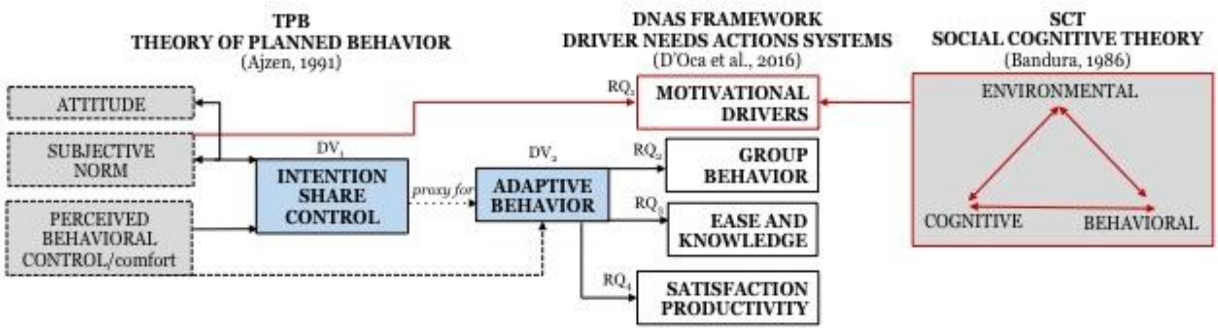
Annex 66: Definition and Simulation of Occupant Behavior in Buildings

Technical Report:

An International Survey of Occupant Behavior in Workspaces

November 2017



The Integrated Interdisciplinary Survey Framework

EBC is a programme of the International Energy Agency (IEA)

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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 (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
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Annex 25: Real time HVAC Simulation (*)

Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
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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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.

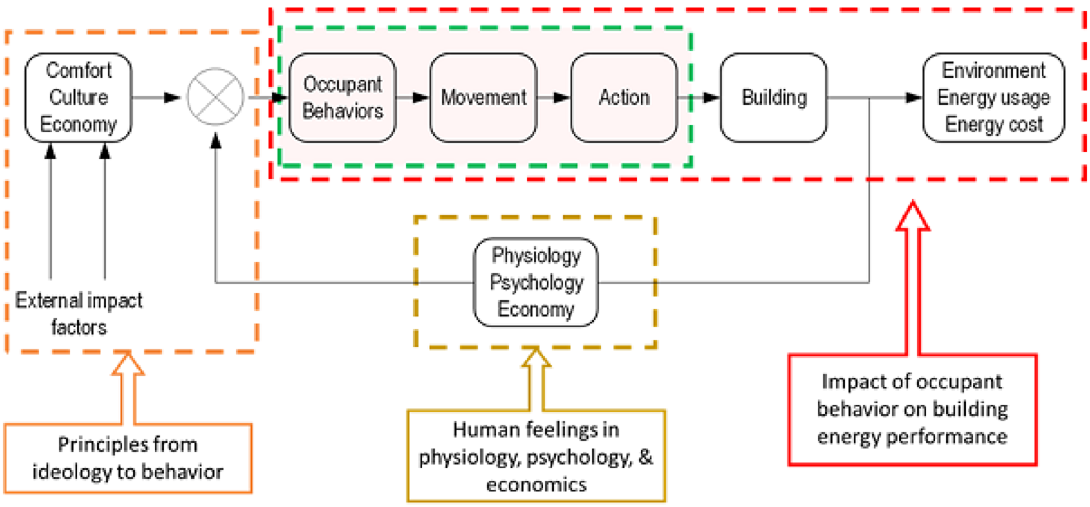

Figure 1: Relationship between occupants and buildings

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 current 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 consultant companies, 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 introduces a cross-country questionnaire survey based on theories and insights from building physics and social psychology, aiming to investigate the building-user interaction in the workspace, having an impact on comfort provisions and energy use and costs, in diverse office settings and cultural contexts worldwide. We based a survey data collection on an interdisciplinary research framework grounded on the Drivers–Needs–Actions–Systems ontology for energy-related occupant behavior in buildings, the Social Cognitive Theory, and the Theory of Planned Behavior. First, this research attempts to expand the state-of-the-art understanding of the environmental, cognitive and behavioral drivers motivating occupants to interact with the control systems in the office settings – such as opening/closing windows, blinds, and shades, adjusting thermostats and switching on/off or dimming artificial lights. Secondly, we extend the Theory of Planned Behavior, to investigate how occupants' attitudes and subjective norms, such as group negotiation dynamics in various workspace configurations and densities, influence the group interaction with control systems. Thirdly, the perceived ease of usage and knowledge on how to interact with building technologies is correlated to the intention to share controls in office space, and hence the choice of adaptive actions during the heating and cooling seasons. Finally, our study endeavors to highlight the correlation between perceived behavioral control and perceived comfort, satisfaction and hence productivity in office spaces. A total number of 37 questions have been designed by an interdisciplinary team having architecture, engineering and social science backgrounds, to collect responses from administrative staff and faculties among 14 universities and research centers in six countries in the U.S., Europe, China and Australia. This methodology addresses the context to particular types of 'public sector' offices and hence provides applicability to any other types of commercial offices.

