite interestingly, about 37% of participants believe their clients would lose confidence in them or BPS if they properly expressed uncertainty. Perhaps this result indicates that the community needs to better inform clients of the uncertainty of BPS results to manage clients’ expectations. About 77% of survey participants believe BPS users should better communicate the uncertainty of results.

Three-quarters of survey participants agreed that BPS tools should have more occupant modeling features, even if this meant increasing the number of related inputs. 35% of participants agree or somewhat agree that BPS tools need to do a better job of communicating occupant-related assumptions.

When asked about occupant-related modeling features that should be added, some of the common and interesting suggestions include:

- Visualization to show the relative sensitivity of occupant-related phenomena
- Uncertainty to key performance indicators that is caused by occupants
- High-resolution occupant modeling to inform and improve furniture and luminaire positioning
- Better prediction of energy-savings from occupancy-based controls and daylight sensors based on real behavior
- More accurate or easy-to-use methods to model indoor environmental quality
- Improved characterization of occupants across different building types
- Detailed documentation on occupant modeling and how to use the results to improve design

Finally, most participants rate their knowledge of occupant modeling as “moderate”, followed by “basic”, and “advanced” (Figure 2). However, the vast majority of participants (81%) stated that they would be willing to invest considerable time in learning more about occupant modeling if the appropriate resources were available. This indicates a significant market for occupant modeling educational material and tool functionality.

1.4 Conclusions

This report provided a summary of the results of 274 valid responses of a 36-question survey that was used to understand occupant modeling practice in building simulation. The results indicate that, while current occupant modeling practice in BPS is quite simplistic, there is a strong awareness of its importance from BPS users. Just over half (56%) of survey participants agreed or somewhat agreed to this statement: in reality, occupants use more energy than we typically assume in building simulation. 58% of survey participants feel that it is not acceptable to represent occupants consistently, if the modeling approach is not realistic. About three-quarters of participants agreed or somewhat agreed that modeling standards should impose greater occupant modeling requirements.

The participants responded that the primary purpose for improving occupant modeling is to reduce the discrepancy between modeled and measured building performance. Moreover, 44% of participants stated that occupant behavior is the biggest cause of such discrepancies.

When the literature about occupant monitoring studies was compared to the assumptions that modeling makes, according to the survey, it was found that current modeling assumptions are simplistic and often optimistic. Some participants stated that modeling assumptions about clothing level, metabolic rate, and domestic hot water consumption are all important – although the survey did not mention them. Numerous other new BPS tool features were suggested by participants, such as inclusion of visualization to better communicate uncertainty in energy performance caused by occupants.

While 76% of participants stated that BPS tools should address uncertainty more effectively, 37% of participants thought that their clients would lose confidence in BPS if uncertainty were reported.

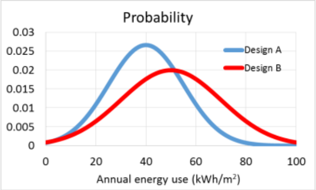
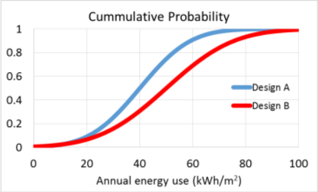
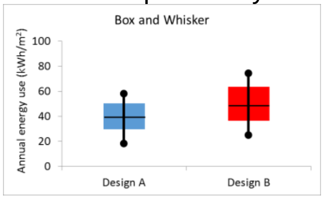
This survey indicated that there is significant and necessary future work on occupant modeling research and education, model and software development, and policy making. Finally, code and standards developers should begin to increase the rigor of occupant modeling requirements to better reflect observed occupant behavior. Case studies demonstrating the importance and capabilities of occupant modeling have the potential to greatly improve awareness of BPS users and building designers.

