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Abstract
It is well established that occupant-building interactions impact both (1) building energy performance and (2) occupant satisfaction with indoor environmental quality. As part of an international research collaboration (the International Energy Agency, Energy in Buildings and Communities Programme, Annex 79 *Occupant-Centric Building Design and Operation*), an international survey investigated how occupants are currently considered in the building design process and how occupant-related information is communicated in this process, seen from the viewpoint of architects, HVAC designers, and other building professionals. This paper gives insights on the use of occupant-related information within guidelines and in building performance simulation. Results show the need to make occupant-related information integrated part of the building design process. Guidelines are a relevant source of information in this process and can positively contribute to close the research – practitioner gap regarding the application of more complex occupant behaviour models in building simulation.

Keywords occupant-centric building design, building performance simulation, guidelines, building operation, building professional

1.0 Introduction
Many publications highlight that occupant behaviour is one of the main factors contributing to the energy performance gap of buildings, next to the factors related to uncertainties of climate representation and properties of building elements (e.g. Hoes et al., 2009; O'Brien et al., 2020a). However, a review by Mahdavi et al. (2021) showed limited scientific evidence for the role of occupants as significant contributors to the energy performance gap, indicating the need for more research. Yet, scientific evidence shows that energy use in offices and homes with the same architectural layout at similar climatic conditions may vary largely from the estimated one due to the stochastic interaction of occupants with building elements (Bahi and James, 2007; Hong and Lin, 2013). The way spaces are used in daily occupancy practice compared to widespread calculation and simulation assumptions, how much control occupants are given, and how much control they perceive, may contribute to this performance gap (Hellwig, 2019, He et al. 2021, Yang et al. 2022).

Occupant-centric control and operation of buildings represent an approach to building management which integrates sensing of indoor environmental quality, occupant presence, and occupant-building interactions to optimise both operational efficiency and occupant comfort (Nagy et al. 2023). Therefore, better accounting for the way people interact with their buildings should be implemented already in the buildings' design stage. Ongoing practice in this part of the design process was investigated by O'Brien et al. (2017). One conclusion was that there is limited time and knowledge for a deeper analysis of occupants' impact, however, the design community is interested in developing their workflows. In actual design practice, indications and recommendations from building energy codes, regulations, standards, and guidelines are used as references - in part to avoid liability of deviating from norms. Bleil de Souza et al. (2023) describe types of occupant-related information used in practice comprising: mandatory (e.g. building regulations, codes, legislation), normative (e.g. standards, guidelines, handbooks), business-oriented (e.g. client), and lessons-learned (e.g. client, practitioner, occupant consultation). A review of occupant-related considerations in energy codes and standards of 23 countries by O'Brien et al. (2020) highlighted that occupant-related assumptions or considerations are typically rather simple and typically based on static schedules of occupants' presence, their interaction with building controls, and their use of appliances. However, such a schedule-based approach may not be adequate for accounting for occupant behaviour (Jia et al., 2017) and may lead to an oversimplification of human-building interaction, contributing to discrepancies between predicted and real energy use of the building (Yan et al., 2015).

As a part of the research initiated by the international collaboration within the IEA EBC Annex 79 - *Occupant-centric building design and operation* (O'Brien et al., 2020b), an international survey on *'Occupants in building design and operation'* was conducted. The survey was developed by a group of around 30 academic researchers, and was distributed internationally among architects, engineers, HVAC designers, and facility managers involved in building design and/or operation. The goal was to collect information about (1) how occupants are considered during the building design process, (2) which user-related information is available, and (3) where this information originates from and (4) how it is processed in building performance simulation. This paper focuses on the use of guidelines and simulation regarding occupant-related information.

2.0 Material and Methods

An online survey among practitioners in different countries was conducted, which consisted of three parts: Part one collected background information on the respondents' role (questions 1-6), part two focussed on the integration of occupant information in the planning process (questions 7-25), and a third part on the use of simulation tools and occupant models (questions 26-33). Appendix 1 shows the selection of questions we are referring to in this paper, which included multiple-answer questions, such as professional role and field of expertise.

