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IEA EBC Annex 79 – Occupant - Centric Building Design and Operation

Participation of Architecture and Buildings Systems Group, ETH Zürich, 2020-2023

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Zusammenfassung

Ziel des IEA Annex 79 ist es, neue Erkenntnisse über das komfortbezogene Verhalten der Bewohner von Gebäuden und dessen Auswirkungen auf deren Gesamtenergieeffizienz zu gewinnen. Eine offene Kooperationsplattform für Daten und Software wird dabei den Einsatz von Data-Mining-Methoden und fortschrittlichen Modellen für das Nutzerverhalten unterstützen. Diese wird den Einsatz dieses Wissens bei der Planung und dem Betrieb von Gebäuden weiter fördern, dabei die Entwicklung von effektiven Umsetzungsstrategien fördern, Vorschläge für Normen ausarbeiten und Leitlinien für Praktiker bereitstellen.

In den Jahren 2020 bis 2023 haben Forscher der Gruppe Architektur und Gebäudesysteme der ETH Zürich zu den subtasks 1 (Multi-aspect environmental exposure and building interfaces), subtask 2 (Data-driven occupant modeling strategies and digital tools) und subtask 4 (Development and demonstration of occupant-centric building operating strategies) beigetragen. Diese Beiträge bestanden aus der Teilnahme an meetings, Beiträgen zu gemeinsamen Publikationen und eigenen Forschungspublikationen zu den Themen der subtasks.

In Jahr 2023 wurden die Arbeiten zum Ende des IEA Annex 79 heruntergefahren. Die Beiträge der Forschungsgruppe haben sich zunehmend auf den IEA Annex 81 'Data-driven Smart Buildings' konzentriert. Der IEA Annex 81 'Data-driven Smart Buildings' ist, insbesondere in Bezug auf die Arbeiten an der Forschungsgruppe, thematisch verwandt.

Summary

The purpose of the IEA Annex 79 is to provide new insight into comfort-related occupant behaviour in buildings and its impact on building energy performance. An open collaboration platform for data and software will support the use of data-mining methods and advanced occupant behaviour models. It will further promote the usage of this knowledge in building design and operation processes by giving policy support, preparing proposals for standards and providing guidelines for practitioners.

In the years 2020 to 2023, researchers from the Architecture and Building Systems (A/S) Group have contributed to subtasks 1 (Multi-aspect environmental exposure and building interfaces), subtask 2 (Data-driven occupant modelling strategies and digital tools) and Subtask 4 (Development and demonstration of occupant-centric building operating strategies). These contributions included participating in meetings, contributions to joint publications and preparing own scientific publications in context of the topics of the subtasks.

In 2023, the work within Annex 79 was ramped down due to the ending of the Annex. The activities of the research group increasingly focused on the contribution to the IEA Annex 81 'Data-driven Smart Buildings'. The IEA Annex 81 is thematically related, especially in the context of the research undergone by the group.

Contents

Abbreviations

ASHRAE: American Society of Heating and Air-Conditioning Engineers

A/S Group: Architecture and Building Systems Group, Department of Architecture, ETH Zürich

IEA: International Energy Agency

DNN: Deep Neural Network

EBC: Energy in Buildings and Communities Programme by the IEA

HiLo: Demonstrator unit of ETH Zürich at Empa NEST

MPC: Model-Predictive Controls

NEST: Next Evolution Sustainable Technology: building research platform at Empa, Dübendorf

NVivo: Software for data analysis

1 Introduction

1.1 Background information and current situation

“According to the International Energy Agency’s Energy Efficiency 2017 report (IEA, 2017), total energy use of the building sector continues to increase over time. While energy efficiency (measured by energy use intensity) is slowly improving (mostly driven by technology and policy), it is being exceeded by the floor area growth rate. This means the total absolute energy use of the buildings sector is still increasing. The majority of policies (e.g., building codes and incentives) are focused on traditional domains, including building envelopes and HVAC efficiency. Meanwhile, the unrealized energy efficiency potential of buildings exceeds 80% - greater than the other major sections: industry, transport, and power generation (IEA, 2017).