1.5 Appendix: The survey

Questions	**Possible answers**
Background	
1. How would you best describe your profession?	Engineer; Architect; Policy maker; Researcher and/or educator; other:________
2. For how many years have you been using building performance simulation (BPS) (also known as building energy modeling)?	Fewer than 2 years; 2 to 5 years; 5 to 10 years; Over 10 years; I do not use BPS *(jump to end of survey)*
3. In which country is the majority of your work?	(dropdown list)
4. For which of the following purposes do you use BPS? (check all that apply)	Building code compliance; Environmental assessment schemes (e.g., LEED, BREEAM, DNGB, etc.); Early design; Detailed design and equipment sizing; Post-occupancy evaluation of performance, controls optimization, or retrofit analysis; Life cycle cost assessment (LCAA); Other(s): ____
5. Which whole-building simulation tool(s) do you use? (select all that apply)	AECOsim Energy Simulator; DesignBuilder; DeST; DOE-2.1x; Ecotect (Autodesk); EnergyPlus; eQuest; ESP-r; Green Building Studio (Autodesk); HAP (Carrier); Hevacomp; HOT2000/3000; IDA ICE; IES VE; Modelica; OpenStudio; RETScreen; Safeira; SIMBIAN; Simergy; Tas; Trace (Trane); TRNSYS; Other(s):______
6. From my experience, the leading source of discrepancy between BPS predictions and measurements is inadequate model representation of ______	Weather data; Raw material properties; Building component/equipment quality; Construction quality; Occupant behavior; Controls and operations; HVAC system functionality; Numerical approximations in BPS tools; Input assumptions in BPS tools; None: there are minimal discrepancies between BPS predictions and measurements; Other(s)_____
Current modeling practice	
7. Which of the following best represents your overall assumptions about occupants in BPS?	I use default values and do not check assumptions; I use values derived from standards (e.g., ASHRAE 90.1); In each project, I modify the default settings based on my prior experience and judgment; I assume occupants will act to minimize energy use (e.g., optimally control lights, blinds, windows, equipment, etc.); Other (please elaborate): ________________
8. It does not matter if assumptions about occupants' in BPS tools fully represent real occupants as long as occupants are represented the same way in all design variants.	Agree; Somewhat agree; Neither agree nor disagree; Somewhat disagree; Disagree
9. The BPS tool(s) that I use are effective at communicating assumptions and default settings about occupants.	Agree; Somewhat agree; Neither agree nor disagree; Somewhat disagree; Disagree
10. What modeling assumption do you most frequently make about occupancy (occupant presence) schedules?	Always occupied during typical operating hours (e.g., 9:00-17:00/5PM for offices); I use default BPS tool schedules for the building/space type; I use some other resource. Please specify______; None of the above
11. What modeling assumption do you most frequently make about the number of occupants in a space?	Full rated capacity of each room; Partial capacity based on default settings for the space type; Partial capacity based on custom settings Other_________

12. Regarding the above answer about occupancy, I feel confident that this representation is appropriate for the aim of my simulation.	Agree; Somewhat agree; Neither agree nor disagree; Somewhat disagree; Disagree
13. What modeling assumption do you most frequently make about appliances and plug loads power use?	By summing the power rating of each piece of equipment; By using power density (e.g., W/m^2 or BTU/hr·ft^2); Other__________
14. What modeling assumption do you most frequently make about appliances and plug loads schedules?	All equipment is always on; Default schedules in the BPS tool for the space type; Standard profiles from modeling standards (like ASHRAE Std. 90.1); Based directly on occupancy schedules Other__________
15. Regarding the above answers about appliances and plug loads, I feel confident that this representation is appropriate for the aim of my simulation.	Agree; Somewhat agree; Neither agree nor disagree; Somewhat disagree; Disagree
16. What modeling assumptions do you most frequently make about manual movement and positioning of window blinds/shades?	Always open or no blinds/shades at all; Always closed; Closed just for glare - otherwise open; Closed for high solar gains and/or high indoor/outdoor temperatures; Partial closing to reduce glare but maintain some daylight and views; I don't know - I use default settings; Other _______________
17. Regarding the above answer about manually-controlled window blinds/shades, I feel confident that this representation is appropriate for the aim of my simulation.	Agree; Somewhat agree; Neither agree nor disagree; Somewhat disagree; Disagree
18. What modeling assumptions do you most frequently make about manual light switching/dimming?	Always on (24 hours per day); Always on during occupancy; On during occupancy only if daylight levels are inadequate; Dimming to supplement daylight levels; I don't know - I use default settings Other _________
19. Regarding the above answer about light switching/dimming, I feel confident that this representation is appropriate for the aim of my simulation.	Agree; Somewhat agree; Neither agree nor disagree; Somewhat disagree; Disagree
20. What modeling assumptions do you most frequently make about manual movement and positioning of operable windows?	The buildings I model typically don't have operable windows; Always open; Always closed; Windows open/closed based on a schedule; Windows open/closed based on inside and outside temperatures; I don't know - I use default settings; Other:________
21. Regarding the above answer about operable windows, I feel confident that this representation is appropriate for the aim of my simulation.	Agree; Somewhat agree; Neither agree nor disagree; Somewhat disagree; Disagree
22. What modeling assumptions do you most frequently make about thermostat settings?	Fixed annual setpoints; Daily and/or seasonal setpoint schedules (e.g., nighttime setback); Hourly or sub-hourly set point adjustments based on rules that I define, such as when it is too warm or cold inside; I don't know - I use default settings; Other:____
23. Regarding the above answer about thermostat settings, I feel confident that this representation is appropriate for the aim of my simulation.	Agree; Somewhat agree; Neither agree nor disagree; Somewhat disagree; Disagree