The survey was translated into 12 languages and distributed through the online platform LimeSurvey (2016). The link to the online survey was shared with professional groups, including chartered institutions, for example, CIBSE/Energy Performance group, the Royal Institute of British Architects, the Turkish Chamber of Civil Engineers, the German Facility Management Association, as well as planning and consultancy companies in different countries. A convenience sampling strategy was employed, so that the sample is not representative of all professional groups and countries.

A total of 888 responses were collected between May 2021 and April 2022. All data preparation and analyses were conducted using the R software environment (R Development Core Team, 2023). The data cleaning criteria included the removal of test responses, incomplete data, and surveys with unusually short response times. Incomplete responses, defined as those failing to provide information in the second section of the survey entitled "Occupant Information Integration" (n = 416), were excluded from the dataset. Finally, data from questionnaires with a response time related to the second section less than the median (median = 340 sec, interquartile range = 376 sec) were also eliminated (n = 71). Once the dataset was cleaned, a final sample of n = 349 was further processed to derive the results presented in the following sections.

3.0 Results

General information on professionals, projects, companies

The respondents (n = 330) described their current professional role as architects (36%), followed by people with a multidisciplinary role (22%), HVAC designers/consultants (14%), building engineers (9%), simulation experts (4%), electrical engineers (3%), facility management or building operators (2%), and building information modelling (BIM) experts (1%). Regarding their expertise, 40% described themselves as having multidisciplinary expertise, followed by architecture (28%), HVAC design (10%), building physics and energy efficiency (3%), structural building engineering (7%), and BIM (1%).

In the survey, a about half of respondents indicated they work in small firms with 1 to 9 employees (n = 117) or 10 to 49 employees (n = 84). There were 31 respondents from companies with more than 1000 employees. The group of respondents with multidisciplinary roles in the company was similarly represented among small companies with 1 to 49 employees (65%) compared to the overall sample (66%).

Typically, respondents' companies were involved in a variety of project types (n = 245, 70%). Only a small number of the respondents' companies seemed to be specialised in only one project type, for example, architectural design (named by 24 respondents). Figure 1 shows how often each project category was mentioned. New buildings (n = 229), building retrofit (n = 206), and architectural design (n = 156) were the three categories most often mentioned. About 62% of respondents' companies were involved in 1 to 15 projects per year, 14% in 16 to 25 projects and 24% in more than 26 projects per year.

Results indicate that simulation services (n = 66) are offered by very small companies with 1 to 9 employees (32%) and small companies with 10 to 49 employees (25%), which represents – contrary to our expectations - a similar distribution to the total sample. Simulation services were offered by companies that employ professionals describing themselves as multidisciplinary experts (34%), simulation experts (15%), HVAC designer/consultants (15%), architects (8%), and building engineers (7%). Multidisciplinary experts and simulation experts have a disproportionately high representation compared to the total sample. Professionals with a role in facility management or as electrical engineers did not report that their company would get involved in simulations.