Depending on the building type and degree of automation, occupants remain one of the greatest influences of building energy use. For instance, Hong and Lin (2013) performed a simulation study to show that occupant behaviour at the office scale could increase energy use by 80% or reduce it by 50% from standard assumptions. While modern automation technologies have been introduced into buildings – in part to reduce absolute energy use and uncertainty of energy use associated with occupants – emerging evidence suggests that occupants are often dissatisfied with automation and may intervene (e.g., Lee, Fernandes et al. 2013). Such interventions can include energy-intensive behaviours such as leaving a window open in winter, covering motion sensors that control lighting covering inefficiently using a space heater, or prompting building operators to make permanent overrides to reduce further complaints (Gunay, Shen et al. 2018). Designers often overlook or do not understand the fact that providing greater control to occupants increases their acceptance and preference for a wider range of indoor environmental conditions (Brager, Paliaga et al. 2004). Thus, a major question emerges and remains in the field: what is the ideal between building automation and manual systems to optimize occupant comfort, usability, perception of control, and energy efficiency?”[1]

1.2 Purpose of the project

The purpose of this project is to contribute to the international Annex 79, given the aforementioned background and the following objectives. The reason for participation is the alignment of the research of the Architecture and Building Systems group with these goals and objectives, especially within the subtasks 2 and 4, but also beyond. The research exchange on occupancy-related research in building is highly beneficial for the advancement of research on these topics in Switzerland, and vice versa: Our research, which has been acknowledged by the IEA Annex, contributes to the joint body of research collected and reviewed as a working basis for all Annex 79 contributors, thus disseminating Swiss-based research into the international research domain.

1.3 Objectives

“The overall goal to which Annex 79 is to contribute is:

Developing, demonstrating, and deploying methodologies, technologies, and policies to design and operate buildings that are comfortable, usable, adaptable, and energy-efficient – particularly in the context of occupancy and occupant behaviour.

[1] Cited from the EBC Annex proposal document, prepared by A. Wagner and L. O’Brian, 10.2018

To achieve the above goal, the following objectives will be addressed:

- Improvement of knowledge about occupants' interactions with building technologies. A specific focus will be on comfort-driven actions caused by multiple and interdependent environmental influences which are not yet covered by current models.
- Understanding of building technologies' interfaces which play an important role on whether occupants take advantage of adaptive opportunities for improving their actual comfort situation at all. As most behavioural actions relate to building energy consumption, special emphasis will be given to energy-saving strategies with regard to the use of building technologies.
- Deployment of 'big data' for the building sector as the availability of various data related to occupants' behaviour in buildings increases rapidly. It will be investigated whether techniques as data mining and machine learning offer new modeling strategies which are suitable to represent occupant behaviour in an improved manner.
- Sustainable implementation of occupant behaviour models in building practice by developing guidelines and preparing recommendations for standards for applying occupant behaviour models during building design and operation. Focused case studies will be used to implement and test the new models in different design and operation phases in order to get valuable feedback for the researchers. "[2]

1.4 Subtasks

In the following section the subtasks of the IEA Annex 79 are outlined, based on the project description[3]:

Subtask 1: Multi-aspect Environmental Exposure, Building Interfaces, and Human Behaviour

Leaders: Ardeshir Mahdavi, Marcel Schweiker, Julia Day

This subtask focuses on understanding the impact of multi-aspect environmental exposure on occupant behavior and comfort, as well as the implications of building interfaces on comfort, usability, and energy. The activities include:

1. **State of the Art Assessment:** A comprehensive review of existing theoretical and experimental work relevant to multi-domain models of human comfort, perception, and behavior is conducted. This assessment aims to extend the understanding from single-domain to multi-domain environmental exposures.
2. **Multi-disciplinary Platform:** The task involves developing a common conceptual framework that integrates technical and social sciences for the development of next-generation behavioral models. This requires a structured overview of past interdisciplinary efforts and establishing a common terminology and methodology.
3. **Building Interfaces and Human Behavior:** This involves a systematic review of human-building interfaces to understand their impact on energy use and occupant comfort. The goal is to categorize these interfaces and initiate new research studies to explore identified knowledge gaps.
4. **Method and Studies:** New field and laboratory studies are planned to investigate human comfort and behavior in relation to multi-aspect environmental variables. The studies aim to close knowledge gaps and contribute to the development of occupant behavior models.

[2] Cited from the EBC Annex proposal document, prepared by A. Wagner and L. O'Brian, 10.2018
[3] Summary of the subtask description on the website: https://annex79.iea-ebc.org/subtasks

Subtask 2: Data-driven Occupant Modeling Strategies and Digital Tools

Leaders: Bing Dong, Salvatore Carlucci, Romana Markovic

The focus of this subtask is on developing methodologies and tools for data-driven Occupant Presence and Action (OPA) modeling. The key activities include:

1. **Novel Data Collection Approach:** The activity involves assessing current sensor-based methods for collecting OPA data and developing new methods that balance accuracy, privacy, and cost.
2. **Investigation of Data-driven Methods for OPA:** This includes a systematic review of existing data processing methods and the development of new approaches for data-driven models for OPA modeling.
3. **Development of a Platform for Sharing Data-Driven Methods:** The task is to create an online platform for sharing data and methods related to OPA, and to organize a data competition to foster community engagement.