1. Introduction

There is a need for an interdisciplinary-shared framework able to isolate data-driven knowledge on climatic, cultural and socio-demographic factors of the human-building interaction and to ensure validity, robustness, and efficiency for future studies in office settings worldwide.

The importance to consider occupant behavior in buildings from an interdisciplinary perspective emerges now timely. Explorations regarding the achievement of energy efficient usage in the building sector are today established around the understanding of the socio-technical link between building occupants' behavior and usage of building technologies, energy services and controls. Abrahamse and Steg [1] anticipated this interdisciplinary approach as a two-way exchange of knowledge from socio-technical disciplinary fields of sciences.

Specifically, in the commercial sector, the uptake of behavior-based interventions among the employees, having an impact on the organization's energy, environmental and economical performances, calls for an interdisciplinary disciplinary approach.

A significant contribution towards the configuration of an interdisciplinary approach to understanding occupant behavior, comfort and satisfaction impacting the achievement of high-performing buildings, has been provided by researchers in the field of architecture and social science. Day and Gunderson[2] proposed a methodology blending disciplinary perspectives and research techniques stemming from interior design, building science, data science, and social science. They confirm the hypothesis that occupants receiving effective training on the usage of building technology and energy systems were significantly more likely to be comfortable and satisfied with their office environment. By focusing on the social-psychological factors of energy concerns affecting employees' energy saving intentions within the workplace, Chen and Knight[3] contributed to the confirmation of the role of social scientific perspectives in energy research. These results are significant to the extent social science theories, analytical methods and insights can provide measurable improvement in promoting energy conservation, which is both behavior-based and technology-driven.

However, data-driven frameworks for comprehensively describing the energy-relevant human-building interactions in office buildings based on the knowledge of these fields are still little explored.

[1] W. Abrahamse, L. Steg, Factors Related to Household Energy Use and Intention to Reduce It: The Role of Psychological and Socio-Demographic Variables, Hum. Ecol. Rev. 18 (2011) 30–40.

[2] J.K. Day, D.E. Gunderson, Understanding high performance buildings: The link between occupant knowledge of passive design systems, corresponding behaviors, occupant comfort and environmental satisfaction, Build. Environ. 84 (2015) 114–124. doi:10.1016/j.buildenv.2014.11.003.

[3] C. Chen, K. Knight, Energy at work: Social psychological factors affecting energy conservation intentions within Chinese electric power companies, Energy Res. Soc. Sci. 4 (2014) 23–31. doi:10.1016/j.erss.2014.08.004.

2. Methodology

We developed an interdisciplinary research framework as the foundation for a cross-country questionnaire survey on the human-building interaction in office buildings. By adopting a modification to the main Theory of Planned Behavior (TPB) developed from Ajzen[4] – attitudes, subjective norms and Perceived Behavior Control (PBC) – to the Social Cognitive Theory (SCT) explained by Bandura[5], and a motivational survey framework grounded on the DNAS ontology[6], this study attempts to investigate as dependent variables the intention to share controls *(DV_1)* and adaptive control behaviors *(DV_2)* within the context of the workplace (Figure 2). Specifically, the research framework attempts to address four key research questions:

I. *(RQ_1) - Which are the environmental, cognitive and behavioral motivational drivers influencing the human-building interaction in diverse office settings and cultural contexts worldwide?*
II. *(RQ_2) - How social pressure (attitude and subjective norm) from coworkers and employers on how one is expected to act in the workspace and how group decision is made to negotiate and share controls in office spaces having different layout, influence the intention to share control (DV1) and hence the occupants' interaction with control systems (DV2)?*
III. *(RQ_3) - How the perceived ease and knowledge on how to interact with the building control systems (PBC) influence the individual's intention to share controls (DV1) and the choice of adaptive actions (DV2) during the heating and cooling seasons in office spaces?*
IV. *(RQ_4) - The relationship between individual's intention to share controls (DV1), the choice of adaptive actions (DV2) and the perceived sense of satisfaction and productivity (perceived comfort) during the heating and cooling seasons in office spaces.*