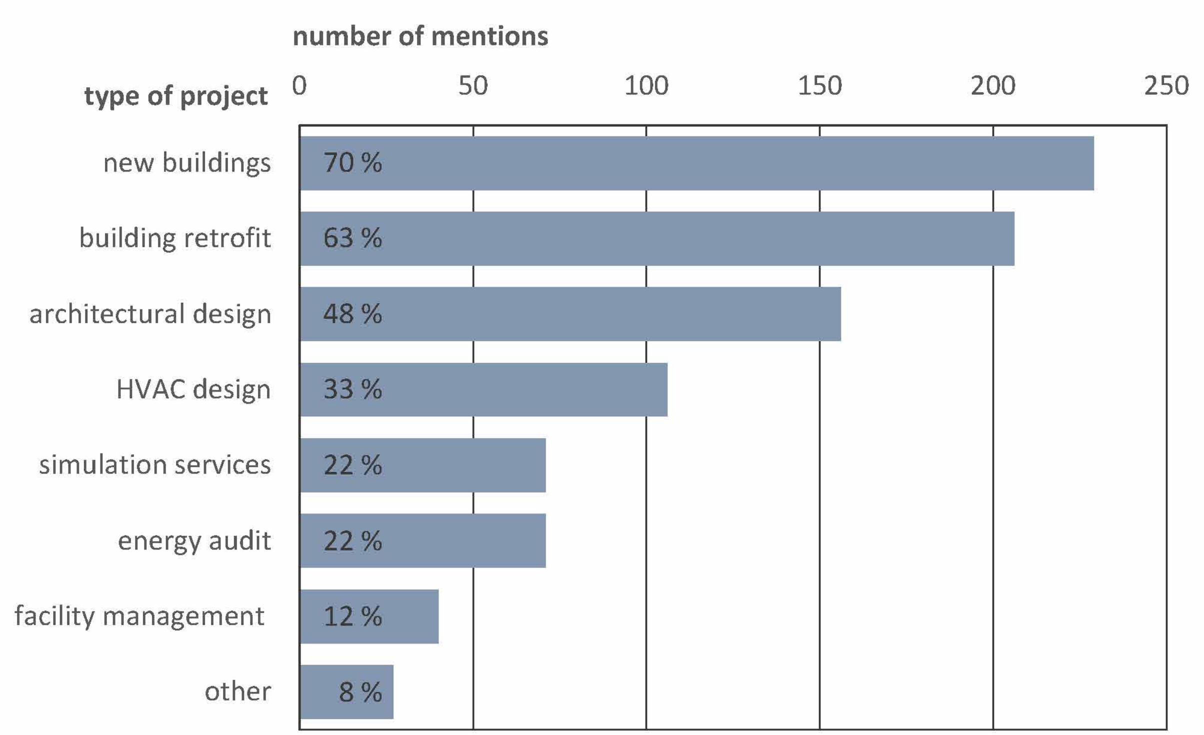

Figure 1 – Count and percentage of typical projects the respondent's company is involved in (respondents: n = 325, multiple-choice, mentions: n = 906)

The projects the respondents have been involved in are predominately located in Europe (n = 204), followed by Asia (n = 51), the Americas (n = 45), and Africa (n = 2). Whereas respondents from companies working in Asia (n = 51) predominately reported company sizes of more than 1000 employees, the opposite trend was identified for companies working in Europe, with most companies having less than 1000 employees. However, as mentioned before, the sample may not be representative; therefore, this result should be considered with caution. Furthermore, no major differences were found in the representation of projects having new buildings versus retrofits in focus among the different project locations on the continents.

Information on occupants in projects

Almost one-quarter of the respondents indicated that they would *'always'*, and a further 40% that they would *'usually'* receive some information about the future occupants from the client or the project manager. Only 3% indicated that they '*never*', and 22% indicated that they '*seldom'* receive occupant-related information. Table 1 shows what types of detailed information about future occupants the respondents typically receive from the client or the project manager. Hereby, *'occupancy profiles/schedules'* are defined as hourly percentage values with respect to the full occupancy determined by the occupant density of the space. '*Room functionalities/ activities/tasks*' are typical room usages for different building types; for example the building type "office building" includes room functionalities such as single office, open space office, meeting room, etc. The features of each room's functionality imply, among others, typical occupancy profiles, hot water usage profiles and lighting requirements.

Category	**Responses**	
	Mentions	**Share (%)**
Number of occupants	268	83
Room functionalities/activities/tasks	265	82
Occupancy profiles/ schedules	131	41
Temperature preferences	117	36
Information about occupants' habits, personalities attitudes, values, or motivations	79	25
Occupants' demographics (gender, age, education)	65	20
None	8	2
Other	0	0

Table 1 – Absolute and relative responses to the question: 'When you receive a project from a client or a project manager for building design, retrofit, or operation, what types of detailed information about the future occupants does it typically include?' (Multiple choices, n = 933 mentions, 322 people replied - 92% of the sample)

When asked whether they would receive information on the indoor environmental quality, 46% of the respondents mentioned requirements on the thermal and 41% on the visual environment, 30% mentioned indoor air quality, but only 3% mentioned acoustics (multiple answers possible). However, 50% stated that they would not receive specific requirements and 7% reported they would not receive requirements at all.