Subtask 3: Applying Occupant Behavior Models in Performance-Based Design Process

Leaders: Farhang Tamahsebi, Tianzhen Hong, Da Yan

This subtask aims to integrate occupant behavior models into the building design process to improve energy performance and occupant comfort. The activities include:

1. **Review and Development of Methods:** The task involves reviewing current practices and developing new methods and guidelines for choosing appropriate occupant modeling approaches in various design contexts.
2. **Case Studies:** Conducting focused case studies to evaluate and disseminate new occupant modeling approaches in design practice is a key part of this subtask.
3. **Collaboration with Subtask 4:** There is an emphasis on working closely with Subtask 4 to ensure the integration of building design, operation, and controls.

Subtask 4: Development and Demonstration of Occupant-centric Building Controls

Leaders: Burak Gunay, Zoltan Nagy, Clayton Miller

The focus of this subtask is on developing and demonstrating occupant-centric building controls for improved comfort and energy efficiency. The activities include:

1. **Review of Current State and Future Challenges:** This involves assessing the current state of building automation systems and occupant sensing technologies, and identifying future challenges in occupant-centric operating strategies.
2. **Development of Occupant-centric Control Algorithms:** The task is to modify existing algorithms for compatibility with common sensor configurations and to develop new strategies for occupant-centric control.
3. **Demonstration and Verification:** This includes integrating the developed algorithms into building automation systems, testing them in real-world scenarios, and evaluating their impact on energy performance and occupant comfort.

1.5 Deliverables of the IEA Annex 79 (2018-2025)

The following constitute the planned deliverables, as outlined in the Annex proposal[4]. Additionally, scientific contributions such as conference and journal papers, data and case study repositories, and special issues of journals are foreseen. The following table summarises the deliverables as per the Annex proposal:

Stakeholder	**Deliverable (Subtasks)**
Scientists and academics	Report on: • Comprehensive literature review for the four Subtasks (*1,2,3,4*) • Unified theoretical framework for perceptual and behavioural theory of building occupants; • Guidelines for research methods related to: evaluating occupant comfort and building interfaces (*1*), occupant data collection (*2*), and applying data analytics to occupant data (*2*)
Practitioners (architects, engineers, building managers)	Report on: • Best-practices for building interfaces (*1*), occupant-centric design workflows (*3*), and optimal control strategies (*4*) • Focused case studies, including lessons learned (*3 and 4*)
Industry (controls, HVAC, mechanical and electrical equipment, etc.)	Report on: • Best-practices for interface design and evaluation criteria of new products considering multi-aspect comfort (*1*)
Policy-makers (e.g., government, building code officials)	Report on: • Recommendations on occupant modelling in building energy codes (*1*) • Recommendations for standards on occupant metering/sensing infrastructure and controls (*2*)

2 Procedures and methodology

The contributions of the A/S research group to the IEA Annex 79 in 2020-2022 utilised the following procedures and methodologies:

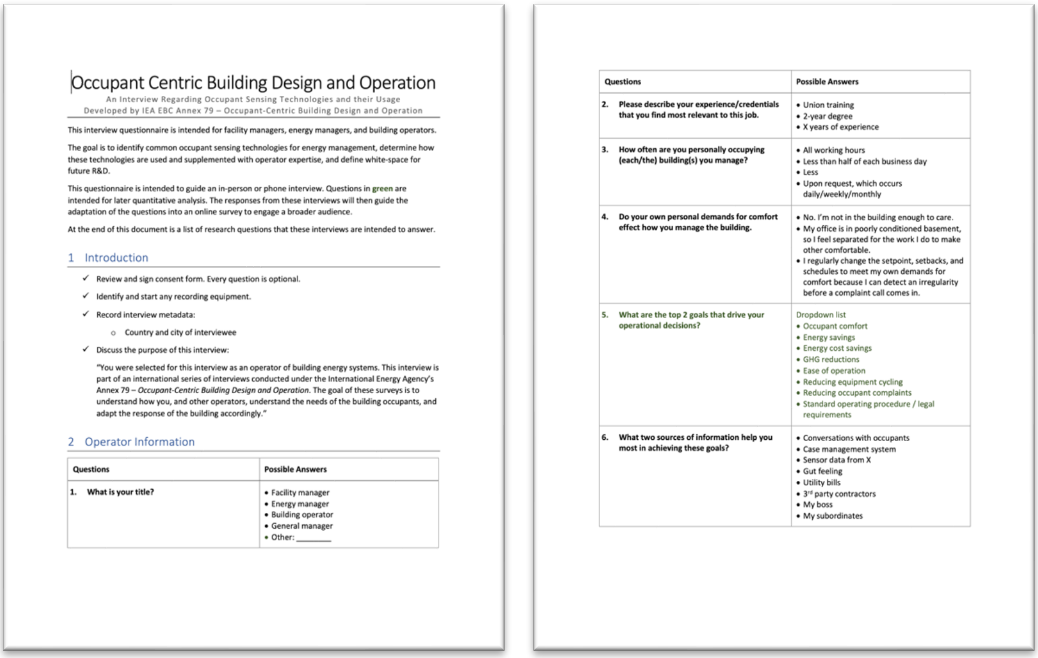
1. Literature review

A comprehensive literature review was executed by an international team of researchers and authors. This review has led to the contributions of two high-level, foundational review papers described in section 2. These papers were published in leading journals and serve as a reference for the entire Annex. Both papers have already received significant citations.