24. What other occupant-related model inputs do you typically specify in your models?	(Please list all.)
Attitudes and future practice	
25. Designing buildings that rely on occupants to adapt to discomfort (e.g., open windows if overheating occurs) could save energy but is risky due to potential liability (e.g., chronic occupant discomfort) or increased costs.	Agree; Somewhat agree; Neither agree nor disagree; Somewhat disagree; Disagree
26. In my experience, real occupants use more energy through their actions and habits than I assume in BPS tools.	Agree; Somewhat agree; Neither agree nor disagree; Somewhat disagree; Disagree
27. How do you rate your current knowledge of occupant behavior modeling?	Non-existent; Basic; Moderate; Advanced; World-leading authority
28. The most important reason to appropriately represent occupant behavior in BPS is...	To help fill the gap between predicted and actual building performance; To aid in risk assessment; To improve building controls/operations; To improve general building design quality; To improve occupants' comfort; Other(s)_________
29. Modeling standards should mandate more accurate occupant modeling approaches.	Agree; Somewhat agree; Neither agree nor disagree; Somewhat disagree; Disagree
30. Simulation tools should have more occupant modeling features to improve accuracy, even if it requires substantially more user inputs and effort.	Agree; Somewhat agree; Neither agree nor disagree; Somewhat disagree; Disagree
31. I would read a comprehensive document or attend an all-day workshop about occupant modeling if it were available.	Agree; Somewhat agree; Neither agree nor disagree; Somewhat disagree; Disagree
Barriers to using advanced occupant behavior models in BPS	
32. What is the biggest current barrier to using more detailed occupant behavior modeling approaches?	Time and effort; Understanding/education; Client interest; Codes and modeling standards; BPS tool limitations; Other(s)___ ______
Researchers are developing stochastic occupant models that are based on probabilities and data from monitored occupants. For example, instead of assuming occupants will turn on lights below a specific daylight level, the models assume there is a certain likelihood that occupants turn on lights associated with each daylight level. But as a result, each time a simulation is run, it may yield different results. As a result, it may be necessary to run 50 to 100 simulations in order to obtain a proper characterization of occupants.	
33. Running simulations 50 to 100 times to obtain probabilistic results would be an acceptable practice if it were done automatically by the software tool.	Agree; Somewhat agree; Neither agree nor disagree; Somewhat disagree; Disagree
34. If I told my clients that BPS predictions are uncertain, they would lose confidence in me and/or simulation.	Agree; Somewhat agree; Neither agree nor disagree; Somewhat disagree; Disagree

35. BPS users should do a better job of communicating to clients that building performance predictions are uncertain.	Agree; Somewhat agree; Neither agree nor disagree; Somewhat disagree; Disagree
36. Which of the following uncertainty visualization techniques would be most effective for communicating uncertainty to clients?	None of these – they are confusing to me; None of these – they would be confusing to my clients  Probability distribution  Cumulative probability distribution  Box and whisker

2. Survey 2: Assessment of the occupant modeling functionality of eight BPS programs

2.1 Introduction

Given the conclusion from Survey 1 that “while current occupant modeling practice in BPS is quite simplistic, there is a strong awareness of its importance from BPS users”, there is a need to quantify the simplicity and assess the gaps in functionality that may be addressed by Annex 66 deliverables. For this purpose, a survey of occupant behavior modeling capabilities in a selection of current BPS programs was performed; this report briefly presents and discusses the results. These results are also presented in a conference paper[2].