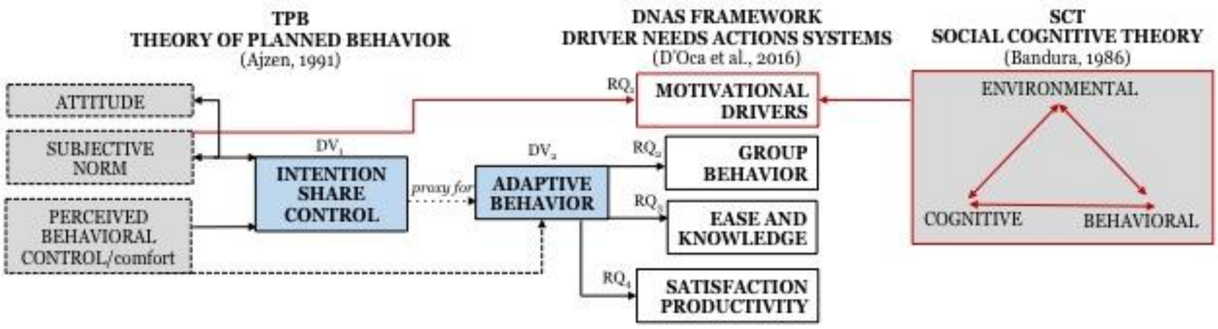

Figure 2. The proposed interdisciplinary research framework, as an extension of the TBP, SCT and DNAS Framework.

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4 I. Ajzen, The theory of planned behavior, Organ. Behav. Hum. Decis. Process. 50 (1991) 179–211. doi:10.1016/0749-5978(91)90020-T.

5 A. Bandura, Social foundations of thought and action: A social cognitive theory, Prentice-Hall, Inc., Englewood Cliffs, NJ, US:, 1986.

6 S. D'Oca, S. Corgnati, A.L. Pisello, T. Hong, Introduction to an occupant behavior motivation survey framework, in: Clima 2016, 2016.

2.1. Motivational Drivers

Traditional research on energy-related occupant behavior in office buildings mainly focused on the understanding of cause/effect mechanisms driving human interaction with the building systems and envelope to optimize energy consumption and comfort. Such approach explained motivations (drivers) of behaviors by establishing correlations between specific observable (and monitored) variables and a particular behavior under observation – i.e., opening a window, turning on/off lights and operating thermostats and shades. These variables typically included indoor and outdoor environmental parameters – i.e., indoor/outdoor temperature, illuminance level, CO_2 concentration –, contextual parameters – i.e., time of the day, day of the week –, and personal traits, such as gender, age, and user profiles. Recently, models accounting for influential contextual factors such as ease of control, freedom of movement, knowledge of technology and usability factors are discussed within the building engineering community.

By adopting the SCT in extension to the DNAS framework, this section of the survey attempts to explain (RQ1) what are the motivational drivers of adaptive behaviors – such as opening and closing windows, operating blinds and shades adjusting thermostats and turning on and off artificial lightings – in shared office settings. These motivational drivers can be further explained as a function of the available, exercised, and self-reported behavioral control, as well as user profiles, demographic factors, building characteristics and season of the year.

2.2. Group Behavior

Additional knowledge on individual adaptive behavioral patterns and motivational drivers is especially needed from the office environment, where the interaction with building control devices to establish individual's comfort conditions is negotiated in social networks, and because monetary incentives for engaging in pro-environmental behaviors are negligible, compared to residential spaces. Accordingly to Ajzen[7], subjective norms are the perceived social pressures from a meaningful reference person or group and/or beliefs about how these “significant others” believe one should act in a given situation. For "significant others," this work refers to "perceived social pressure" of performing an adaptive behavior from specific reference person (i.e., the employer or the building manager) or group of individuals (i.e., the co-workers).

By using elements of the TPB, we aim to predict (RQ2) how behavioral and normative beliefs in the working environment, as the perceived social pressure from coworkers and employers on how one is expected to act in the workspace and how decision is made to negotiate and share controls, influence the intention to share control (DV1) and hence the occupants’ interaction with

[7] I. Ajzen, The theory of planned behavior, Organ. Behav. Hum. Decis. Process. 50 (1991) 179–211. doi:10.1016/0749-5978(91)90020-T.

control systems (DV2). This evaluation can be conducted for workspace having different layouts (workspace type) and dynamics.

2.3. Ease and knowledge of use

Accordingly to Ajzen, PBC is outlined as "the perceived ease or difficulty of performing the behavior" in a specific situation. As illustrated in Figure 2, PBC is a function of control belief and perceived power of the control. In the TPB model, PBC has both a direct influence on behaviors and an indirect influence on behaviors through behavioral intentions. Experimental tests have been conducted by Schweiker and Wagner[8] in order to gain insights into the effect of perceived control on negotiated behaviors in the working environment. Results demonstrated the number of people sharing the workspace negatively affects perceived control, and a lack of perceived control negatively influences the attainment of neutral comfort temperature.

