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USING HUMAN FACTORS TO ESTABLISH OCCUPANT TASK LISTS FOR OFFICE BUILDING SIMULATIONS

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The purpose of this research is to establish an in-depth understanding of task-related occupant behaviors to serve as the basis for the design of an occupant-building interaction interface. Building simulations are frequently used to design buildings and predict energy performance. Yet, all of these assumptions are related to occupant behavior and interactions with the building. In an occupant-controlled environment, an understanding of the occupant decision-making process must be represented in the simulation task lists. Current task lists assume general occupant behaviors based on averages, and lack the details required for this understanding. This paper looks to strike a balance between simplicity and complexity in the generation of task lists to establish a process for developing an understanding of occupant behavior at a greater level of detail than current practice. A contextual task analysis questionnaire characterizes occupant behavior to provide the link between the building, occupant, and task. Generation of a sample task list demonstrates how a detailed understanding of task-related occupant behaviors can be effectively used as the basis of an occupant-building control scheme.

INTRODUCTION

Building simulations are frequently used to design buildings and predict building energy performance by accounting for heat gains and energy usage (e.g. from equipment and lights). All of these assumptions are related to occupant behavior and their interactions with the building making an accurate representation of occupant behavior a prerequisite for predicting building energy performance and designing occupant-building interactions.

Occupant-building interactions are represented in traditional building simulations as schedules. Schedules are intended to provide a reasonable estimate of control-oriented occupant behavior. Schedules represent occupant behavior as a set of static events that occur regardless of environmental influences (Klein et al., 2012). For instance, lighting schedules determine when lights are on or off and equipment schedules determine when equipment is in use or not. In reality, due to the stochastic nature of occupant behavior, system operation takes on the stochastic behavior than previously represented. Further, the schedules are driven from a system-based viewpoint (e.g. lights need to be on from 8:00 AM to 5:00 PM) rather than from an occupant-based viewpoint (e.g. I need light to see when I am working). This creates a disconnect between the system and the occupant (i.e. the one who controls the system). Therefore, simulation requires a more realistic representation of occupants that links occupant behavior to system interaction.

The purpose of this research is to establish an in-depth understanding of task-related occupant behaviors to serve as the basis for the design of an occupant-building interaction interface. In an occupant controlled environment, information about what an occupant is doing is needed to derive what, when, why, and how an occupant may take action to change their environment. This knowledge is needed to examine the occupant behavior impact on building energy and future occupant behavior (An, 2012; Hoes, Hensen, Loomans, de Vries, & Bourgeois, 2009).

Agent-based modelling (ABM) has been particularly successful in representing occupants in building simulation (Langevin, Wen, & Gurian, 2015). ABM is a computer simulation technique that replicates the unique decision-making behavior of individual occupants, and their interactions with the environment and other occupants. The ABM then shows how the overall, complex building behavior emerges as a result of those individual occupant behaviors (Axtell et al., 2002). In commercial office buildings, tasks define occupant behavior. *Individual tasks* define what an occupant is doing and where an occupant is performing the task. A *task list* defines when and for how long an occupant is performing a task. Together, these can derive what action an occupant might do to change their environment so their task is properly supported. Therefore, tasks are used define occupant behavior in an ABM.

The most basic ABMs define “tasks” as the occupant being present or absent (Page, Robinson, Morel, & Scartezzini, 2008; Wang, Federspiel, & Rubinstein, 2005). The “task list” says when the occupant is performing those tasks (i.e. being present or absent) and for how long. While these provide realistic patterns of occupancy, they lack the required understanding of how and what environmental influences could impact occupant behavior. Goldstein, Tessier, and Khan (2010) improves on the definition of task using words such as work, meet, and eat that describe what the occupant is doing. However, the general category of “work” is used to describe any work the occupant does in their workspace. This lacks the specificity to distinguish between different types of work that have different environmental requirements.

Zimmerman (2007) and Tabak (2008) define “work” into planned and unplanned tasks that provide a more detailed understanding of what occupants are doing. Planned tasks are pre-determined activities while unplanned tasks are randomly generated during simulation. Planned and unplanned tasks can be primary or secondary tasks. Primary tasks are the main activities occupants are doing, and are broken into sub-tasks. For instance, presentation includes attend a presentation and give a presentation. While breaking down primary tasks into

sub-tasks provides a detailed understanding of what the occupants are doing, the process overly complicates ABM processes by requiring the ABM to identify a sufficient number of available participants to perform each role for the task and calculate if there are enough for the task to occur. The authors also use secondary (Zimmerman, 2007) or intermediate tasks (Tabak, 2008) to account for occupant social and psychological needs, such as get a drink or walk to printer. While secondary tasks compliment primary tasks, secondary tasks are generated separately from primary tasks. As a result, it is possible the secondary task may not be directly associated with the primary task. Further, secondary tasks require two different algorithms to generate increasing computer computational resources.

This paper looks to balance between simplicity and complexity in task lists to establish a realistic representation of occupant behaviors for building simulation (e.g. ABM). This research creates a daily task list that defines occupant behavior in terms of tasks performed, rather than as simply being present or absent, to provide the information needed to design occupant-building interactions. This research contributes to an increased fidelity of occupant actions to define when and how occupants interact with the building (e.g. what environment is the occupant trying to achieve for optimal task performance) so 1) building systems can be properly selected and designed to support tasks, and 2) a more realistic building system operation, as controlled by the occupants, is generated to better predict building energy demand.

This work is outlined in three sections. The next section of this paper describes the collection of task-specific data. A contextual task analysis (CTA) questionnaire, designed to address the gaps between task performance and occupant behavior, identified tasks occupants perform in a commercial office building, task requirements (e.g. furniture, equipment, and environment), and task performance characteristics (e.g. workload demand, frequency task performed, and for how long). The questionnaire data are analyzed to define task categories and task list types. Task categories define the specific task an occupant is performing at a specific time during a workday. Task list types define the entire workday by delineating when a task category is performed and for how long. The subsequent section describes the resulting task categories and task list types prior to describing the task list generation process. The final section discusses an example application for how the task list will be used to design occupant-building interactions before concluding with future work.

METHODS

Participants

CTA responses were from 37 participants (22 male and 15 female) aged 22 to 56 with a mean age of 34 years. Participants were from three different businesses located in five buildings. All participants were volunteers. Inclusion criteria for participation were that the occupant works in a typical commercial office setting and performs at least 50% of tasks in their workspace. Typical office setting is defined as business group B of the International Building Code where the use of a building is for professional or office-type services (IBC, 2011).

Survey and Procedure

The primary task consisted of a CTA questionnaire, which explored the occupant's perspective on behavior, comfort, health, productivity, and the physical characteristics of their workspace in relation to their tasks. The questionnaire included 24 questions, along with demographic questions, developed from a variety of well-known measurement instruments for building performance and post-occupancy evaluation (IBPE Consortium, 1995; Ornstein, de Andrade, & Coelho Leite, 2005; Vos & Dewulf, 1999). Follow-up interviews were used to clarify any of the questionnaire responses, and to allow the occupant to demonstrate and expand on any comments.

The questionnaire took no longer than 30 minutes to complete, and it was conducted in the participant's workspace. In the questionnaire, participants were asked to list, in order, each task they perform in a typical workday, and include at what time the tasks began, ended, and where the task was performed. If a task was performed in more than one location, they were asked to separate it into two tasks. For example, a meeting occurred in their workspace from 9:00 AM to 9:30 AM, and a meeting occurred in the conference room from 9:30 AM to 10:30 AM. Tasks that occurred sporadically throughout the day were to be indicated with a star, such as phone calls or checking email. Next, from this typical daily task list, participants were asked to identify five tasks that were the most critical, frequently performed, and important to their job.

Data Analysis

Task categories. The five tasks, from each participant, were listed along with a short description of the task process and required furniture and equipment. Based on these tasks and corresponding descriptions, similar tasks were grouped into task categories. These task categories are what make up and define a task list. While not detailed in this paper, task category descriptions contain information about the task's environmental parameters (e.g. optimal light levels), workload demand (i.e. visual, auditory, cognitive, and psychomotor demands), number of occupants, and workspace location. Starred activities were also categorized, but were distinguished with each category, as applicable, as "irregular" tasks because they are more spontaneous in nature and induce a certain prioritization factor on the occupant to which they must attend.

Task list constraints and modifiers. Prior to forming the task lists, 33 task lists were broken down into 15-minute time slots to be examined for constraints and modifiers. (Four participants did not complete the task list portion of the questionnaire.) Constraints are the workday start time, end time, and fixed tasks (i.e. lunch and breaks). Modifiers are occupant specific activities, such as the need for a smoke break. Constraints and modifiers were examined for general trends in duration and frequency of occurrence.

Task list types. The tasks occupying the remaining time slots in each individual participant's task list were assigned into one of the task categories. Across all task lists, each task category was examined for its frequency distribution across the time slots and the number of consecutive times slots the task category occurred (duration). The frequency distribution was

used to identify the time of day a task category would occur. Duration was used to determine the average time spent on each task category each time it occurred, and represented as a percentage of the workday spent on the task category. All participants that performed the same task categories, with similar percentages of time spent on each task category, were grouped to form task list types. Each task list type contains a specific set of task categories the occupant performs, and the percentage ranges of working time spent on each task category, calculated using standard deviation.

Generating daily task lists. Using constraints, modifiers, and task list type, daily task lists can be generated using the process shown in Figure 1. First, start and end times are determined to define the workday. Second, lunch and any other breaks are established. Finally, the percentage of task occurrence for a task list type is used to distribute the task categories throughout the remaining time-slots in the workday to create the occupant's specific daily task list. Irregular tasks are included in the task list prior to the start of the day even though they are considered random to reduce simulation complexity while still maintaining the stochastic nature of an occupant's workday.

Figure 1. Daily task list generation process. Task list constraints and modifiers define the workday and periods of break while task list type defines the percentage of time spent on task categories to generate an occupant's daily task list.

RESULTS

Task Categories

Six task categories were identified: search, analyze, create, process, manage, and meeting.

Search for information includes accessing databases, using reference manuals and books, browsing to find information, and general research. These tasks occur at a secondary work surface (e.g. desk return or side desk) in the occupant's workspace. They have high motor actions, but a low cognitive demand.

Analyze information includes organizing, summarizing, interpreting, and synthesizing information, such as when editing documents, proofreading, testing code, preparing agendas, or making recommendations. These tasks occur at the primary work surface in the workspace, and require high cognitive demand to maintain a continuous train of thought in order to establish new facts and reach new conclusions.

Create information includes creating presentations, writing reports, and general work activities, such as completing work order requests. These tasks occur at the primary work surface in the workspace, and could be interrupted without necessarily having a significant impact on overall task performance.

Process information require an electronic device (e.g. computer) to perform the task, and include the maintaining electronic databases, keyboarding, data entry, and managing work order requests. Process includes both the irregular and regular task of email, and occur in the workspace.

Manage information is the act of arranging physical objects in the proper order for easy retrieval or transmittal. Manage includes the physical act of handling incoming/outgoing communications (e.g. shipping), filing documents in a cabinet, and photocopying. Small electronic devices (e.g. label printer and postage meter) may be required. Manage is mostly performed in the workspace, but also requires the occupant to leave temporarily to access other objects and equipment.

Meeting includes three sub-task groups of team, small meeting, and large meeting. Team meeting is a group meeting with fewer than five occupants that takes place within (e.g. at a table in a private offices) or near an individual's workspace (e.g. at a shared table immediately adjacent to the individual's cubicle). The team meeting is a discussion-style meeting where there is no designated speaker, and typically includes visual devices such as a television or white board in which occupants are gathered around for collaboration. Small meeting is similar to the team meeting. However, in the small meeting, the team size consists of five to ten occupants and takes place in a small conference room. The equipment requirements involve a projector and screen. Both the team and small meetings can also be regular and irregular. The large meeting consists of 11 or more occupants in a large conference or assembly room. There is one designated speaker at any given time at the front of the room. The large meeting requires the use of large visual aids such as a projector and screen.

In addition to team and small irregular tasks, phone calls and question-answer (QA) sessions are irregular, and both take place in the occupant's workspace. Phone call is an audible conversation between two or more people not at the same location. Some type of technology, such as a telephone or video conferencing equipment, is required to enable the task. QA are quick one-on-one conversations, such as providing instructions to colleagues or responding to questions. No specific equipment is required, but any equipment the occupant was using with task previous task would remain "in-use".

Depending on the occupant's location (as determined by the task category), irregular tasks may occur. For example, an occupant would not be able to perform the phone call task while in a large meeting, but it is possible if the occupant is in a team meeting because the occupant is near a phone.

Task List Constraints and Modifiers

Work day start and end times, and the start times for lunch, smoke, and general break frequencies are shown in Figure 2 for each time slot. Table 1 shows the mean, maximum, and minimum durations for each break type, if taken. Participants started their workday between 7:00 AM and 9:00 AM with 67% starting between 8:00 AM and 8:30 AM. Participant ended their day between 4:00 PM and 6:30 PM with 76% ending between 4:30 PM and 5:00 PM. Lunch occurred from 11:30 AM to 1:00 PM with 60% starting their lunch break between 11:30 AM and 12:00 PM. Average duration was 35.9 minutes. One participant smoked, and took their smoke break at 2:00 PM that lasted for 15-minutes. General breaks occurred in 18% of task lists. If a break occurred, 85% of breaks were for 17.5-minutes, and occurred between 8:30 AM and 10:00 AM (to get coffee) and 2:45 PM and 3:00 PM.

Figure 2. Frequency in each time slot for start, end, and start time occurrences for lunch, smoke, and general breaks.

Table 1. Duration (minutes) of lunch, smoke, and general breaks

Break Type	Mean (SD)	Maximum	Minimum
Lunch	35.9 (22.8)	60	15
Smoke	15 (none)	15	15
General	17.5 (6.1)	30	15

Task List Types

The overall percentage of the workday spent on each task category (duration) generated five task list types shown in Table 2. The task list types are engaged, dual, flex, dual flex, and specialist. Engaged task list has mostly meetings. Dual splits time between create and meetings with some time spent on analyze and email. Flex task list distributes time across all task categories. Dual-flex splits time between create and process, but also dedicates up to 40% of the work time to other task categories. Specialist task list focuses heavily on the analyze task category with the remainder of the work time spent on meetings, email, and phone calls.

Table 2. Percentage of task category duration for each task list type.

Task	List Type	Engaged	Dual	Flex	Dual-Flex	Specialist
Search		0%	0%	15%	1-2%	0%
Analyze		0%	4-6%	0-11%	3%	73-78%
Create		4-9%	38-40%	10-14%	43-58%	0%
Process		4-13%	0%	16-7%	14-30%	0%
Manage		4-7%	0%	6-24%	0%	0%
Meeting		50-59%	45-50%	14-15%	4-10%	<5%
Email		8-12%	2-9%	12-14%	3%	15-19%
Phone		8-12%	0%	11-13%	<27%	2-3%
QA		5%	3%	1%	2%	4%

For each task list type, the frequency distribution of task categories was examined. Due to little deviation between the frequency distribution of task category occurrences across the task list types, the results in Figure 3 show the general trend of task category frequency distribution for all task list types. Frequency results show large meetings and process occur mostly right after lunch and continue through the afternoon.

Email peaks first thing in the morning while manage occurs most often at the end of the workday while. Analyze occurs first thing in the workday and at the end of the workday. Team meeting has peaks around 9:30 AM and 2:00 PM. The remaining task categories are distributed evenly throughout the workday.

Figure 3. Task category frequency as a percentage of occurrence during a time slot.

Generating Daily Task Lists

A sample task list has been generated (Table 3) to demonstrate a possible single day task list using the dual-flex task list type. The task list includes the task category and task start time (end times are assumed when the next task begins).

Table 3. Sample task list generated using the dual-flex task list type.

Time	Task Category	Time	Task Category
8:02 AM	Email	12:00 PM	Lunch
8:07 AM	Search	12:30 PM	Process
8:15 AM	Analyze	12:37 PM	Phone
8:29 AM	Phone call	12:43 PM	Process
8:59 AM	Team meeting	1:02 PM	Phone
9:47 AM	break	2:08 PM	Create
10:02 AM	Process	2:39 PM	QA
10:23 AM	QA	2:47 PM	Create
10:29 AM	Create	4:23 PM	Email
		4:34 PM	Leave

DISCUSSION

The sample task list is designed to be used in building simulations, such as agent-based and energy models, to enable a realistic representation of occupant behavior. The task list does this by defining what occupants are doing when they are “working” using task categories. Task categories contain the simulation-required information that can explain how and why occupants might interact with the building, and include number of occupants, performance location, workload demand, and environment parameters. The analyze task category performed at 8:15 AM by the occupant will be used to demonstrate how the task list and description are used in an agent-based model (Kalvelage, Dorneich, Passe, & Krejci, 2016).

The analyze task category description reveals this task is performed alone and is performed in the occupant's workspace. The workload demand is the combination of occupant processing resources in terms of visual, auditory, cognitive, and psychomotor (VACP) components. Each category of tasks place a specific workload demand on an occupant (Keller, 2002). Resources required for the analyze task category include the visually reading (V), evaluation (C), and discrete actuation (P). No auditory (A) workload demand is required by the task. These task-induced VACP values are determined when the environment is at optimal task performing conditions.

The environment parameters not only define the task's optimal environment, but are used to establish if a mismatch between the workspace and task requirements occurs. If a mismatch occurs, the type of mismatch (e.g. thermal, visual, or auditory) adds an environment-induced workload on top of the base task workload. For example, low illumination levels (perceived brightness) for the highly visual analyze task, increases the visual workload demand. Unless the occupant takes action to ameliorate the mismatch, the occupant succumbs to decreased task performance and decreased well-being due to the increased workload. On the other hand, if the occupant decides to take action, the occupant can choose from options that can eliminate the mismatch. In this case, opening the window shade or turning on a task light are available actions to increase illumination. While each action places additional workload on the occupant by disrupting the task (i.e. stopping the task to take action), this action-induced workload impacts task performance less than the environment-induced workload. Further, any action-induced workload is quickly negated by the improvement in working conditions.

Occupant actions can be guided to select the "best" action through interface design, and action-induced workload can be reduced or eliminated through various modes of input (e.g. automatic or detected). Using occupant intention to improve the task working environment provides the understanding of when and why an occupant may take action to determine what action the occupant may take.

CONCLUSION

This paper demonstrates how occupant behavior intentions can be captured in a task category and represented in a task list. The process presented goes beyond current practice by defining what occupants are doing when they are "working" using task categories. Simulations require information about what an occupant is doing to derive why and how an occupant may take action to change their environment in order to understand future occupant decisions-making and behavior as a result of previous behavior. Task categories contain the simulation-required information that can explain when, how, and why occupants might interact with the building, and include environment parameters, VACP values, and task location. This information is stored in a pre-defined database, and the specific task information is retrieve during the ABM simulation as determined by the task list. By separating task categories, task lists, and occupant roles enables the ABM to be further expanded.

The generated task lists in this paper are designed to be used in building simulation. These task lists will support future work to evaluate various building control strategies in an agent-based model coupled with a whole-building energy simulation. The overall work is aimed to develop a task-based occupant-building interface to improve occupant satisfaction, task performance, and building energy performance.

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