2.2 Methodology

Eight BPS programs were studied: DeST v2.0, DOE-2 v124, EnergyPlus v8.3, ESP-r v12.3, IDA ICE v4.6, IES-VE 2016, Pleiades + Comfie v3.5.8.1 and TRNSYS 17 v5.3.0. Where the conductors of this research were not intimately familiar with a program, information was sought from external sources, either users/developers with extensive knowledge of the program or the parent company. A questionnaire was filled out for each program, gathering information in six modeling categories; occupant movement and presence, use of lights, use of windows, use of HVAC, other casual gains (e.g., small power), and any other occupant behaviors (e.g., shading). The last two categories were combined for the purpose of reporting results. The questions are listed in the Appendix.

Questions were selected to try to ascertain a broad overview of available functionality, explicitly differentiating between stochastic and deterministic models. References for their theoretical basis and use were also sought to ensure a thorough understanding of complex functionality. Modeling categories were selected to broadly match the functionality provided by Annex 66 deliverables (obFMU), to facilitate a clear assessment of the contribution of the Annex outputs.

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[2] Cowie, A., Hong, T., Feng, X., Darakdjian, Q. Usefulness of the obFMU Module Examined through a Survey of Occupant Modelling Functionality in Building Performance Simulation Programs. *Building Simulation 2017, San Francisco CA, USA*.

However, an “any others” category was included to avoid restricting responses to just these areas, allowing a further assessment of areas in which Annex deliverables could potentially be developed to provide a meaningful contribution in future.

The results have been anonymized for the purpose of this report; full results are presented in the conference paper.

Table 1: Summary of questionnaire responses relating to occupant movement and/or presence.

Program	Stochastic functionality	Deterministic functionality
Program 1	None.	Prescribed schedules of number of occupants.
Program 2	Can implement user-defined models via: 1) source code modification, 2) external function interaction, 3) proprietary model input language.	Prescribed schedules of number of occupants.
Program 3	Can implement user-defined models via proprietary model input language.	Prescribed schedules of percentage or number of occupants.
Program 4	Can implement user-defined models via standardised model input language.	Occupancy can be characterised as a control system e.g. input from monitoring sensors. Prescribed schedules.
Program 5	Can implement user-defined models via: 1) Open source code, 2) Proprietary model input language, 3) Standardised co-simulation interface(s).	Prescribed schedules of number of occupants.
Program 6	Can implement user-defined models via external function interaction.	Prescribed schedules of number of occupants.
Program 7	Markov chain occupant movement/presence model.	Prescribed schedules of number of occupants.
Program 8	Gaussian distribution of arrival and departure times via bespoke coupling with external code. Can implement user-defined models via open source code.	Prescribed schedules of occupant casual gains. Input from monitoring sensors.

Table 2: Summary of questionnaire responses relating to lighting operation.

Program	Stochastic functionality	Deterministic functionality
Program 1	None.	Prescribed schedules of required workplane illuminance.
Program 2	Can implement user-defined models via: 1) source code modification, 2) external function interaction, 3) proprietary model input language.	Prescribed schedules of lighting gains. Can co-simulate with external programs to provide daylighting control functionality.
Program 3	Can implement user-defined models via proprietary model input language.	Prescribed schedules of light operation. Lighting levels can be daylight compensated.
Program 4	Can implement user-defined models via standardised model input language.	Prescribed schedules.
Program 5	Can specify schedules of operation probabilities. Can implement user-defined models via: 1) Open source code, 2) Proprietary model input language, 3) Standardised co-simulation interface(s).	Prescribed schedules of light operation. Control based on required workplane illuminance.
Program 6	Can implement user-defined models via external function interaction.	Prescribed schedules of light operation. Control based on required workplane illuminance.
Program 7	Operation probability related to event or environment.	Prescribed schedules of light operation.
Program 8	Probabilistic control via integrated model and bespoke coupling with external code. Can implement user-defined models via open source code.	Prescribed schedules of lighting casual gains. Control based on required workplane illuminance.