By using this element of the TPB, we are interested in predicting (RQ3) how the intention to share controls (DV1) and the exercised interaction (order of adaptive actions) with the office control systems (DV2) during the heating and cooling seasons are influenced by the perceived ease of use and knowledge on how to interact with the building control systems. This correlation can be further explained as a function of diverse user profiles, demographic factors, and building characteristics.

2.4. Satisfaction and productivity

Key components of the human-building interaction have foundation on the concepts of perceived comfort, satisfaction, productivity and control over indoor environmental condition. However, choices of adaptive behaviors can be perceived as a stressful component too. Studies on behavioral selection demonstrated the greater the number of behavioral options, the more difficult the task of selection. This mechanism induces to a reduced number of choices taken; accordingly, people tend to be more dissatisfied with the choices they have made, provoking a vicious circle of demotivating effect. On the other hand, prohibiting actions or persuading people too much can be perceived as constraints, resulting in a desire for what has been banned or restricted, or even a repulsion towards the persuading message. As a general tendency, to the extent users perceive positive realization of exercised control to ensure comfort conditions, their satisfaction over the indoor environment is guaranteed.

By using some extended elements of the TPB, we are interested in predicting (RQ4) how the intention to share controls (DV1) and the chosen adaptive actions (DV2) during the heating and

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[8] M. Schweiker, A. Wagner, The effect of occupancy on perceived control, neutral temperature, and behavioral patterns, Energy Build. (2015). doi:10.1016/j.enbuild.2015.10.051.

cooling seasons are influenced by the perceived comfort, satisfaction, productivity, and source of discomfort. These correlations can be further explained as a function of distinct user profiles, demographic factors, and building characteristics.

3. Results

Based on the proposed framework, a survey questionnaire has been designed, consisting of 37 questions plus two additional variables to be inferred from the survey data.

3.1. Survey Design

Appropriate geographical coverage of the data and sample diversity is ensured to provide reliable and valuable outcomes on climatic, cultural and gender distribution.

The survey questionnaire is designed to collect responses from the targeted 20,000 administrative staff and faculties among 14 universities and research centers across four continents (America, Asia, Europe, Australia).

The questionnaire, originally developed in English, is translated into national survey questionnaires, in diverse languages (Italian, Polish, Hungarian, Chinese). A translation guideline protocol has been followed to ensure equivalence across languages. Semantic, conceptual and normative equivalence of survey questions is guaranteed by re-translating survey questions back into English before submission, by following a Double Translation Process[9], one of most adopted translation processes for survey questionnaire:

Preparation Step. We first identified two bilingual translators for each language. We identified elements of The English Original Version (EOV) which might be problematic to translate to the target languages due to any reasons (terminology or differences in culture or built environment).

First Translation. The EOV is translated by the first translator into each of the four Target Language Version (TV) – Italian, Polish, Hungarian, and Chinese.

Second Translation. The second translator took the results from the previous step (TV) and independently translated the survey questions back to the original language – the English Translated Version (ETV).

Comparison Step. We had at this point two versions of the survey questionnaire in the original language (EOV) and in the translated version (ETV). These two versions have been compared

[9] S.Y. McGorry, Measurement in a cross- cultural environment: survey translation issues, Qual. Mark. Res. An Int. J. 3 (2000) 74–81.

for inconsistencies, mistranslations, meaning, cultural gaps and lost words or phrases. If any differences were found, we consulted with the translators to find out why this occurred and how the instrument can be revised.

Verification Step. Both the EOV and ETV of each of the four target languages are compared.

Having access to a contact database is crucial to ensure the success of cross-country survey questionnaire at a large scale. In this perspective, both quality and quantity of the survey sample have been evaluated. The Qualtrics survey link is sent out to participants through the university, corporate, and staff email lists. Detailed procedures and strategies for collecting data take account of steps of sending out the survey and collect data, such as (a) the survey should not be sent out during the weekdays; and (b) 3-4 reminders should be sent out before closing the survey.

The sample size is a paramount challenge to consider in questionnaire design to avoid bias in results. Response rate can be kept high by providing respondents with some incentives motivating them to fill in the questionnaire, such as monetary awards or gift certificate. However, we deliberated providing the same incentive to the respondents from different institutions as impractical.

Ensuring semantic, conceptual and normative ethical consistency between translations of the questionnaire defines the key intrinsic risk and challenge of this cross-country survey. Ethical protocols and privacy issues for handling human subject data have been considered in designing the survey questions.

Diverse statistical analysis methods, such as logistic and multiple regression, structural equation modeling, and data mining approaches (e.g., clustering, Bayesian Network) have been used to investigate the survey data.