[4] https://annex79.iea-ebc.org/about

2. Stakeholder Surveys

As part of WP4, we have successfully conducted interviews with building operators. All five participants were senior professionals (8 to 20-year career experience), in building facilities in Singapore. The link to the survey can be found in the references.



Occupant Centric Building Design and Operation

An Interview Regarding Occupant Sensing Technologies and their Usage
Developed by IEA EBC Annex 79 – Occupant-Centric Building Design and Operation

This interview questionnaire is intended for facility managers, energy managers, and building operators.

The goal is to identify common occupant sensing technologies for energy management, determine how these technologies are used and supplemented with operator expertise, and define white-space for future R&D.

This questionnaire is intended to guide an in-person or phone interview. Questions in green are intended for later quantitative analysis. The responses from these interviews will then guide the adaptation of the questions into an online survey to engage a broader audience.

At the end of this document is a list of research questions that these interviews are intended to answer.

1 Introduction

- ✓ Review and sign consent form. Every question is optional.
- ✓ Identify and start any recording equipment.
- ✓ Record interview metadata:
  - Country and city of interviewee
- ✓ Discuss the purpose of this interview:

  "You were selected for this interview as an operator of building energy systems. This interview is part of an international series of interviews conducted under the International Energy Agency's Annex 79 – *Occupant-Centric Building Design and Operation*. The goal of these surveys is to understand how you, and other operators, understand the needs of the building occupants, and adapt the response of the building accordingly."

2 Operator Information

Questions	Possible Answers
1. What is your title?	• Facility manager • Energy manager • Building operator • General manager • Other: ________
2. Please describe your experience/credentials that you find most relevant to this job.	• Union training • 2-year degree • X years of experience
3. How often are you personally occupying (each/the) building(s) you manage?	• All working hours • Less than half of each business day • Less • Upon request, which occurs daily/weekly/monthly
4. Do your own personal demands for comfort effect how you manage the building.	• No. I'm not in the building enough to care. • My office is in poorly conditioned basement, so I feel separated for the work I do to make other comfortable. • I regularly change the setpoint, setbacks, and schedules to meet my own demands for comfort because I can detect an irregularity before a complaint call comes in.
5. What are the top 2 goals that drive your operational decisions?	Dropdown list • Occupant comfort • Energy savings • Energy cost savings • GHG reductions • Ease of operation • Reducing equipment cycling • Reducing occupant complaints • Standard operating procedure / legal requirements
6. What two sources of information help you most in achieving these goals?	• Conversations with occupants • Case management system • Sensor data from X • Gut feeling • Utility bills • 3rd party contractors • My boss • My subordinates

Figure 1: Page 1 and 2 of building operator survey

3 Activities and results

3.1 Reports

During the contract period from 03.2020 to 12.2023, two interim reports and one final report were submitted. Due to the COVID pandemic, physical project meetings and overall collaboration during 2020 and 2021 were constrained. The documents can be accessed following this link: https://www.aramis.admin.ch/Texte/?ProjectID=46575

1 Interim Report 2020-2021

Interim report for 2020 and 2021 reporting on the contributions from researchers from the Architecture and Building Systems (A/S) Group, which have contributed to subtasks 2 (Data-driven occupant strategies and digital tools) and 4 (Development and demonstration of occupant-centric building operating strategies). These contributions included participating in online meetings, as physical meetings were not possible, paper contributions and foundational stakeholder surveys.

2 Interim Report 2022

Interim report 2022, reporting on the contributions from researchers from the Architecture and Building Systems (A/S) Group, which have contributed to subtasks 1 (Multi-aspect environmental exposure and building interfaces), subtask 2 (Data-driven occupant modelling strategies and digital tools) and Subtask 4 (Development and demonstration of occupant-centric building operating strategies). These contributions included participating in online meetings and preparing own scientific publications in the context of the topics of the subtasks.

Link: https://www.aramis.admin.ch/Dokument.aspx?DocumentID=69901

3.2 National Activities

In the years 2020 and 2021, researchers from the A/S research group took part in the following subtask meetings of associated subtasks. Due to the ongoing COVID-19 pandemic, all meetings were held online without physical presence. As a result of the international collaboration and the respective meetings in 2020 and 2021, the publications listed in 2) have been successfully published or are forthcoming.

In 2021, group members participated in four meetings. The topics discussed included executing and launching the operator survey in task 4.1.2 and its publication as a journal paper, specifically the uses of the NVivo platform, writing, and overall feedback. Furthermore, the contribution to the ASHRAE 2022 seminar was discussed. In the fall meeting, new members joining were introduced to the activities of Annex 79. In overview and breakout sessions, the different subtasks were presented and discussed, including the formulation of the subtask summary reports.

Annex 79 ST 2 – PhD forum

In November 2021, an Annex 79 PhD forum was held. Two PhD projects were presented, showcasing the integration of advanced machine learning techniques in building control and automation. The first project, led by Antonio Liguori from RWTH Aachen, Germany, focused on applying deep neural networks (DNNs) in resource-constrained environments within building automation. Liguori's research addresses the challenge of implementing complex DNN models where computational resources are limited, optimising neural network architectures to balance high performance with minimal resource demands.

The second project, conducted by Moritz Frahm from KIT, Germany, investigated Model Predictive Control (MPC) in buildings, with a specific emphasis on accommodating uncertainties in weather and occupancy behaviour forecasts. Frahm's research enhances the robustness and efficiency of demand-side management in building systems by integrating these variabilities into the MPC framework. This approach is key to optimising energy usage and ensuring building control systems are both responsive and adaptive. Together, the presentations highlight significant advancements in the application of machine learning for building automation, contributing to the development of intelligent, efficient, and adaptable control systems.

End of 2021, Dr. Yuzhen Peng, a postdoctoral researcher, left the group. In 2022, researchers Dr. Esther Borkowski and PhD student Alberto Silvestri took over the participation in the Annex and took part in the following subtask meetings of associated subtasks for exchange and further collaboration:

Annex 79 Experts Meeting

The purpose of the meeting in March 2022 was to give all Annex participants an overview of the ongoing activities in the subtasks and to discuss cross-subtask activities, dissemination reports and follow-up research. Dr Borkowski, who had recently joined the Architecture and Building Systems research group at the time, attended the meeting to explore possibilities of contributing to the Annex but learned that it was too late to participate in publications as the Annex was already in the final publication and reporting phase. However, the contribution of the HiLo Unit at NEST as a case study was still possible

The following contributions to joint activities of the subtasks were made:

Library of Operations-Based Case Studies for the Annex 79 (subtask 4)
This initiative, led by Prof. Clayton Miller of the National University of Singapore (NUS), aims to create a catalogue of case studies in which occupant-centric operations and/or controls are implemented. The A/S research group contributes the HiLo research unit at Empa NEST, Dübendorf, for which occupant-centric controls are currently researched and developed. In 2023, these controls (Reinforcement learning controller) will be implemented and tested in the occupied unit.

IEA Annex 97 ST1 Global IEQ study (subtask 1)
This initiative, led by Prof. Adam Rysanek of University of British Columbia (UBC) aims to identify the impact of working from home on productivity, health and well-being: 'More than any time in modern human history, large segments of the workforces of the world's major economies are carrying out their work from home offices. Many questions face the office-based work sector after the COVID-19 pandemic: Has working from home been healthier? Does working from home make one more productive? How should companies and offices change to accommodate some of the positive aspects of working from home?' Our research group contributed through participation in the study, promotion and dissemination using own communication channels.

3.3 Results

Over the duration of the project, the group has contributed to foundational research papers, international surveys, and a case study database. Throughout the participation, researchers from the Architecture and Building Systems group, namely Dr. Yuzhen Peng and Dr. Arno Schlueter, have contributed to the following review and survey work, to establish the foundation of the IEA Annex 79. This work has been continued by Dr. Esther Borkowski and Alberto Silvestri.

Journal paper: A review of select human-building interfaces and their relationship to human behavior, energy use and occupant comfort

Authors: Julia K. Day, Claire McIlvennie, Connor Brackley, Mariantonietta Tarantini, Cristina Piselli, Jakob Hahn, William O'Brien, Vinu Subashini Rajus, Marilena De Simone, Mikkel Baun Kjærgaard, Marco Pritoni, **Arno Schlüter, Yuzhen Peng**, Marcel Schweiker, Gianmarco Fajilla, Cristina Becchio, Valentina Fabi, Giorgia Spigliantini, Ghadeer Derbas, Anna Laura Pisello,

Published: Building and Environment, Volume 178, 2020, 106920, ISSN 0360-1323,

Link: https://doi.org/10.1016/j.buildenv.2020.106920.