Table 3: Summary of questionnaire responses relating to window operation.

Program	**Stochastic functionality**	**Deterministic functionality**
Program 1	None.	Hourly prescribed schedules of opening fraction.
Program 2	Can implement user-defined models via: 1) source code modification, 2) external function interaction, 3) proprietary model input language.	Prescribed schedules of air change rate.
Program 3	Can implement user-defined models via proprietary model input language.	Prescribed schedules of window operation. Window opening can be weather or comfort compensated.
Program 4	Can implement user-defined models via standardised model input language.	Prescribed schedules.
Program 5	Can implement user-defined models via: 1) Open source code, 2) Proprietary model input language, 3) Standardised co-simulation interface(s).	Control based on temperature, enthalpy, wind velocity and other metrics.
Program 6	Can implement user-defined models via external function interaction.	Control based on temperature.
Program 7	Opening/closing probability related to event or environment.	Prescribed schedules of window operation.
Program 8	Probabilistic control. Can implement user-defined models via open source code.	Control based on temperature, wind velocity and other metrics.

Table 4: Summary of questionnaire responses relating to HVAC operation.

Program	Stochastic functionality	Deterministic functionality
Program 1	None.	Prescribed schedules of heating/cooling set points. Prescribed schedules of ventilation fraction.
Program 2	Can implement user-defined models via: 1) source code modification, 2) external function interaction, 3) proprietary model input language.	Prescribed schedules of heating/cooling set points, capacities and humidification/dehumidification.
Program 3	Can implement user-defined models via proprietary model input language.	Prescribed schedules of HVAC component operation. Control by fuzzy logic and standard control algorithms.
Program 4	Can implement user-defined models via standardised model input language.	Prescribed schedules.
Program 5	Can implement user-defined models via: 1) Open source code, 2) Proprietary model input language, 3) Standardised co-simulation interface(s).	Prescribed schedules of HVAC availability/operation and thermostat settings.
Program 6	Can implement user-defined models via external function interaction.	Prescribed schedules of fan and thermostat settings.
Program 7	Operation probability related to event or environment.	Prescribed schedules of window operation.
Program 8	Can implement user-defined models via open source code.	Control by a variety of generally set point-based algorithms, based on weather, environment, etc.

Table 5: Summary of questionnaire responses relating to any other aspect of occupant actions.

Program	**Stochastic functionality**	**Deterministic functionality**
Program 1	None.	Prescribed schedules of other casual gains and DHW use.
Program 2	Can implement user-defined models via: 1) source code modification, 2) external function interaction, 3) proprietary model input language.	Prescribed schedules of casual gains. Prescribed schedules of occupant clothing level, external work and metabolic rate.
Program 3	Can implement user-defined models of other casual gains via proprietary model input language.	Prescribed schedules of other casual gains.
Program 4	Can implement user-defined models via standardised model input language.	Prescribed schedules.
Program 5	Can implement user-defined models via: 1) Open source code, 2) Proprietary model input language, 3) Standardised co-simulation interface(s).	Prescribed schedules of casual gains and DHW use. Control of shading by a variety of strategies, including schedules, trigger events and set points. Control of occupant clothing based on ASHRAE standard 55.
Program 6	Probabilistic shading control when predefined criteria are met. Can implement user-defined models via external function interaction.	Prescribed schedules of casual gains and DHW use.
Program 7	None.	Prescribed schedules of appliance use.
Program 8	Probabilistic control of fans. Can implement user-defined models via open source code.	Sub-hourly prescribed schedules of other casual gains. Occupant-linked appliance use via bespoke coupling to external code.

Table 6: Overview of stochastic functionality.