Such occupant-related information is obtained from different documents: '*contract*', '*design brief*', '*references to building regulation or codes*', '*references to standards*', or '*references to guidelines*', which were the specific response options for this question. Some types of occupant-related information were considered '*not applicable'* to some respondents' work, i.e. *'occupant's demographics (gender, age, education)'* was considered '*not applicable'* to about half of the respondents. On the question in which documents they normally would receive occupant-related information, about half of the respondents replies that is '*not applicable'* to their work.

About one-quarter of the respondents reported that '*occupancy profiles/schedule'*, '*occupant requirements regarding indoor air*, *acoustics*, *visual* and *thermal indoor environment'* is not applicable to them. However, regarding '*number of occupants'* and '*room functionalities/activities/tasks',* only 4% of the respondents reported that this would not be applicable to them, meaning it would be the type of information used by most of them.

For those who indicated they receive occupant-related information in documents, the '*design brief'* played the most important role for '*number of occupants'* and '*room* *functionalities/activities/ tasks*', both mentioned by about two-thirds of the respondents. '*Guidelines*' appear to play a similar role as '*standards'* and '*regulations and codes*'. Table 2 shows how many respondents reported receiving specific types of occupant-related information from '*guidelines'*.

A total of 205 respondents (59% of the sample) said that they would consult '*guidelines'* (e.g. CIBSE Guidelines (UK and international), VDI Guidelines (Germany), ASHRAE Guidelines (US and international)) besides codes and standards for occupant-related assumptions in the design phase. To understand '*Who are the professionals who use guidelines?*', reported guideline use was correlated to the respondents' professional role. A similar distribution of professional roles as in the overall sample was found, indicating that none of the groups was disproportionately represented.

Category (number of respondents who regard the category as applicable to them)	**Responses**	
	Mentions	**Share (%)**
Occupant requirements and preferences regarding the indoor air (responses n = 220)	85	39
Occupant requirements and preferences regarding the thermal indoor environment (responses n = 247)	93	38
Occupant requirements and preferences regarding the visual indoor environment (responses n = 232)	85	37
Occupant requirements and preferences regarding the acoustic quality (responses n = 227)	84	37
Number of occupants (responses n = 307)	86	28
Room functionalities/activities/tasks (responses n = 298)	76	26
Occupancy profiles/ schedules (responses n = 216)	52	24
Occupants' demographics (gender, age, education) (responses n = 147)	28	19

Table 2 – Which occupant-related information do you receive from guidelines? (Multiple choices, n = 589 mentions)

Simulation tools and occupant models

Building performance simulation (BPS) uses physics-based software to calculate potential design impacts such as annual energy use and to project conditions of the indoor environment, such as thermal and visual comfort. Building performance simulation comprises building energy simulation or indoor environmental quality assessment including passive solar gains, shading, daylight, glare, thermal comfort, and natural ventilation analysis, to name some examples.

Simulation as a tool to investigate indoor environmental quality is used by 64% of the 301 respondents who answered this question. 36% of the respondents are not using simulation. 48 respondents did not reply to this question (14% of 349). In the latter two groups, professionals describing their role as architects were highly represented (44% and 47%, respectively, compared to 36% in the overall sample). In the group not using simulation, those describing their role as multidisciplinary have a lower representation (14%) compared to the overall sample (22%).

Some respondents indicated that they would use building performance simulation exclusively to evaluate one of the following domains: the thermal environment (28%), visual environment (15%), and acoustics (1%). Furthermore, 55% reported they would evaluate several domains of the indoor environment with building performance simulation. Results show that when indoor air quality is evaluated by simulation, the thermal environment is also simulated (but not vice versa). The most frequently mentioned combination is that of visual and thermal environments (19%), followed by indoor air quality and thermal environments (8%) and the latter additionally combined with visual environment (9%).