Abstract: In recent years, research has emerged to quantitatively and qualitatively understand occupants' interactions with buildings. However, there has been surprisingly little research on building interfaces and how their design, context (e.g., location), and underlying logic impact their usability and occupants' perceived control, as well as the resulting comfort and energy performance. Research is needed to better understand how occupants interact with building interfaces in both commercial and residential applications; both applications are important to address as there are many differences in interface types, level of control and understanding, and even expectations of engagement. This paper provides a cursory review and discussion of select common building interfaces: windows, window shades/blinds, thermostats, and lighting controls. The goal of this paper is to review literature related to these human-building interfaces to explore interface characteristics, current design and use challenges, and relationships between building interfaces and occupants. Human-building interface interactions are complex, more research is needed to understand design, use, and characteristics. Common themes emerged throughout the literature review to explain occupant interactions (or lack of interactions) with building interfaces, which included thermal and visual comfort, ease and access of control, interface/control placement, poor interface/control design, lack of understanding, and social-behavioral dynamics.

Journal paper: Modeling occupant behavior in buildings,

Authors: Salvatore Carlucci, Marilena De Simone, Steven K. Firth, Mikkel B. Kjærgaard, Romana Markovic, Mohammad Saiedur Rahaman, Masab Khalid Annaqeeb, Silvia Biandrate, Anooshmita Das, Jakub Wladyslaw Dziedzic, Gianmarco Fajilla, Matteo Favero, Martina Ferrando, Jakob Hahn, Mengjie Han, **Yuzhen Peng,** Flora Salim, **Arno Schlüter,** Christoph van Treeck,

Published: Building and Environment, Volume 174, 2020, 106768, ISSN 0360-1323,

Link: https://doi.org/10.1016/j.buildenv.2020.106768.

Abstract: In the last four decades several methods have been used to model occupants' presence and actions (OPA) in buildings according to different purposes, available computational power, and technical solutions. This study reviews approaches, methods and key findings related to OPA modeling in buildings. An extensive database of related research documents is systematically constructed, and, using bibliometric analysis techniques, the scientific production and landscape are described. The initial literature screening identified more than 750 studies, out of which 278 publications were selected. They provide an overarching view of the development of OPA modeling methods. The research field has evolved from longitudinal collaborative efforts since the late 1970s and, so far, covers diverse building typologies mostly concentrated in a few climate zones. The modeling approaches in the selected literature are grouped into three categories (rule-based models, stochastic OPA modeling, and data-driven methods) for modeling occupancy-related target functions and a set of occupants' actions (window, solar shading, electric lighting, thermostat adjustment, clothing adjustment and appliance use). The explanatory modeling is conventionally based on the model-based paradigm where occupant behavior is assumed to be stochastic, while the data-driven paradigm has found wide applications for the predictive modeling of OPA, applicable to control systems. The lack of established standard evaluation protocols was identified as a scientifically important yet rarely addressed research question. In addition, machine learning and deep learning are emerging in recent years as promising methods to address OPA modeling in real-world applications.

Journal paper: A critical review of field implementations of occupant-centric building controls,

Authors: June Young Park, Mohamed M. Ouf, Burak Gunay, **Yuzhen Peng,** William O'Brien, Mikkel Baun Kjærgaard, Zoltan Nagy,

Published: Building and Environment, Volume 165, 2019, 106351,

Link: https://doi.org/10.1016/j.buildenv.2019.106351.

Abstract: Recent developments in information and communication technology have sparked the notion of smart buildings; an example of which is occupant-centric control (OCC). In this approach, a control system acquires various data from occupants, the indoor environment, and outdoor climate, and learns or derives useful information for building control, e.g., room occupancy patterns and adaptive set-points. Ultimately, these adaptive control parameters are used to improve both occupant comfort and energy efficiency. Typical OCC approaches have been put forward in concept papers, small-scale experiments, as well as simulations. However, there are relatively few studies in which OCC is implemented in real buildings. In this article, we review OCC research, focusing on field-implementation case studies in actual buildings under realistic use conditions. First, we analyze the topical aspects of these studies, e.g., building types, location, and building systems. Next, we present a methodological review focusing on the different approaches used to implement OCC in existing building systems. Lastly, we investigate the experimental design approach of the reviewed case studies, focusing on measurement and verification techniques. Results highlight wide discrepancies in the implementation approach of OCC case studies and identify common challenges facing OCC in actual buildings. We propose future directions for OCC research by providing recommendations to address these challenges and to standardize OCC implementations.

Keywords: Occupant-centric control; Smart building; Occupant behavior; Occupant comfort; Building energy

Journal paper: Improving Occupant-Centric Building Controls: Opportunities from an International Interview Study of Operators

Authors: Michael Kane[NU], Krissy Govertsen[NU], and Ciana Winston[NU], Zakia Afroz[ABUD], Philip Agee[VT], Maíra André[FUSC], Karol Bandurski[PUT], Arkasama Bandyopadhyay[AM], Mateus Bavaresco[FUSC], Cristina Becchio[PDT], Carolina Buonocore[FUSC], Luiza De Castro[FUSC], Stefano Paolo Corgnati[PDT], Julia Day[WSU], Bing Dong[SU], H. Burak Gunay[CU], Jakob Hahn[MUAS], Sarah Heiler[FIBP], Brodie W. Hobson[CU], Carola Lingua[PDT], Clayton Miller[NUS], Zoltan Nagy[UT], Zheng O'Neill[AM], **Yuzhen Peng**[ETH,NUS], Benedetta Pioppi[DOE], Cristina Piselli[DOE], András Reith[ABUD], Kunind Sharma[NU], Giorgia Spigliantini[PUT], Lilla Zelovich[ABUD]