	Stochastic models or potentially stochastic input capabilities for …				
Program	**Presence / movement**	**Lighting operation**	**Window operation**	**HVAC operation**	**Others**
Program 1	None	None	None	None	None
Program 2	User-defined	User-defined	User-defined	User-defined	User-defined
Program 3	User-defined	User-defined	User-defined	User-defined	User-defined
Program 4	User-defined	User-defined	User-defined	User-defined	User-defined
Program 5	User-defined	Scheduled probability, user-defined	User-defined	User-defined	User-defined
Program 6	User-defined	User-defined	User-defined	User-defined	Probabilistic shading control, user-defined
Program 7	Markov chain	Probabilistic control	Probabilistic control	Probabilistic control	None
Program 8	Markov chain, user-defined	Probabilistic control, user-defined	Probabilistic control, user-defined	User-defined	Probabilistic appliance use, probabilistic shading control, user-defined

2.3 Results

Table 1 to Table 5 give summaries of results for each of the categories, and Table 6 gives an overview of stochastic functionality. It is useful to define some of the terms used, particularly in Table 6. “Markov chain” refers to a type of model whereby the probability of a state change depends on the state. Higher order variants may also factor derivatives and duration of states into transition probabilities. “User-defined” refers to the capability for the user to input bespoke functionality in a generalized fashion. These methods are clearly very flexible, but generally are also much more difficult to use, often requiring technical skills such as computer coding.

Deterministic occupant modeling functionality is reasonably well homogenized in most cases. All of the studied BPS programs use prescribed schedules and/or rule-based control to represent occupant behavior. There are differences in the functionality that is available, for example some programs include shading or DHW models and some don’t, but generally speaking the level of input requirements for deterministic models are similar. It is also worth mentioning that capacity for user-defined functionality may be applied to both deterministic and stochastic functionality.

Stochastic occupant modeling functionality is far less consistent. Results reveal that while capacity for user-defined stochastic models is widespread, existing models integrated into BPS programs are less common. Two of the programs investigated had only one stochastic model available, three programs had more extensive stochastic modeling capabilities, and four programs had none. In-built stochastic models of occupant control of HVAC systems seems to be a particular gap, with only one program having this functionality.

Ability to implement user-defined models provides advanced users with a great deal of flexibility, though the methods by which this functionality is enabled are diverse. Provision for greater portability between BPS programs is attempted by external co-simulation or model input standards in some cases, but the BPS program must include the necessary I/O capability defined by the external standard. The usefulness of these methods for providing consistent functionality is therefore dependent on uptake of external standards.

2.4 Conclusions

This study has reviewed currently available occupant behavior modeling functionality in a variety of BPS programs, and established that while deterministic functionality is largely consistent, stochastic functionality is not. Given that current trends in the field are moving toward integrating stochastic modeling in BPS programs, this highlights the widening gap between knowledge and implementation in the field of occupant behavior modeling.

Overall, there is a clear need to homogenize advanced occupant modeling functionality in BPS programs. A single platform with wide-ranging compatibility would allow distribution of state-of-the-art occupant behavior models with relative ease, which may provide a highly effective path to impact for occupant behavior model development. Furthermore, this would help close the gap between knowledge and implementation in occupant behavior modeling, which may contribute to bringing building simulation closer to reality. However, the usefulness of such a platform would be dependent on BPS program developers providing the co-simulation functionality as previously discussed. It is therefore critical that Annex 66 deliverables of modeling tools be widely publicized and well documented to stimulate uptake, though the results of Survey 1 do indicate that the building simulation community would support and be receptive to such developments.

2.5 Appendix A: the questionnaire

Preamble questions:

- Name of the BPS program
- Version and release year of the BPS program
- Name of person filling out questionnaire
- Relationship to BPS program (e.g., user, developer, salesperson, etc.)

Questions for each modeling category (occupant movement/presence, light operation, window operation, HVAC operation, other casual gains, any others):

- Does the BPS program include any stochastic model(s) of [modeling category]?
- If yes, please briefly describe the model(s).
- If yes, please give up to three references detailing each model.
- Please briefly describe any deterministic models of occupant movement and/or presence included in the BPS tool. Please also provide one reference detailing each model and/or its application.

2.6 Appendix B: bibliography of survey response references

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