Table 3 shows the number of tools reported for each indoor environmental domain examined herein. Overall, 332 entries were counted for the specific domains. The table also lists the most frequently mentioned tools for the domains. The list shows mainly internationally known tools and few tools known only in some of the participating countries.

	Acoustics	**Air quality**	**Visual**	**Thermal**
Number of tools	19	45	115	153
Most frequently mentioned tools	CadnaA (2)	EnergyPlus (4) TRNSYS (4) IES-VE (3) ANSYS (3) CFD (3)	Dialux (29) Radiance (8) Sketchup (7)	EnergyPlus (21) DesignBuilder (12) TRNSYS (8) IES-VE (7) TerMus Plus (6) Winwatt (5) ANSYS (3) CFD (3)

Table 3 – Building performance simulation tools for the evaluation of the four indoor environment domains: number of tools reported in each domain and most frequently mentioned tools (absolute numbers in brackets).

Occupant behaviour models are used to represent the presence or occupants' actions that have an impact on building energy consumption and indoor environmental quality. Such models comprise simple assumptions such as: i) constant values (e.g. fixed manually set point temperature or the assumption that lights are always switched on); ii) simple schedules, most often rule-based, that vary by building type (e.g. occupancy profiles based on office working hours). More complex models are iii) data-driven models, which are black-box models derived from relating input and output data. Such models often rely on probabilistic, stochastic or machine learning approaches (Carlucci et al. 2020). Finally, to be mentioned even iv) more complex analytical models that are numerical models representing physical phenomena, e.g. detailed numerical thermal comfort models.

142 respondents (equalling 69% of all who replied to this question) reported they would use occupant behaviour models. About half of them reported they would use *'mostly behaviour models from standards'*, 17% use *'mostly tailor-made behaviour models'*, and 35% used a mix of both. Figure 2 shows the reported use of occupant behaviour models by professional role. Though overall only 17% of the respondents answered they would use '*mostly tailor-made behaviour models'* the relative proportion of architects in these group is almost double as high compared to the other response categories. the relative share of the multi-disciplinary group among those using a mix of behaviour models is also higher than in the other two response categories.