Published: Forthcoming

Abstract: Building operators are tasked with the day-to-day monitoring, management, and maintenance of building HVAC systems in mid- and large-sized commercial buildings. Due to the complexity of these buildings, occupants are typically unable to understand and effectively control the system themselves, therefore relying on the expertise of building operators. Thus, operators play a critical role in occupant-centric buildings to reduce occupant-related building energy consumption and to improve individual occupant comfort. To better understand this role, an activity within the IEA EBC Annex 79 conducted seventy-two interviews with building operators across seven countries and four climate zones.The study intended to survey occupant-centric control technologies; operator skills, trust, drivers, needs, and opinions. Using the findings of these international interviews of building operators, this study aims to qualitatively understand the relationship between occupants; operators; sensors and interfaces; and buildings and heating, ventilating, and air conditioning (HVAC) equipment and their role regarding occupant-centric building design and operation. We then discuss the current limitations of these relationships and how these relationships can be strengthened to improve occupant-centric building controls. The relationship based analysis of these interviews revealed the four following opportunities to enhance occupant-centric operations: (1) adapting occupant-centric operation policies, (2) adopting emerging occupancy sensing technologies, (3) improving operator and occupant communication methods, and (4) encouraging occupant autonomy through education.

The following paper denotes a contribution both to IEA Annex 79 on occupant-centric building controls (Reinforcement learning) as well as to Annex 81 on IoT and sensors (Smart Buildings)

Conference Paper: Comparison of Two Deep Reinforcement Learning Algorithms towards an Optimal Policy for Smart Building Thermal Control

Authors: **Silvestri, Alberto**, Davide Coraci, Duan Wu, **Esther Borkowski**, and **Arno Schlueter**

Published: *Journal of Physics: Conference Series* 2600 (7): 072011.
Link: https://doi.org/10.1088/1742-6596/2600/7/072011.

Abstract: Heating, Ventilation, and Air Conditioning (HVAC) systems are the main providers of occupant comfort, and at the same time, they represent a significant source of energy consumption. Improving their efficiency is essential for reducing the environmental impact of buildings. However,

traditional rule-based and model-based strategies are often inefficient in real-world applications due to the complex building thermal dynamics and the influence of heterogeneous disturbances, such as unpredictable occupant behavior. In order to address this issue, the performance of two state-of-the-art model-free Deep Reinforcement Learning (DRL) algorithms, Proximal Policy Optimization (PPO) and Soft Actor-Critic (SAC), has been compared when the percentage valve opening is managed in a thermally activated building system, modeled in a simulated environment from data collected in an existing office building in Switzerland. Results show that PPO reduced energy costs by 18% and decreased temperature violations by 33%, while SAC achieved a 14% reduction in energy costs and 64% fewer temperature violations compared to the onsite Rule-Based Controller (RBC).

4 Evaluation of results of the Annex

Annex 79 aimed to integrate and implement occupancy and occupant behavior into building design and operation to enhance energy performance and occupant comfort.

As per the project webseite, Annex 79 was "focussing on:

- developing new scientific knowledge about adaptive occupant actions driven by multiple interdependent indoor environmental parameters,
- understanding interactions between occupants and building systems, e.g. how interfaces en-/discourage occupants taking advantage of adaptive opportunities for improving their comfort situation, as well as the impact on building energy use,
- deploying 'big data' (e.g. data mining and machine learning) for the building sector based on various sources of building and occupant data as well as sensing technologies,
- developing methods and guidelines and preparing standards for integrating occupant models in building design and operation, and
- performing focused case studies to test the new methods and models in different design and operation phases in order to obtain valuable feedback for the researchers, practitioners, and policy makers."[5]

The results of the Annex have been widely published and gained significant attention both in research as well as in practice. As a result of the participation, the international collaboration, and the respective meetings in 2020 and 2021, the A/S research group contributed to three review papers that were published in leading journals and serve as a foundation and reference for the entire Annex (references in section 8). These papers have gathered international recognition and have accumulated a significant number of citations. One publication listed above is still forthcoming. The operator study, as mentioned above, will shed light on the relationship between occupants, operators, sensors and interfaces, and buildings and heating, ventilating, and air conditioning (HVAC) equipment and their role regarding occupant-centric building design and operation. This study pursues a global approach. Parts of the results for Germany have already been published [6]

5 Next steps

In 2023, Annex 79 was ramped down, and only one meeting in June 2023 was conducted in Aachen, Germany, with no researchers from the A/S group present. During 2023, the A/S group has already

[5] https://annex79.iea-ebc.org/about
[6] (https://www.frontiersin.org/articles/10.3389/fbuil.2022.838859/full)

focused on our participation and contributions to IEA Annex 82 (see IEA Annex 82[7] on www.aramis.admin.ch).

6 National and international cooperation

Contributors and participants of the IEA Annex 79 came from a broad international background: Australia, Austria, Brazil, Canada, China, Denmark, Germany, France, India, Italy, Netherlands, New Zealand, Norway, Poland, Sweden, Switzerland, United Arab Emirates, United Kingdom, United States of America[8].

The most important international collaborations of the ETH group of Architecture and Building Systems, which have led to the respective publications, were with the University of Texas in Austin, USA, Prof. Dr Zoltan Nagy, with Prof. Dr Clayton Miller, National University of Singapore and with Prof. Dr Adam Rysanek, University of British Columbia. Furthermore, a deeper exchange and collaboration has been established with Politecnico di Torino, Italy, which is continued in the IEA Annex 81.

7 Communication

The communication of the EBC IEA Annex 79 is facilitated by the operating agents, and primarily over the IEA Annex 79 website: https://annex79.iea-ebc.org/

Results of the Annex have been widely disseminated through conference and journal publications, journal special issues, panel discussions, presentations, books, technical reports, and guidelines.

A complete list of publications can be accessed via the project website: https://annex79.iea-ebc.org/publications

8 Publications

In the context of the IEA Annex79, the ETH Architecture and Building Systems research group was involved in the following publications:

Carlucci, Salvatore, Marilena De Simone, Steven K. Firth, Mikkel B. Kjærgaard, Romana Markovic, Mohammad Saiedur Rahaman, Masab Khalid Annaqeeb, et al. 'Modeling Occupant Behavior in Buildings'. *Building and Environment* 174 (1 May 2020): 106768. https://doi.org/10.1016/j.buildenv.2020.106768.

Day, Julia K., Claire McIlvennie, Connor Brackley, Mariantonietta Tarantini, Cristina Piselli, Jakob Hahn, William O'Brien, et al. 'A Review of Select Human-Building Interfaces and Their Relationship to Human Behavior, Energy Use and Occupant Comfort'. *Building and Environment* 178 (1 July 2020): 106920. https://doi.org/10.1016/j.buildenv.2020.106920.

Park, June Young, Mohamed M. Ouf, Burak Gunay, Yuzhen Peng, William O'Brien, Mikkel Baun Kjærgaard, and Zoltan Nagy. 'A Critical Review of Field Implementations of Occupant-Centric Building Controls'. *Building and Environment* 165 (1 November 2019): 106351. https://doi.org/10.1016/j.buildenv.2019.106351.

Silvestri, Alberto, Davide Coraci, Duan Wu, Esther Borkowski, and Arno Schlueter. 2023. 'Comparison of Two Deep Reinforcement Learning Algorithms towards an Optimal Policy for Smart Building

[7] https://www.aramis.admin.ch/Grunddaten/?ProjectID=53229
[8] https://annex79.iea-ebc.org/about

Thermal Control'. *Journal of Physics: Conference Series* 2600 (7): 072011. https://doi.org/10.1088/1742-6596/2600/7/072011.

9 References

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Gilani, S. and W. O'Brien (2018). "A preliminary study of occupants' use of manual lighting controls in private offices: A case study." Energy and Buildings **159**: 572-586.

Gunay, H. B., W. Shen, G. Newsham and A. Ashouri (2018). "Modelling and analysis of unsolicited temperature setpoint change requests in office buildings." Building and Environment **133**: 203-212.

Hong, T. and H.-W. Lin (2013). Occupant behavior: impact on energy use of private offices, Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, CA (US).

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Lee, E., L. Fernandes, B. Coffey, A. McNeil, R. Clear, T. Webster, F. Bauman, D. Dickerhoff, D. Heinzerling and T. Hoyt (2013). "A Post-Occupancy Monitored Evaluation of the Dimmable Lighting, Automated Shading, and Underfloor Air Distribution System in The New York Times Building."

Operation-Based Case Study: https://yalenus.au1.qualtrics.com/jfe/form/SV_e2JhKdq7SC0f1pb

Empa NEST HiLo, https://www.empa.ch/de/web/nest/hilo

International Survey on the Perceived Indoor Environmental Quality of Home-based Workplaces During the COVID-19 Pandemic**,** https://ubc.ca1.qualtrics.com/jfe/form/SV_dj1EcebICVzksAu

10 Appendix

Webseite of the EBC IEA Annex 79: https://annex79.iea-ebc.org