3.2. Validation of the interdisciplinary cross-country survey: the Italian Case study

The survey questionnaire was firstly validated in three university institutions across Italy, located in Turin (Polito), Perugia (UniPg) and Rende (UniCal). The target for the proposed survey was administrative staff, faculty members, and students regularly occupying their workspace. The Qualtrics survey link was sent to the sample through the institutional email list of the three universities over a period of four weeks during the spring season (from April 5th to May 8th, 2017). Three reminders were sent to the participants at the end of each week. A total number of 1160 valid responses were collected from the online questionnaire (Table 1). Despite incentives provided, the response rate was not high (between 11% and 16%).

Table 1. *Response Rate*	PoliTo - Turin	UniPg - Perugia	UniCal - Rende
Total Valid	**502**	**405**	**253**
Total Sent	4424	2991	1598
Response Rate	**11%**	**14%**	**16%**

Survey **compilation time** (time respondents spent answering the whole survey) was around 20 minutes for the majority of the collected responses, where no predominant variation in compilation time was found among the three institutions.

Gender of respondents was almost equally distributed (50% male and 48% female, 2% NA). Respondents are mostly full-time employees (with 31-40 hours workspace occupancy), who typically occupy shared or private offices (33%), or shared open offices (30%). Cubicle spaces are seldom used in the sample (2%). Significantly, single private offices emerge typically occupied by men (61%) in the range of 40-61 years old, and less frequently by women (37%) or younger people in the range of 18-28 years old (1%). The majority of the sample population holds a Ph.D. or post-laureate Master degree (41%), or a master or an equivalent 5-year degree (36%).

Regarding the individual's **motivational drivers** towards the interaction with shared building environmental controls, office workers mainly open windows to have fresh air, while they typically close windows because the indoor temperature is perceived as too cold or too warm. Window blinds and shades are more frequently pulled up or opened to let more daylight in the office space, while they are drawn mainly to reduce glare on the computer screens or workspace. Thermostat set points and lighting systems are generally regulated to restore comfort conditions in the workspace (because the temperature is perceived as too hot or too cold or to adjust lighting level in the room) and less frequently as a consequence of an energy conservation behavior.

Regarding **group dynamics** (Figure 3), the intention to share controls does not emerge correlated to perceived comfort, satisfaction, productivity or knowledge on how to use technology, but rather as a behavioral trait of the occupant. As a matter of fact, the shared control of the indoor environment in the office space is generally perceived as a fair or good thing across all the climate zones, highlighting a common positive attitude of office workers towards sharing control devices. Occupants in the Northern region (Turin) tend to report a stronger subjective norm on the co-workers' expectation to share the control over the IEQ.

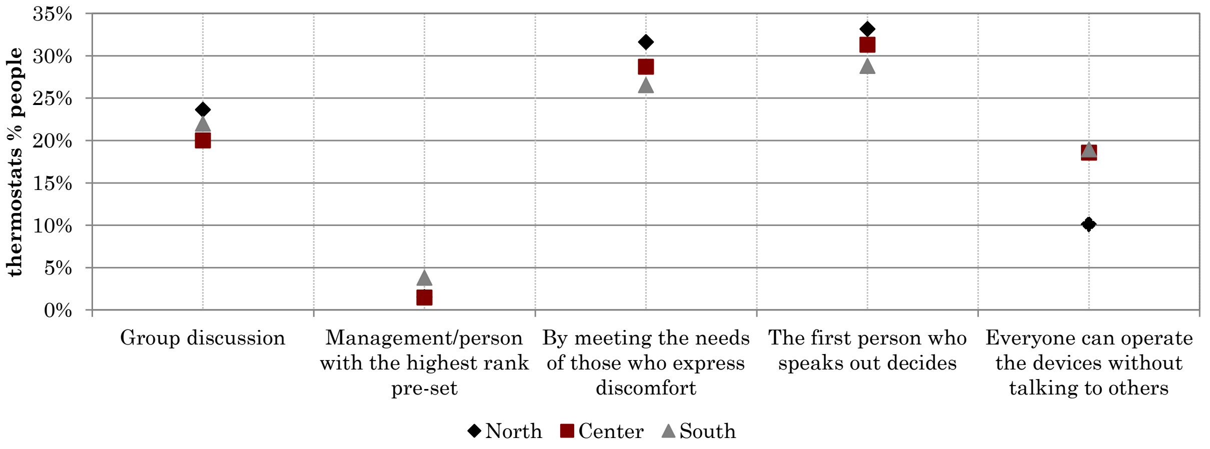

Figure 3. Workspace group norms across the three climatic zones: Northern-continental (black), Central-mild (red) and Southern-Mediterranean (gray).

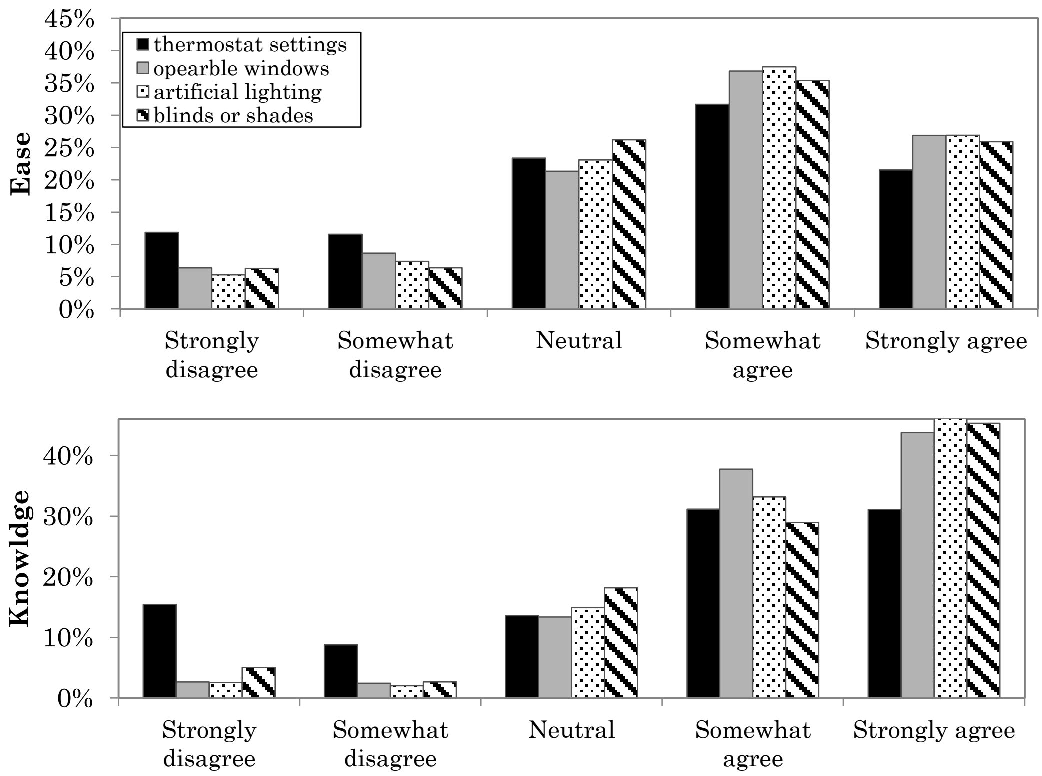

Figure 4. *Frequency of perceived ease of sharing and knowledge of control averaged across the three case studies*

Regarding **perceived behavioral control** (Figure 4) of building technologies (ease of usage and knowledge), office workers tend to perceive greater ease to share the control of operable windows, lighting systems, and blinds and shades, than thermostat settings. Similarly, respondents appear to be more acquainted with the usage of windows, blinds, shades and artificial lighting, than the regulation of thermostats in their workspace. Consequently, a general dissatisfaction over the shared control of the thermostat settings in office spaces emerges (Figure 5).

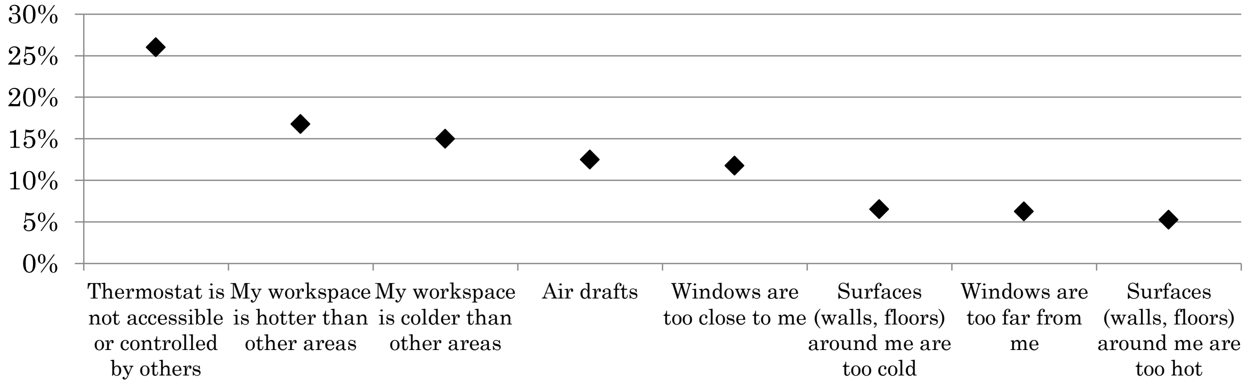

Figure 5. Satisfaction of controls averaged across the three university surveys

Focusing on **perceived comfort, satisfaction and productivity** (Figure 6), office workers tend to appear more satisfied with the quality of natural and artificial lighting than indoor temperature, and indoor air quality. Natural and artificial lighting seems to predominantly influence productivity, while variables such as indoor temperature and indoor air quality are more frequently perceived as responsible for the loss of productivity from the office workers. Perceived comfort is correlated to satisfaction and productivity, and less to the ease of usage and knowledge of control, as well as attitudes and subjective norms.

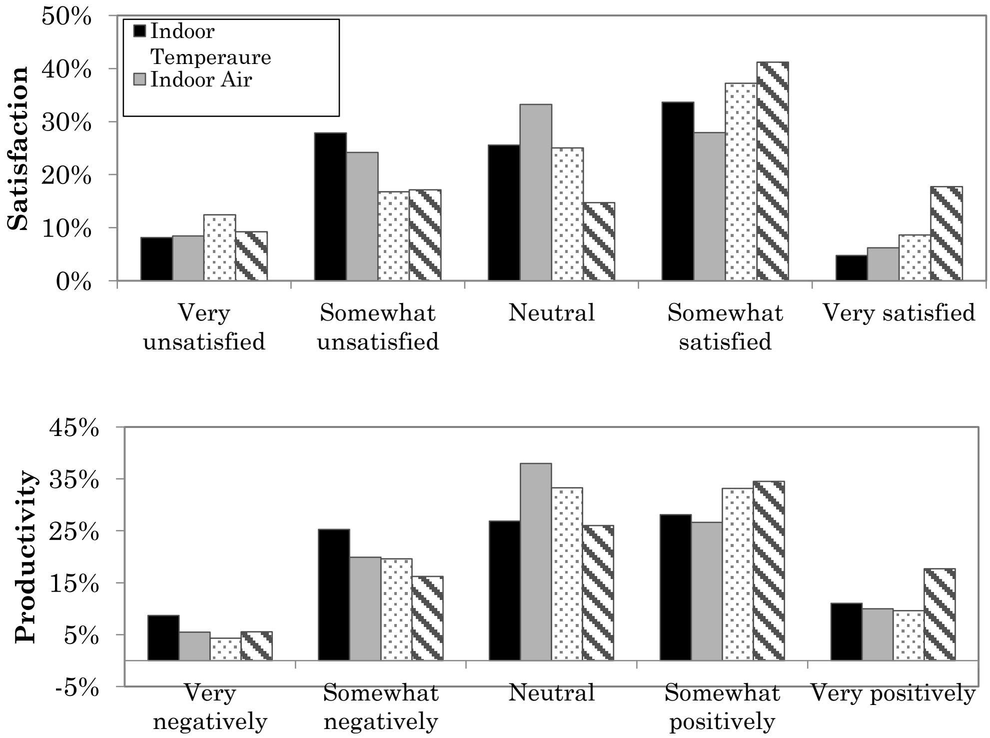

Figure 6. The frequency of self-reported satisfaction and productivity averaged across the three Italian climate zones.

3.3. Data Access, Storage, and Ownership

A push-pull data exchange takes place within the Application Service Provider (ASP) of the software provided by Qualtrics, accessed using the web browser. Structure for data access, storage, and ownership is described as in Figure 7.

Each survey participant receives via email an individual Qualtrics link of the TV to be used for their national survey (data pull). All data collected using Qualtrics are stored in a single secure data center, to avoid data floating around in the cloud (data-pull). Qualtrics treats all data as highly confidential and does not classify or represent the data because only the end-users know what data it is collecting. Qualtrics is presently undergoing certification under the FedRAMP program, the "gold standard" of security compliance. All the coded data are stored in a password-protected data storage to ensure data safety by monitoring computer and network use, controlling user access, and preventing intrusions and failures. Emergency backup systems are actively in place to recover data from intrusions, failures, and unexpected events.

The data are expected to be maintained for long as needed or at least ten years in the Qualtrics Database. Data are transferred to national participants, who possess ownership of the data collected in their national survey buildings.

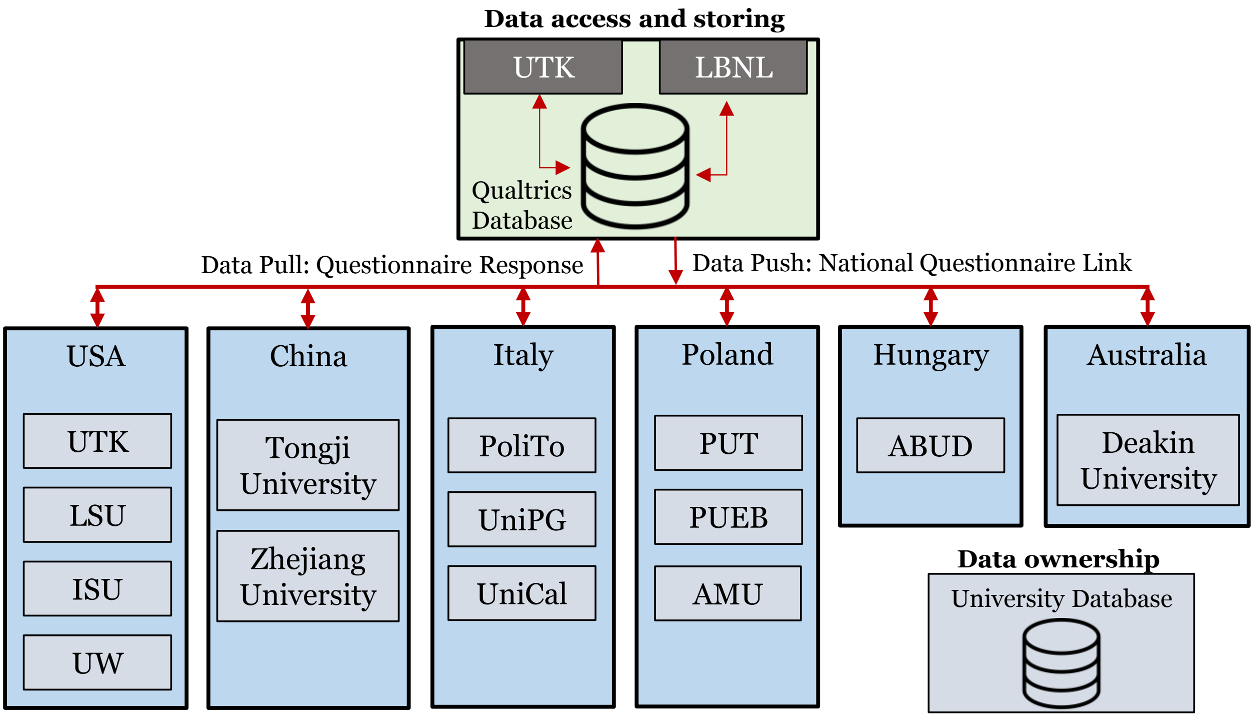

Figure 7. Data Access, Storage, and Ownership among the research participants

4. Conclusions

We proposed an interdisciplinary framework and survey based on the adoption of energy-cognitive-psychological and social theories explaining human-building interaction in buildings. The Drivers–Needs–Actions–Systems framework is chosen for rationalizing motivations of energy-related adaptive occupant behaviors in buildings. The Social Cognitive Theory from Bandura is selected as a general theory explaining cognitive processes of human behavior in social contexts. Following these two theories, the survey attempts to (1) improve understanding of occupants' environmental, cognitive and behavioral motivational drivers leading occupants to interact with the control systems in socially dynamic environments such as office settings. Additionally, based on the elements of the Theory of Planned Behavior from Ajzen, efforts are dedicated to investigate how (2) subjective norms, as well as group negotiation and workspace dynamics influence the group interaction with control systems – such as opening/closing windows, blinds and shades, adjusting thermostats and artificial lights, and how (3) adaptive control behavior (order of actions) is influenced by perceived behavioral control, and correlated to (4) perceived comfort, satisfaction and productivity.

This interdisciplinary framework and survey aim to overcome key barriers of state-of-the-art by uncovering innovative knowledge on the human-building interaction and occupant comfort theories. Authors foresee a new era of "motivational" comfort, where individual's motivational drivers, together with societal norms and group interaction, mediated by interdisciplinary knowledge borrowed from social sciences (for behavioral changes) will bridge the gap of technical potential versus actual operational performance of commercial buildings. By unlocking the innovative knowledge, this survey aims to provide insights into less stringent centralized comfort requirements, allowing reduced energy consumption and increased satisfaction and hence productivity, both resulting in reduced operational costs for building owners.

This study defines an ex-ante discipline setting in a step-by-step framework for data sampling, collection, storing, handling and analysis. To ensure validity, robustness, and efficiency of the study, the study establishes a research protocol which has international replicability potential. Some of the benefits of this approach can be summarized as follows:

- Providing a framework that defines a neutral/concerted interdisciplinary objective of the research.
- Helping to refine the design questionnaire, by mapping the outcome of interest, making sure each of the survey questions is addressing variables to be investigated.
- Facilitating the analysis phase, that would become faster and quicker, by defining a "roadmap" to connect measured outcomes to research questions.

Further advances in research need to be fostered towards the development of effective, informative resources to educate a broad spectrum of stakeholders in an interdisciplinary arena, including building occupants, designers, energy modelers, social scientists and policymakers.