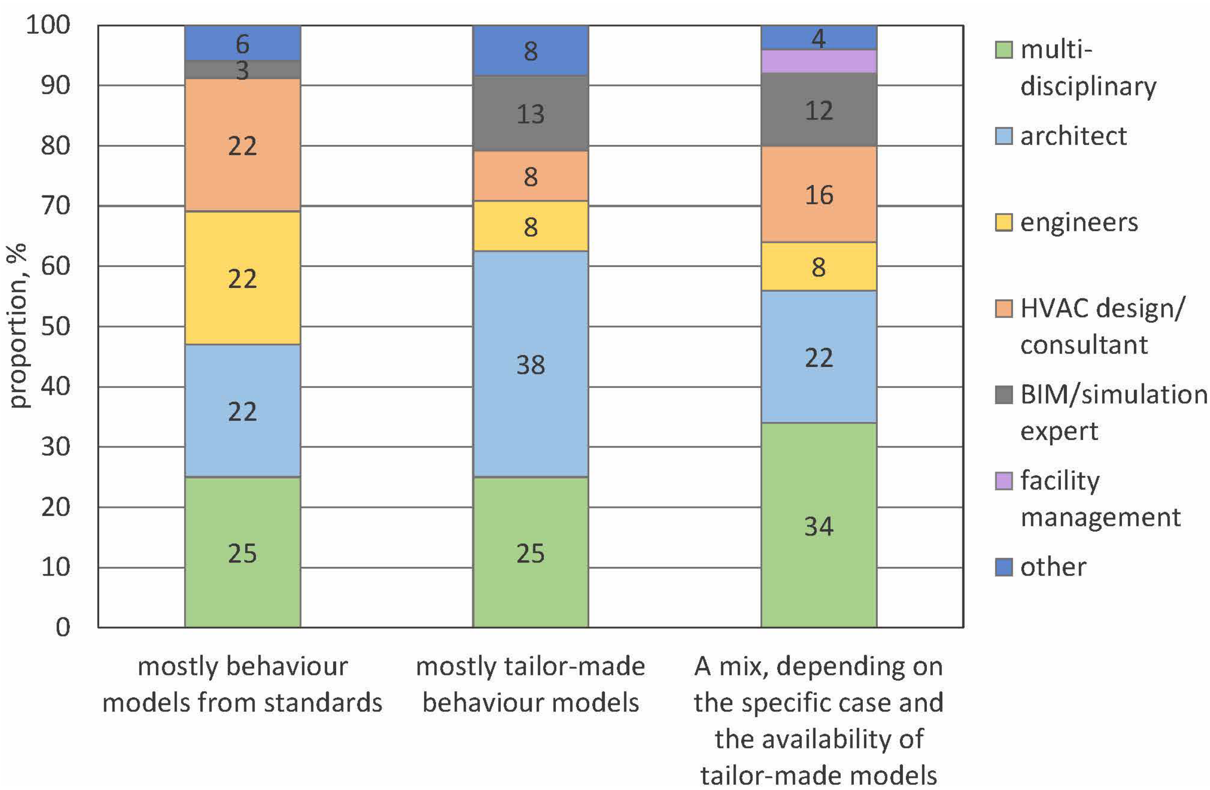

Figure 2 – Percentage of professionals using types of occupant behaviour models in building performance simulation (overall: n = 142, *'mostly behaviour models from standards'*: n = 68, *'mostly tailor-made behaviour models'*: n = 24, *'a mix, depending on the specific case and the availability of tailor-made models'*: n = 50)

The complexity of the occupant behaviour models used by practitioners varies, but overall about one-thirds of the professionals said they use constant values, as well as about one-thirds use simple schedules. Not even one tenth reported they use data-driven models, and another tenth use more complex analytical models. Almost half of the overall 178 respondents reported they would use more than one type of occupant behaviour models. For assumptions on simple occupant behaviour models like constant values or schedules *'guidelines'* are used by 53% of all respondents who answered this question (n = 139).

4.0 Conclusions

The main findings from this survey can be summarised as follows:

- Two-thirds of the respondents said they receive occupant-related information in the design phase.
- About eighty percent of the respondents said they receive occupant-related information on the '*number of occupants*' and the '*room functionalities/activities/tasks*'.
- More than half of the respondents said they do not receive specific requirements on the targeted indoor environmental quality.
- Occupant-related assumptions are received from multiple sources, among them '*guidelines*', which are important sources of occupant-related information for almost two-thirds of the respondents.
- Simulation plays an important role in the design of buildings with regard to indoor environmental quality for almost two-thirds of the respondents.
- Professionals describing themselves as multidisciplinary experts or '*simulation experts*' were disproportionately represented in the study sample when it comes to simulation services. However, other professional groups involved in the building design are also well-represented when it comes to simulation service.
- More than half of the respondents who carry out simulations use tools to simulate multiple domains of the indoor environment. A wide variety of tools were listed by respondents. The tools' capability for including more complex occupant behaviour models was not investigated in this study.
- The occupant behaviour models applied are predominately simple schedules or constant values. More complex occupant behaviour models were rarely reported as being used by respondents.
- Possible international variations/differences will be investigated in a later stage.

The survey results show the need to make occupant-related information an integrated part of the building design process. Providing more detailed occupant-related information to the building professionals would certainly have the potential to improve the quality of simulation results.

Guidelines are a relevant source of information for building professionals. Therefore, guidelines may have the potential to positively contribute to filling the research–practitioner gap regarding the application of more complex occupant behaviour models in building performance simulation.

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Appendix 1 – Selection of survey questions used in this paper.

Part	Nb.	Question
1	Q1	**What is (are) your current professional role(s) in building design and/or operation?** Multiple choice: Architect - Building Engineer - HVAC Consultant - HVAC design - Simulation expert - Facility management/ building operator - BIM expert - Electrical Engineer – Other:
	Q2	**What is your field of expertise?** Multiple Choice: Architecture - Structural/Building Engineering - Building Physics/ Energy Efficiency in Buildings - HVAC design – BIM - Simulation Science/Computational methods - Fire protection - Electrical/Automation Engineering - Other:
	Q3	**What is the approximate total number of employees in your company?** Single Choice: 1-9, 10-49, 50-99, 100-249, 250-499, 500-999, more than 1000
	Q4	**What is(are) the type(s) of typical projects your company is involved in?** Multiple Choice: New buildings, Building retrofit, Architectural design, HVAC design, Facility management (HVAC operation), Simulation services, Energy audit, Other:
	Q5	**Approximately how many projects related to buildings does your team typically deliver on a yearly basis?** Single choice: 1-5, 6-15, 16-25, 26+
	Q6	**Where are the projects you referred to in the previous question mostly located?** Single Choice: fine-grained subcategories of Africa, Americas, Asia, Europe and Oceania
2	Q7	**How often do you receive some information about the future occupants from a client or a project manager for building designs, retrofits, or operations?** Single choice, Always – Usually - About half the time – Seldom - Never
	Q8	**When you receive a project from a client or a project manager for building design, retrofit, or operation, what types of detailed information about the future occupants does it typically include?** Multiple choice: Number of occupants, Occupants' demographics (gender, age, education), Occupancy profiles/ schedules, Room functionalities/activities/tasks, Temperature preferences, Information about occupants' habits, personalities, attitudes, values, or motivations, None, Other:
	Q9	**When you receive a project from a client or a project manager, does the project description involve any of the following requirements regarding indoor environmental quality?** Multiple choice: Thermal (e.g., air temperature, air relative humidity, air velocity), Visual (e.g., daylight and electrical lighting), Acoustics (e.g., noise), Air quality (e.g., CO2 concentration level, air volume flow), The client does not provide specific requirements, other than to follow the Standards and/or Guidelines, None
	Q10	**In which documents do you usually receive the occupant-related information?** Multiple Choice Matrice combining type of occupant information and document type.
	Q16	**Besides codes and standards, which sources of information do you consult for your occupant-related assumptions (their number, demographics, occupancy profiles, etc.) in *building design*?** Multiple Choice: Guidelines, Literature, Design brief, Fulfilment of certification, requirements, Not applicable, Other:
	Q17	**Besides codes and standards, which sources of information do you consult for your occupants- related assumptions (their number, demographics, occupancy profiles, etc.) in *building operation*?** Multiple Choice: Guidelines, Literature, Design brief, Fulfilment of certification, requirements, Not applicable, Other:
	Q23	**Which of the following indoor environmental parameters do you evaluate using building performance simulation tools?** Multiple Choice. Thermal (e.g., temperature), Visual (e.g., daylight and electrical lighting), Acoustics (e.g., noise), Air quality (e.g., CO2 concentration), We are not using any simulation tools, Other:
	Q24	**If you use building performance simulation tools, please specify which tools: Please choose all that apply and provide a comment**: Thermal: comment, Visual: comment, Acoustics: comment, Air quality: comment, Other: comment, Not applicable: comment
	Q25	**Do you use standard or tailor-made occupant behaviour models in building performance simulation tools to represent people's presence and behaviour in buildings?** Single choice: Mostly behaviour models from standards, Mostly tailor-made behaviour models, A mix, depending on the specific case and the availability of tailor-made models, Not applicable
3	Q26	**Which of the following terms can be used to describe the occupant behaviour components you use in building performance simulation?** Multiple Choice: Constant values (e.g. fixed manually set temperature), Simple schedules (e.g. occupancy profiles w.r.t. the working hours), Data-driven models (e.g. probabilistic, stochastic or machine learning models), More complex analytical models (e.g. numerical thermal comfort models), Other: Not applicable
	Q27	**Besides codes and standards, which information sources do you consult for these assumptions related to occupant behaviour components in building performance simulation (constant values and simple schedules)?** Multiple Choice: Guidelines, Literature, Not applicable, Other: