“NASA Ames Sustainability Base Case Study: Behavioral Effects of Net-Zero Energy Facility Developments in Workplace and Residential Environments”

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by

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Authorization to Submit Dissertation

This dissertation of Angela Vanhoozer, submitted for the degree of Doctor of Philosophy with a Major in Environmental Science and titled "NASA Ames Sustainability Base Case Study: Behavioral Effects of Net-Zero Energy Facility Developments in Workplace and Residential Environments," has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

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Abstract

This research details a three-part inter-disciplinary mixed methods case study of the occupant experience in the built environment at NASA Ames Research Center's Sustainability Base. Sustainability Base is the federal government's second net-zero energy facility and the first living test-bed for building energy research and design. Our research first described changes in occupant satisfaction after moving from traditional offices to the high performance work environment. Through post-occupancy evaluation methods, including surveys and physical instrumentation, recommendations were made to improve acoustic and lighting conditions in Sustainability Base, and to explore potential utilization of occupant feedback in external research partnerships as part of the living test-bed model. The second part of the study employed survey research methods to quantify changes in energy conservation awareness, norms, and home behaviors for occupants after two years of working in the building. Results indicated increases in awareness of workplace energy sources, workplace social conservation norms, and influences of workplace on home conservation behaviors. The third part of the study explored the influences of communication channels in Sustainability Base on the diffusion of technological innovations in the work environment and in the homes of occupants. The Diffusion of Innovations (DIT) theoretical framework was used to explore innovation characteristics of the building from the occupant perspective. Findings indicated trade-offs in relative advantages between traditional and high performance work environments, such as increased natural lighting and lack of privacy. Incompatibility in high performance building design standards, organizational infrastructure, and health and safety requirements presented operational challenges for facilities managers. Public showcasing of the building generated positive response from occupants, and adaptability of innovations to the home was indicated, particularly for residential plug load management. However, adaptability of systems in Sustainability Base to home environments was limited by cost and feasibility issues. Findings for the study contributed new methods of post-occupancy evaluation to the architectural field, established behavioral connections between workplace and home environments, and provided a framework for evaluating the implementation and utilization of high performance buildings.

Acknowledgements

I would like to thank my committee members Todd Thorsteinson, Robert Heinse, Bruce Haglund, and my Major Professor Nick Sanyal, for all of their time, collaboration, and advising for this project. I would also like to thank my NASA mentor Nancy Smith and the human factors division at Ames Research Center for all of the support and assistance provided throughout the research process. Special thanks goes to Krisstina Wilmoth, Rosalind Grymes, Scott Poll, Rodney Martin, Paul Lee, and Bonny Parke for continual encouragement over the past three years. And finally, a special acknowledgment to Steven Zornetzer, NASA Ames Research Center's Associate Center Director and Sustainability Base champion, for making this research possible.

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CHAPTER 1

"The Built Environment at Sustainability Base and the Occupant Experience"

Introduction: The Built Environment

Image courtesy of NASA Ames Research Center

Welcome to Sustainability Base, NASA Ames Research Center's newest research facility, designed with the dual purpose of providing working office space and showcasing high performance building technologies. Located in Mountain View, CA, in the heart of the Silicon Valley, Sustainability Base is a working office, living test-bed for net-zero energy technology research, and the site of a ground-breaking post-occupancy evaluation study connecting energy use behaviors at work and home. Funding for the building was won in a Renovation by Replacement (RbR) grant competition held in 2007 between NASA bases across the country (Shuler, Grymes, Poll, & Wilmoth, 2012). The RbR was designed to generate ideas for replacing antiquated NASA buildings with new, energy-efficient buildings, and each of the agency's ten centers participated. Inspiration for the winning design at Ames Research Center came from architect and sustainability pioneer Bill McDonough, and was championed by Steve Zornetzer, Associate Center Director at Ames. Zornetzer saw the opportunity to apply NASA's closed-loop technologies for energy and resource use in space to high performance buildings on Earth, and the Sustainability Base concept was born.

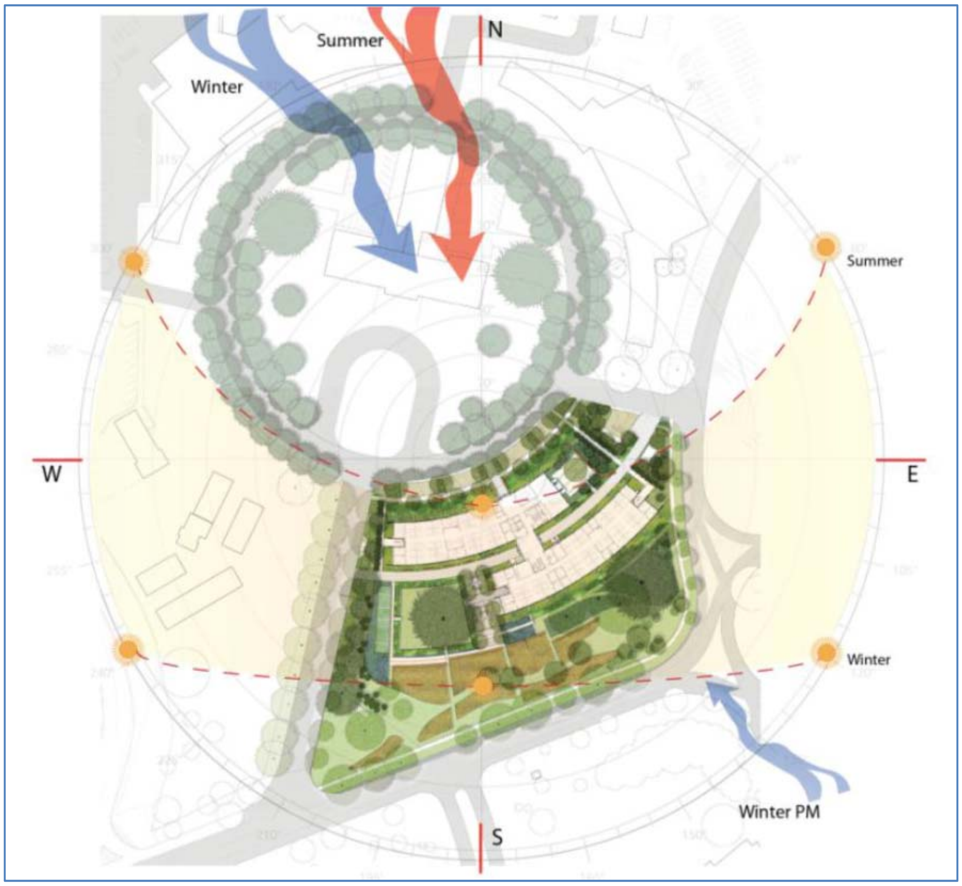


Image Courtesy of William McDonough + Partners

Figure 1.1 Sustainability Base Site Schematic: Building orientation takes advantage of local wind patterns; William Mcdonough + Partners, 2009

McDonough Architects designed Sustainability Base to be "Native to Place" at Ames (Schuler et al., 2012). The orientation of the building was situated to maximize day-lighting and take advantage of local wind patterns on the Bay (Fig 1.1). Additionally, the building was designed with an exoskeleton, which reflected Ames' wind tunnel structures (Fig.1.2) and allowed for interior spaces free of columns.

Figure 1.2 Wind Tunnel: Ames Research Center's wind tunnel exoskeleton structure inspired Native to Place design for Sustainability Base; Vanhoozer 2011

NASA's vision for Sustainability Base followed in the footsteps of the National Renewable Energy Laboratory Research Support Facility (NREL-RSF), a 220,000 square foot research and lab facility constructed in 2008 whose design called for a "net-zero" total energy footprint over the course of a year of building operations (Lammers, 2009). Construction for Sustainability Base began in 2009 and the building was commissioned in 2011.

Sustainability Base's design achieved net-zero energy by taking advantage of local solar and geothermal resources (Schuler et al., 2012), and through the procurement of a 55% electric conversion efficiency solid oxide fuel cell (Fig. 1.3).

Figure 1.3 Bloom Energy Box: Solid oxide Bloom Energy fuel cell at Sustainability Base converts methane into C02 and H20 and generates energy in the process; Vanhoozer 2012

The solid oxide Bloom Box uses natural gas at a 40% reduced C02 emissions rate and at double the efficiency of a conventional power plant to generate 70% of the building's energy needs. The other 30% of building electricity needs are provided through photovoltaic panels with a 19% conversion efficiency rate, which were installed in 24 strings of 9 modules on each wing of the building (Fig. 1.4).

Figure 1.4 Solar Panels: Sunpower photo-voltaics on the roof generate about 30% of Sustainability Base's electricity; Schuler et al. 2010

In addition to electricity generation, separate solar collectors on the roof provide hot water for sinks and showers (Fig. 1.5).

Figure 1.5 Heating Water: Solar collectors are used to heat the water used in sinks and showers in Sustainability Base; Schuler et al. 2010

Water use in Sustainability Base is reduced by almost 90% through dual piping systems and a NASA water recycling system originially developed for habitation in space (Schuler et al., 2012). The system used at NASA (Fig. 1.6) treats grey water by channeling drainage from sinks and showers to a feed tank, from which it is then pumped, treated, and reused in the toilets in the building.

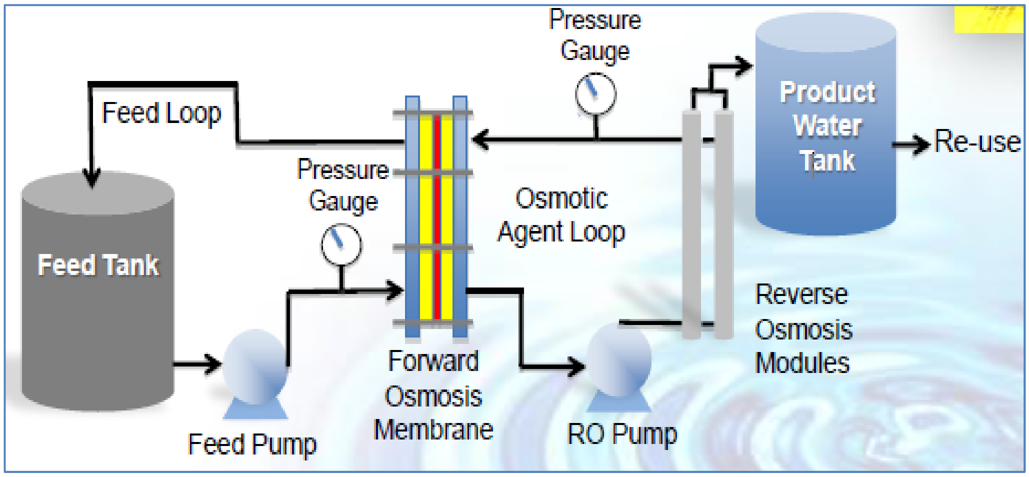


Figure 1.6 Indoor Water System: The forward-reverse osmosis greywater filtration system helps to reduce potable water use at Sustainability Base by almost 90%; Poll 2010

Water conservation in the landscape at Sustainability Base is demonstrated through the reuse of remediated groundwater from a nearby superfund site. NASA scientists treat the groundwater by running it through specialized filters developed at Ames, which they monitor for longevity by conducting prognostic tests on site (Schuler et al., 2012). Surface water and run-off on site pass through bioswale systems planted with native vegetation (Figure 1.7-8).

Figure 1.7-1.8 Stormwater Retention: Bio-swales in the landscape design retain surface water on site; Vanhoozer 2012

Sustainability Base uses water to conserve energy required for temperature controls. The site design took advantage of NASA prognostic tools to test geothermal potentials, boring 106 wells at 58 degree Fahrenheit ground temperature to incorporate a highly efficient geothermal system for both heating and cooling purposes in the building. A Sun Ground Source Heat Pump System was installed with energy efficient heat exchangers to heat water in wall mounted radiators (Figure 1.9). The system is being monitored and studied using NASA degradation modeling technologies.

Figure 1.9 Radiant Heat: Wall-mounted radiators heat the building in winter months; Schuler et al. 2010

From this 58 degree ground temperature, thermally conditioned water is also chilled by heat exchangers and piped to radiant cooling ceiling panels (Figure 1.10), which use 40% less energy than conventional systems. Finally, fresh outdoor air provides ventilation through an under-floor air

Figure 1.10 Radiant Cold: Radiant chill panels suspended from the ceiling provide cooling in summer months; Poll 2010

distribution system (Fig. 1.11), which is incorporated into the building's column-free, low-partition cubicle interior design.

Figure 1.11 UFAD: Under-floor air distribution system construction at Sustainability Base; Poll 2010

THE LIVING TEST-BED FOR BUILDING RESEARCH

The living test-bed model at NASA engages external research partners who want to test new building performance technologies with research staff on site. Technology partnerships for testing and research have included building information modeling with Autodesk, Inc. and electric power demand sensing with Verdigris Technologies, as well as Integrated Building Solutions, Inc. (IBIS) and Enmetric Systems, both of which deployed customized interfaces for monitoring and analysis of systems from which occupants could obtain feedback about building-level and personal energy use (Schuler et al., 2012). Autodesk began partnership at Sustainability Base in 2012 with a project called Project Dasher. Project partners are currently working with NASA scientists to build modeling software (Fig. 1.12) that can visualize systems and monitor real time and historic energy use patterns in the building.

Figure 1.12 BIM: Building model image for Project Dasher software; Autodesk 2012

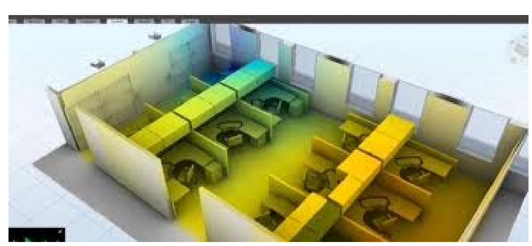


Figure 1.13 BIM Graphic: Open floor plan elevation showing thermal detection capabilities; Autodesk 2012

The Interactive Building Information Model (BIM) under construction (Fig. 1.13) will be capable of visualizing architectural, mechanical, plumbing, power, controls and interior design.

DESIGN CONSIDERATIONS FOR THE OCCUPANT

Figure 1.14 Break Area: Main floor break area in connector between North and South wings of Sustainability Base; Vanhoozer 2012

The design for Sustainability Base integrated NASA software technologies for systems prognostics and diagnostics, originally designed for aerospace applications, and living test-bed research into building systems in a working office facility for 220 NASA employees. The 50,000 square-foot office facility was commissioned with the following working hypothesis:

> *"Overall building performance can be improved, energy usage can be reduced, and individual occupant comfort can be better achieved through integrated building control utilizing intelligent, decentralized, and adaptive control strategies" (Poll 2010).*

The paradigm was that the building's automated system would be so well integrated and adaptive that the occupants as a whole would be able to achieve better comfort than if manual controls were available. After two years of occupation, post-occupancy evaluation survey research (Vanhoozer, Sanyal, Heinse, & Thorsteinson, 2014) validated this hypothesis for natural daylight and ventilation (see Figure 2.3).

At the occupant level, electrical plug loads are the fastest growing segment of commercial energy demand (Kaneda, Jacobson and Rumsey, 2010). Anticipating this, NASA partnered with Enmetric Systems to pilot a plug load management system in the North wing of the building. The Enmetric system allowed loads to be turned off when not in use, eliminating wasted electricity (Fig. 1.15). In addition to monitoring, Enmetric systems afforded occupant viewing and control of their personal electricity usage (Fig. 1.16).

Figure 1.15 Powerstrip: Enmetric allows monitoring of up to 4 devices per workstation

Figure 1.16 Web Interface: Daily output for one channel on an Enmetric monitoring circuit

Sustainability Base used an open floor plan with low partition cubicles to increase natural light levels and air flow (Fig. 1.17). Occupant needs for privacy were accommodated by private offices, conference rooms for larger gatherings, and huddle spaces for private conversations and meetings (Figs 1.18-19).

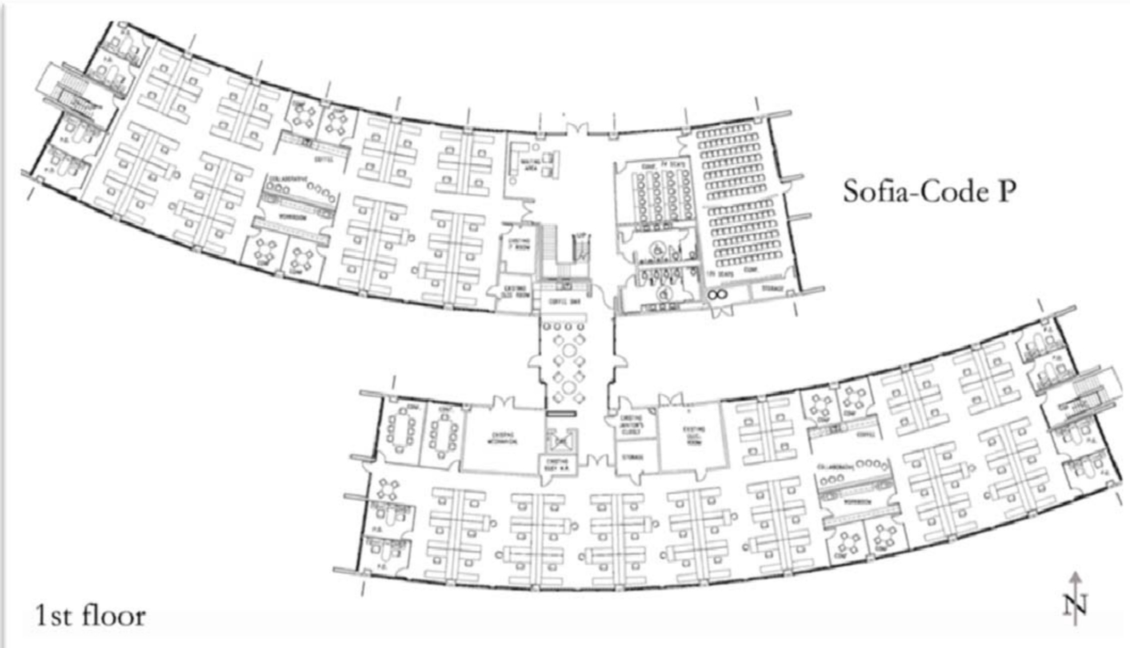
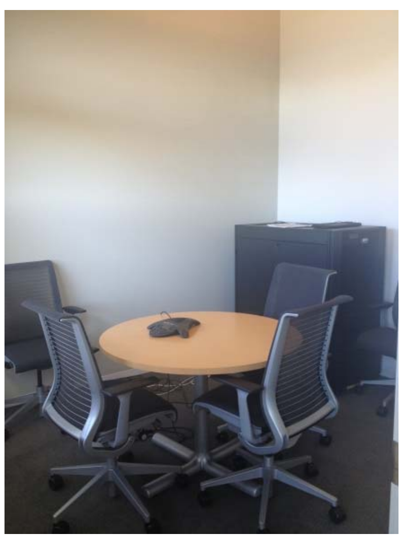


Figure 1.17 Layout: 1st floor open plan workspace layout for Sustainability Base; Schuler et al. 2010



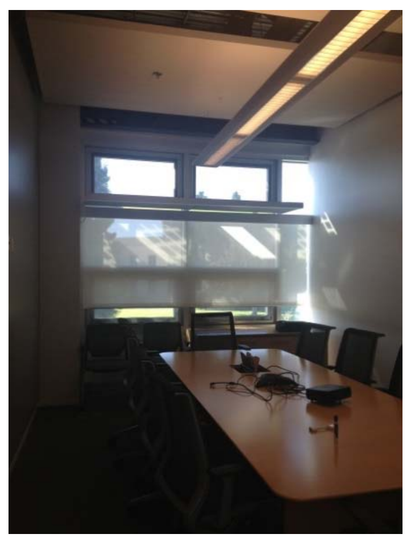


Figure 1.18-19 Speech Privacy Spaces: Huddles and conference rooms outfitted with tele-conferencing capabilities provide space for private conversations and meetings; Probert 2013

Individual needs for lighting, heating and ventilation were provided through zonal manual override controls (i.e. overhead lighting, thermostats for radiant heating panels, operable windows, and floor vents).

SUSTAINABILITY BASE BUILDING AND SITE SPECIFICATIONS

GENERAL

- 50,000 sq. ft. high-performance office building
- ~220 occupants
- Cost $20million
- LEED Platinum certified

DESIGN TEAMS

- NASA 'Renovation by Replacement' proposal winner 2007
- William McDonough + Partners: Design Architect
- AECOM: Architect of Record, Building Engineering, Landscape, Interior Design
- Swinerton Builders: General Contractor

PARTNERS in LIVING TEST-BED RESEARCH

- Carnegie Mellon University
- IBIS
- Enmetric
- Autodesk
- Verdigris Technologies
- University of Idaho Architecture Program

BUILDING AWARDS

- 2012 LEED Platinum Certification (U.S. Green Building Council)
- 2011 "Leadership in Innovation Award" (Center on Environmental Innovation and Leadership)
- 2011 White House "Lean Green and Mean" Green Gov. Award
- 2011 Engineering News Record California "Best Green Building Award"
- 2010 "Real Property Innovation Award" (Government Services Agency)
- 2010 "Green Project of the Year" Structures Award (San Jose Business Journal)

Post Occupancy Evaluation at Sustainability Base


Figure 1.20-1.21 Pre and Post Images: Sustainability Base under construction in August 2010; completed July 2011; Vanhoozer 2010, 2011

Post-occupancy evaluation (POE) research partnership with Ames Research Center began in 2011, during the building's final construction phases, and was conducted in two parts. The first phase addressed changes in occupant satisfaction in the new work environment that were documented via pre and post occupation surveys. We took physical measurements to validate survey data and to document issues with acoustic and daylight satisfaction. Additionally, we made recommendations to remedy these issues, while demonstrating the unique design qualities of Sustainability Base as a living test-bed capable of addressing occupant feedback through external research partnerships. The second phase of POE explored the building as an agent of social change. Through surveys and interviews with occupants, managers, and facilities personnel, we explored building influences on energy conservation norms and behaviors over a 2-year period.

POST OCCUPANCY EVALUATION—OCCUPANT SATISFACTION AND COMFORT

Post-occupancy evaluation studies typically measure occupant satisfaction, comfort and productivity in the workplace. While it is apparent that the efficiency of the systems changes from traditional to high performance work environments, it has been documented that occupant satisfaction does not necessarily correlate positively with efficiency gains (Abbaszadeh, Zagreus, Lehrer & Huizenga, 2006). According to a study conducted at the Center for the Built Environment at University of California Berkeley, mean occupant satisfaction for office layout, lighting and acoustic quality is not significantly different when comparing traditional office buildings and LEED-rated green buildings. Occupants at NASA's Sustainability base indicated increases in daylighting satisfaction and ventilation, however, acoustic quality dropped significantly in the new building (Fig 1.22).

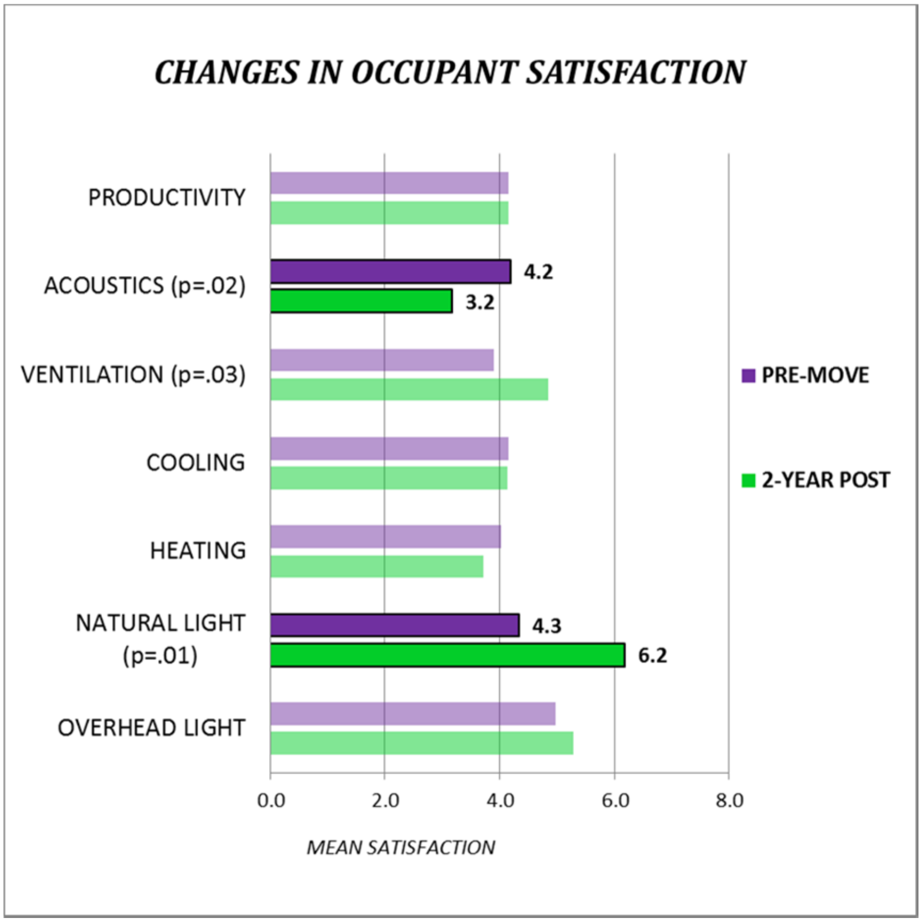


Figure 1.22 Building Satisfaction: Satisfaction in the new building increased significantly for ventilation and natural light, and decreased significantly for acoustic quality. Artificial overhead lighting, heating, cooling, and occupant productivity did not change significantly; Vanhoozer 2013

Occupants reported significant improvements with ventilation quality in Sustainability Base because nearly half of the occupants had moved from cubicles adjacent to the airplane hangar, where exhaust fumes from planes occasionally detracted from air quality. Natural light improved in Sustainability Base. However, open-ended comments in surveys reported lack of lighting controls to mitigate glare issues. Additionally, acoustic satisfaction with speech privacy dropped in the new building. Based on these data and anecdotal comments from informal interviews with occupants, we determined that glare and speech privacy were the building's highest priority for physical instrumentation.

GLARE ANALYSIS

Survey feedback indicated a positive response to daylighting in Sustainability Base. However, open-ended comments in surveys and conversations with employees revealed that glare was an issue. Occupant comments, particularly in the South wing of the building, indicated a desire for manual controls to make adjustments as needed:

"The shading system does not appear to work efficiently but does a good enough job of allowing light into the building. Problems with the automatic blinds is they don't allow users to manually drop the blinds in such case a dark room is desired (e.g., displaying a projector)".

Glare complaints occurred predominantly during the winter months in the South wing of the building. We proceeded with a sampling scheme to deploy Onset Hobo data loggers in identical locations on the first and second floors of the South wing (Fig 1.23). Sensors collected data at 15-minute intervals for a two week period during the midpoint between the autumnal equinox and winter solstice. The *Vital Signs* method from the Center for Environmental Design at the University of California Berkeley was used to take glare photographs and spot check surface temperatures and lux readings.

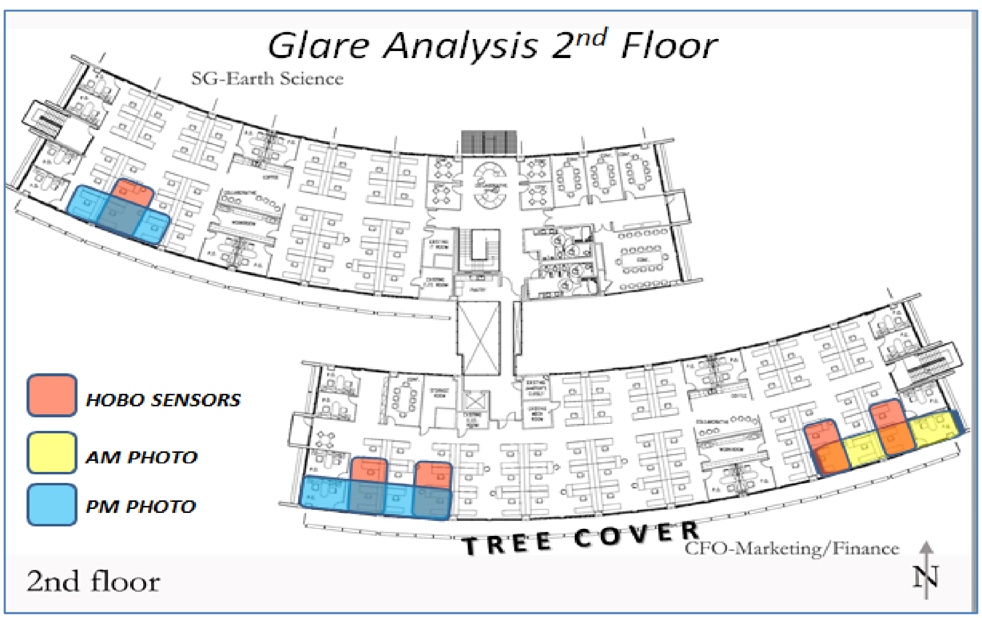


Figure 1.23 Glare Sampling Scheme: Hobo deployment and photos were designed to capture south-facing glare during a two-week sampling period that included the mid-point between the autumnal equinox and winter solstice; Vanhoozer 2013

Three types of glare were documented in Sustainability Base. The first occurred in the mornings through automated windows above the blinds (Fig.'s 1.24-25). This type of glare typically lasted for about forty-five minutes, and occupant recourse during this time was to either move or assemble some sort of obstruction in their work space to impede glare.

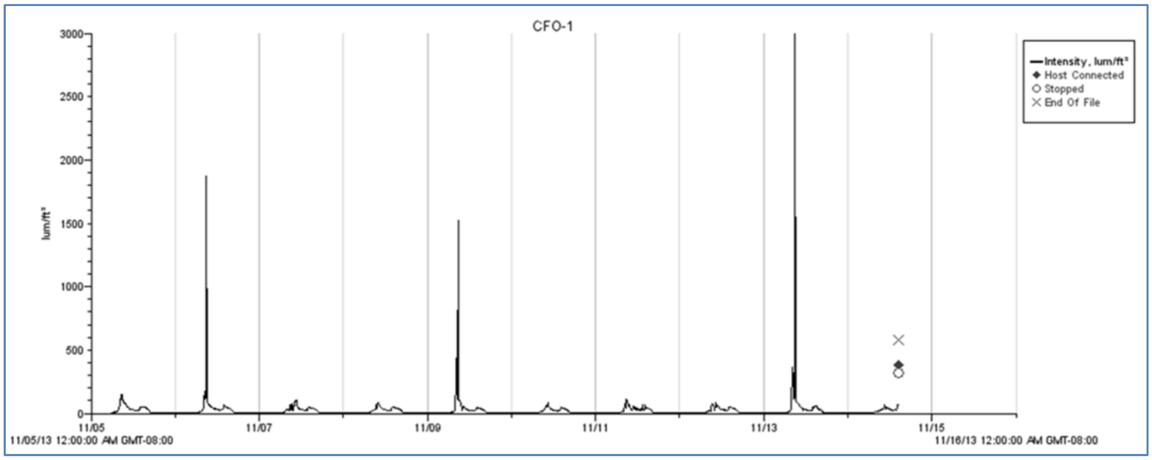


Figure 1.24 Glare Events South-East Wing 2nd Floor: Morning glare occurred 3 times over a two week period through automated windows in a South-facing workstation, generating 2998 lum/ft2 during the peak interval; Probert 2013

Figure 1.25 Glare Through Automated Windows: Glare image taken at 8am on the Southeast wing of the 2nd floor; Probert 2013

The second type of glare generated from insufficient thicknesses of blinds in the most exposed areas of the South façade of the building, which created contrast and radiant heat issues on workspace surfaces. The third type of glare resulted from lack of occupant controls to manually lower blinds when necessary (Fig.'s 1.26-27). Automatic blinds in the building were programmed to lower and raise based on an algorithm that could not always accurately predict occupant needs. Lack of controls to accommodate for individual and group needs generated complaints about blinds being up when they should be down and down when they should be up. The take-home message was that people wanted some degree of manual overrides.

Figure 1.26 Glare Due to Shading Calibration Problems: Contrast glare and intermittent direct sun glare occurred in the South-facing North wing of the first floor of the building because Mecchoshades were not responding to direct sun; Probert 2013

Figure 1.27 Reflective Glare: Contrast glare in North-facing North wing of the second floor of the building due to high reflectivity of adjacent building; Probert 2013

GLARE RECOMMENDATIONS

As a living test-bed facility, Sustainability Base is designed to address building operations and maintenance issues through partnerships that offer innovative solutions. Glare from automated windows without blinds can be mitigated with new technologies in fenestration, such as variable transmission glazing (Fig.1.28-29). This type of installation is appropriate for areas where blinds are not feasible or are not effectively mitigating contrast glare.

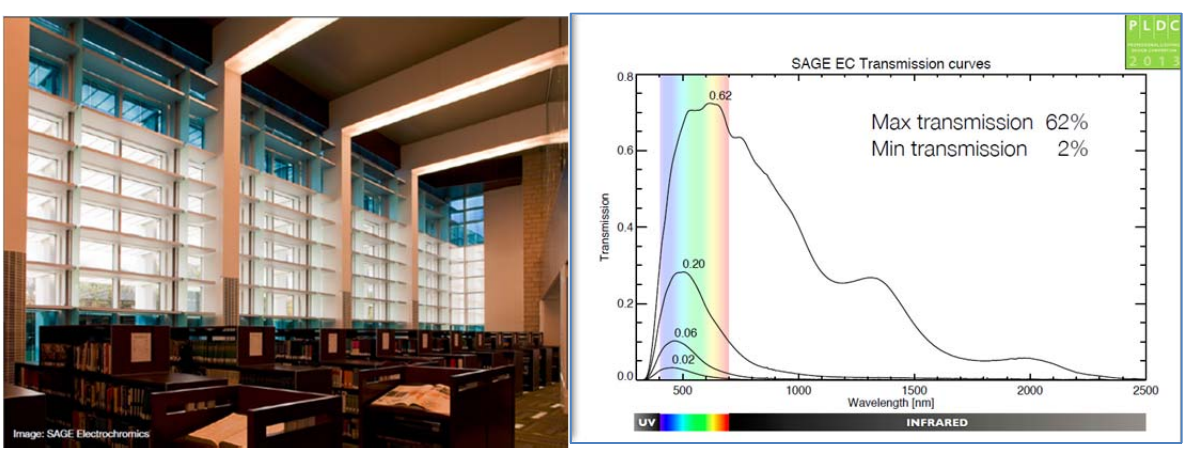


Figure 1.28-1.29 Glazing Solution Example: Variable transmission electro-chromic glazing design by SAGE; Mardaljevic 2013

A glazing installation in the Southwest corner of the building (Figure 1.30) is in progress at Sustainability Base through partnership with View Dynamic Glass, a company in the silicon valley interested in testing a new glazing technology. It is predicted that the View installation will be capable of blocking up to 90% of solar radiation to effectively lower energy use and keep interior spaces cool.

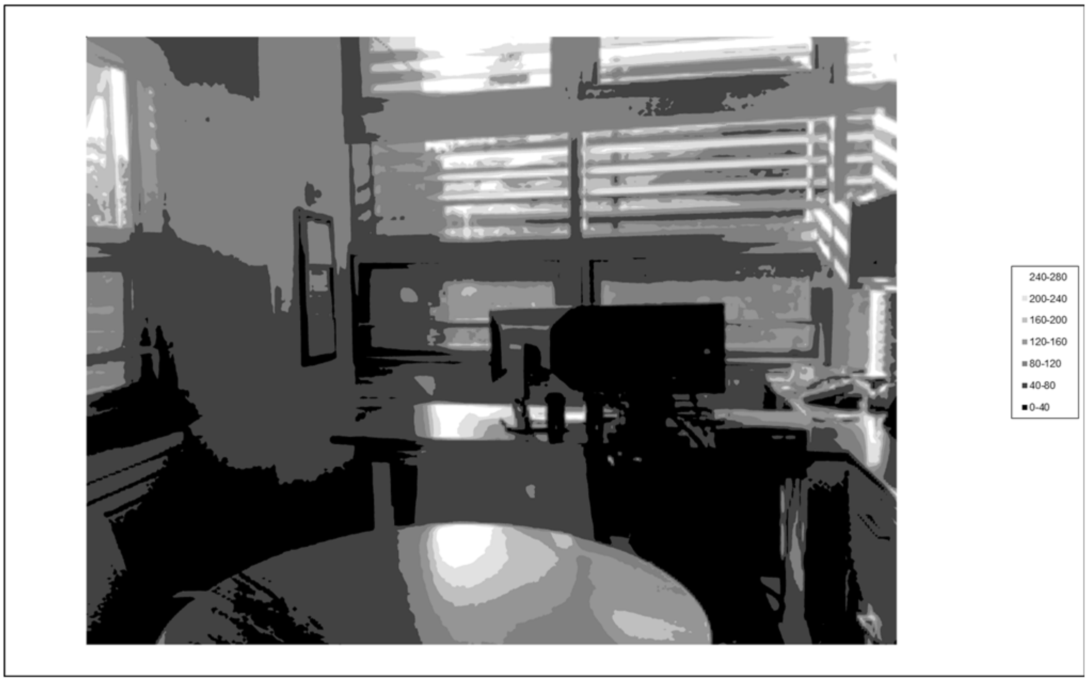


Figure 1.30 Site for Glazing Installation: 2pm glare in Southwest wing of building and site of future View Dynamic Glass installation; Probert 2013

In addition to dynamic glass installations, contrast glare in areas lacking manual controls can be resolved by implementing manual overrides for automated blinds. NASA facilities are currently collaborating with Mecho-systems, Inc. to retrofit occupant controls into the system that can be installed as panels in each zone of the open plan workstations.

SPEECH PRIVACY

"It is too noisy. You can hear everything from co-workers in the cubicles and conversations in the rooms that have the door shut" (survey comment November 2012)

The most common dissatisfaction occupants report in the open plan work space apart from temperature is lack of speech privacy (Salter, Powell, Begault & Alvarado, 2003). Several design strategies have been implemented in high performance buildings to overcome this issue, such as huddle spaces, phone booths, and white or pink noise cancelling machines. The building design in Sustainability Base included radiant chill panels suspended from a corrugate metal ceiling (Fig. 1.31), which created acoustic issues on a few levels.

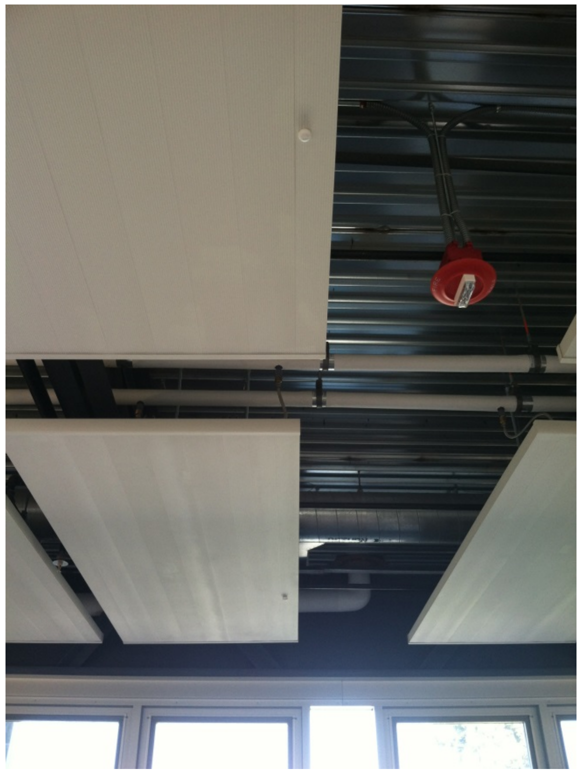


Figure 1.31 Reflective Surfaces: Radiant chill panels and corrugate metal ceiling create highly reflective surfaces for sound; Vanhoozer 2013

The first was that this feature, combined with large surface areas of glass on the windows and the walls of private offices and huddle spaces, generated predominantly reflective surfaces in the work areas. Sustainability Base acoustics were evaluated at the design phase, and plans for absorptive surface materials on low-partition cubicles were not predicted to sufficiently mitigate this level of noise. Recommendations were made to implement absorptive wall paneling and sound masking machines in both open plan areas and conferencing spaces to improve speech privacy, but funds were lacking to procure additional materials. This foretold trouble with excess noise in open plan spaces, and longer reverberation times than desirable in conference rooms. However, the feedback we received immediately from occupants when they moved into the building was that conversations were audible not only in open plan areas, but also in private offices and conference rooms due to a gap between the walls and corrugated ceiling (Fig. 1.32).

"Especially the meeting rooms and private offices are not sound proof. You can easily hear a meeting taking place next door" (Survey comment, November 2012).

Figure 1.32 Mind the Gap: Gap between wall and corrugate ceiling generates sound excess in private spaces; Vanhoozer 2013

We piloted a method used by Salter et al. (2003) at the Center for the Built Environment at UC Berkeley to quantify the degree of noise excess in private spaces in the building. The method uses a simple formula to gauge excess noise:

SOURCE FACTORS-ISOLATION FACTORS = SOUND EXCESS

Factors are quantified between two spaces, referred to as "source" and "receiver" spaces (Fig. 1.33), and include the following:

- Workstation layout
- Room surface treatments and materials
- Partition heights and construction
- Voice levels
- Room size
- Background noise

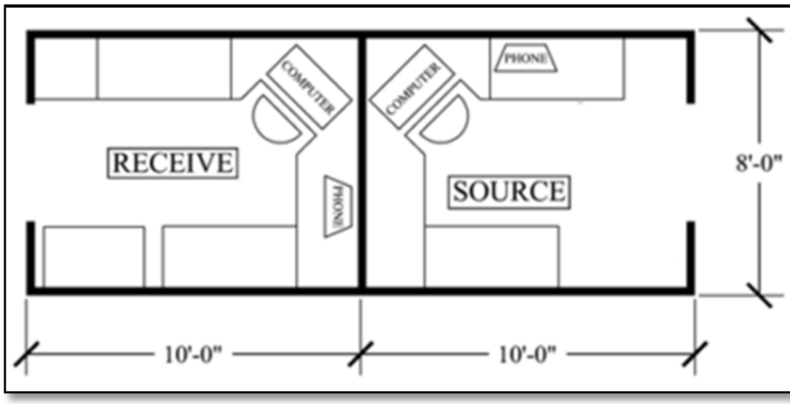
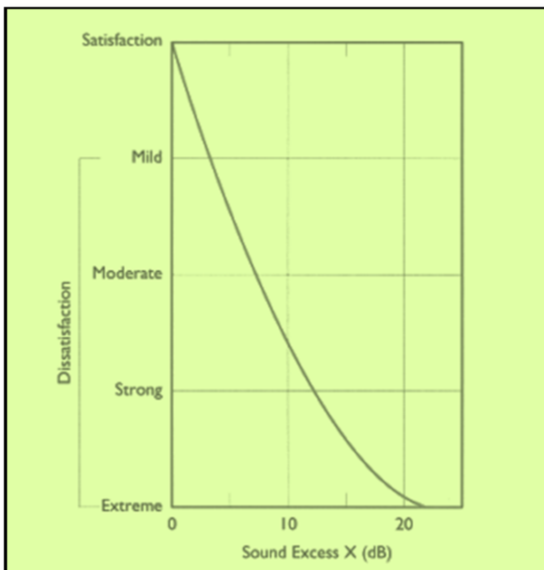


Figure 1.33 Source and Receiver Relationship: Spatial relationships considered for the sound excess formula to predict speech privacy include the source of the sound and the receiver; Salter et al. 2003

Degree of noise excess was calculated from a study called "Speech Privacy in Buildings," where a metric was developed (see Fig. 1.34) categorizing decibels of noise excess and levels of dissatisfaction (Cavanaugh, Farrell, Hirtle, Watters, Beranek & Newman, 1962). This metric was used as a basis for formulation of sound excess calculations.

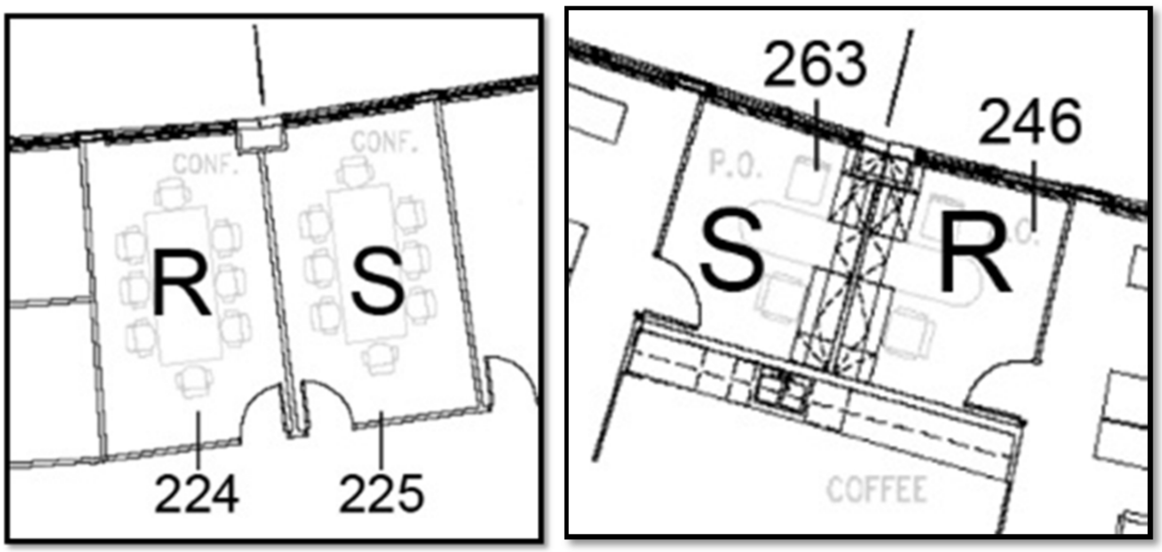


SOUND EXCESS	LEVEL OF DISSATISFACTION
+3	Mild
+7	Moderate
+12	Strong
>+20	Extreme

Figure 1.34 Speech Privacy Dissatisfaction Curve: Sound excess and dissatisfaction curve calculations predict that 7 decibels will generate moderate dissatisfaction from a receiver; Cavanaugh et al., 1962

FINDINGS

Noise excess measurements were calculated between conference rooms, private offices, and huddle spaces (Fig.'s 1.35-36). Depending on the type of exterior noise (i.e. birds and breezes vs. cars and conversations) outside the window of a given receiver (R) room, having operable windows open dampened sound from the sender (S) room by up to 5 decibels. The biggest problem areas were between private offices and huddle rooms outfitted for tele-conferencing, where noise excess could be recorded above 30 decibels (Fig. 1.36).



Figures 1.35-36 Relationships with Moderate to Extreme Ratings: Noise excess between conference rooms was recorded at 8-decibels sound excess; excess noise between private offices and huddles outfitted for tele-conferencing capabilities was recorded at 32 decibels; Probert 2013

SPEECH PRIVACY RECOMMENDATIONS

In order to obtain generalizable results, sound testing piloted for this study would need to be replicated in a sampling scheme that was representative of building operations over a significant time period. The sampling period for the pilot study was representative of only 3 days of building operations. However, the methods employed generated valuable findings for facilities and maintenance staff.

The first recommendation to improve speech privacy in Sustainability Base is to close the gaps between corrugates in the ceiling and walls, concentrating efforts first on private offices adjacent to tele-conferencing spaces. According to Salter et. al (2003), "Private offices with carpeted floors, suspended acoustical ceilings, ***ceiling-heigh***t partitions, and UFAD or HVAC need 40dba background noise to maintain 'normal' speech privacy" and "offices with speaker phones need slab-to-slab partitions; alternatively, 'phone booths' can be designed to accommodate these noise levels" (p.15). Second, rooms with tele-conferencing capabilities will not achieve normal speech privacy without slab-to-slab partition retrofits.

As a result of occupant feedback and findings from the pilot study, NASA facilities have procured steel wool to close ceiling gaps between huddle and conferencing spaces, and acoustic panels have been installed in open plan areas to decrease reverberation times. Additionally, the action plan for 2014 is in early stages of development to retrofit the Northeast wing of the second floor with 2 phone booths.

POST-OCCUPANCY EVALUATION—MEASURING SOCIAL CHANGE

The second phase of Post Occupancy Evaluation in Sustainability Base explored connections between the office environment and changes in the way people responded to energy conservation issues, both at work and in their homes. The question driving the study was *"How does immersion in a net-zero energy work environment influence energy use attitudes and behaviors of occupants, particularly when they leave the workplace?"* The research design measured changes in energy use attitudes and behaviors over a 2-year period by first establishing a pre-occupation baseline in an online survey, which was given to future occupants of the building. After they had been in the building for 2 years, occupants were approached individually and given the opportunity to participate in a printed, follow-up survey, as well as a personal interview about their experiences working in Sustainability Base. This approach afforded the opportunity for a new kind of post-occupancy evaluation—one that included a baseline data set and that centered the inquiry on the occupant rather than the system. This enabled analysis not only of the functionality of building systems to provide satisfaction, comfort, and productivity for its employees, but also of the potential implications for social change. *Would people's perceptions of the importance of energy conservation change as a result of working in the building? Would they become more aware of or more knowledgeable about their energy use, and most importantly, would their own personal energy use behaviors change as a result?* Topics covered in surveys and interviews relevant to energy conservation attitudes and behaviors included the following:

- Number of conservation messages received in the workplace

- Knowledge of workplace energy sources
- Awareness of workplace and home electricity usage
- Workplace influences on home energy conservation
- Energy use habits at home
- Investments in home energy savings
- Personal energy conservation norms
- Perceived importance of energy conservation to peers at work (social norms)

SURVEY and INTERVIEW RESULTS

We knew occupants would be exposed to more conservation messages in Sustainability Base than their previous work environments, however, we wondered if the messages would be effective. We discovered that indeed, people were aware of the increases in conservation messages, and that this awareness persisted 2 years after moving to the new building (Fig. 1.37). We also wanted to know if occupant knowledge of energy sources in the workplace would increase in the Sustainability Base

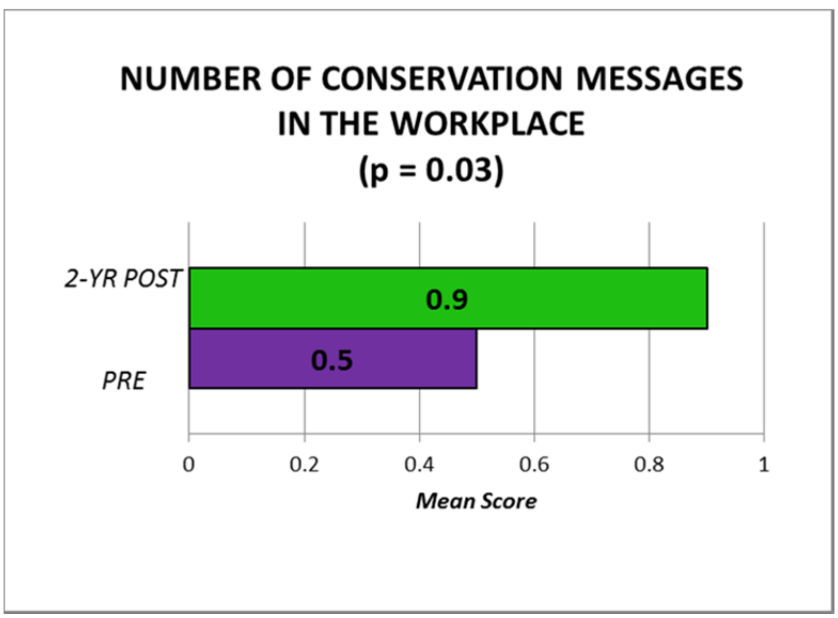


Figure 1.37 Messages Received: Mean scores for conservation messages in Sustainability Base were significantly higher (p = .03) than in the old work environments; Vanhoozer 2013

environment. We discovered that occupants were significantly more knowledgeable about energy sources after 2 years in the new work environment (fig. 1.38).

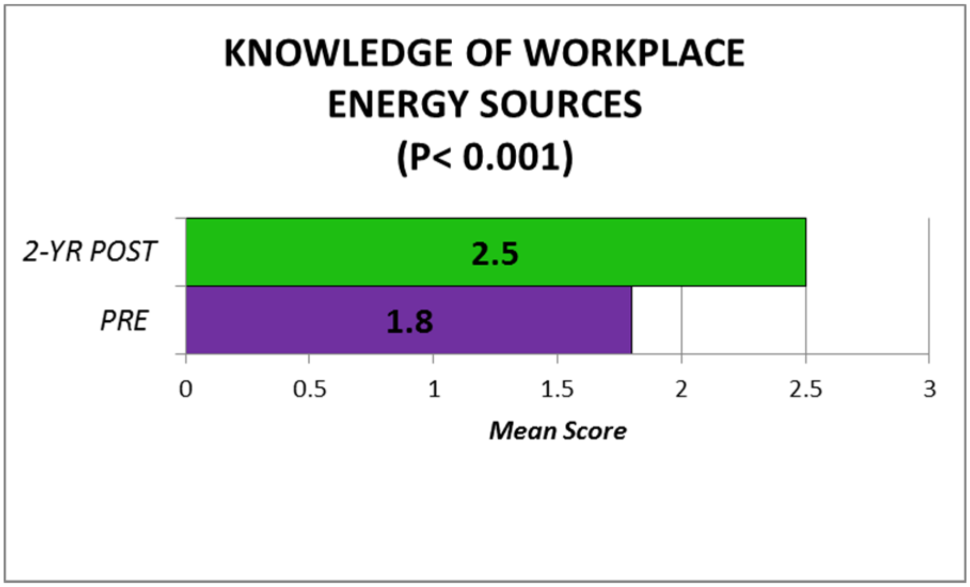


Figure 1.38 Change in Knowledge: Knowledge of energy sources in Sustainability Base were significantly higher ($p < 0.001$) than in the old work environments; Vanhoozer 2013

When we analyzed changes in knowledge of personal electricity use in the workplace, we did not find a significant result. This change was anticipated based on proposed implementation of a personal energy use dashboard in each workstation, which is a feature of the Enmetric plug-load management system. The interface was designed to provide occupants with detailed feedback about personal energy use and has not yet been fully commissioned in the building. Additionally, awareness of home electricity use was high before people moved into the building, and an increase in this awareness was not indicated after working in Sustainability Base. However, occupants maintained that Sustainability Base influenced changes in their energy conservation at home (Fig. 1.39). Occupants said that general awareness of energy conservation at home was enhanced by working in the building. Additionally, features in the new workplace motivated occupants to seek information about home energy savings, and they attributed improvements they had made in their homes to the new work environment.

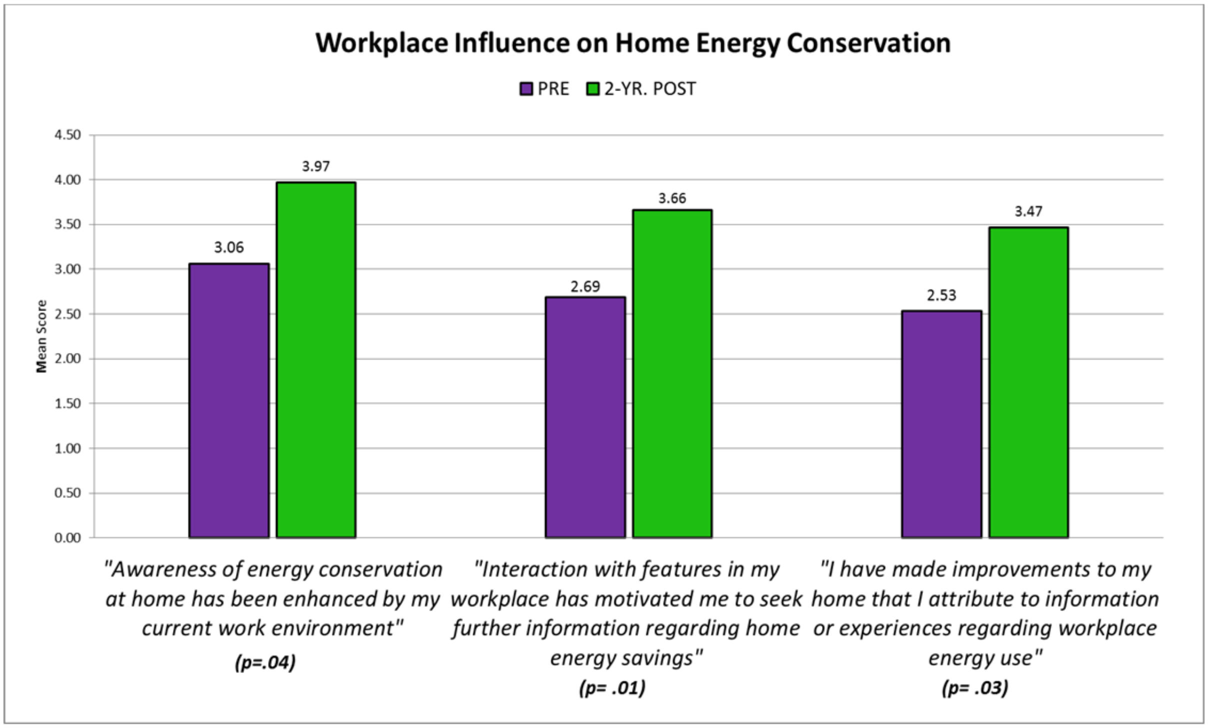


Figure 1.39 Influences of Sustainability Base at Home: Significant changes in awareness of home energy conservation, motivation to seek home energy savings, and home improvements were reported after occupants had spent 2 years working in Sustainability Base; Vanhoozer 2013

We conducted personal interviews to clarify what occupants were more aware of at home because of Sustainability Base. Occupants frequently mentioned the use of geothermal water for both heating and cooling as a novel feature, though not necessarily one that would be transferable to their homes because of cost and feasibility issues. Interaction with the plug load management system has motivated occupants exposed to the Enmetric pilot project to look into vampire power-draw for electricity use in their homes, and one occupant mentioned investing in a “Green at Home” kit to investigate home electricity usage. Many occupants mentioned looking into solar panels for their homes, but discovered the economic payback wasn’t there due to the orientation of their homes to adequate sun. Several occupants also said they have requested electric vehicle charging capabilities at Sustainability Base. Survey data indicated investments in energy savings were limited to small energy-saving features, such as LED/CFL light bulbs and programmable thermostats. The take-home message was that for this highly sensitized group, most of the small investments have already been made, and the larger savings exhibited in Sustainability Base were simply not economically or residentially feasible.

CONCLUSION

The social and behavioral implications of net-zero facilities like Sustainability Base, specifically the capacity for investments in demonstration on site to increase personal energy efficiency off site, have not been documented. We are confident that the methods employed in the Sustainability Base post-occupancy evaluation study offer insights into the behavioral implications of high performance building investments, and that these methods can provide novel strategies for designers and practitioners engaged in POE as a building performance evaluation tool.

References

Abbaszadeh, S., Zagreus, L., Lehrer, D., & Huizenga, C. (2006). Occupant Satisfaction with Indoor Environmental Quality in Green Buildings. *Buildings*, *III*(Figure 1), 365–370.

Bicchieri, C. (2002). Covenants without Swords: Group Identity, Norms, and Communication in Social Dilemmas. *Rationality and Society*, *14*(2), 192–228.

Cavanaugh, W., Farrell, W., Hirtle, P., & Watters, B.G. Watters, (1962). "Speech Privacy in Buildings," *Journal of the Acoustical Society of America*, vol. 34, pp. 475-492.

Center for the Built Environment (2002). Vital Signs Project. Interior Luminance Daylight Controls and Occupant Response Vital Signs Resource Package. Retrieved (7/2013) from http://arch.ced.berkeley.edu/vitalsigns/.

Cooke, R., & Rousseau, D. M. (1988). Behavioral Norms and Expectations: A Quantitative Approach To the Assessment of Organizational Culture. *Group & Organization Management*, *13*(3), 245–273.

Griskevicius, V., Cialdini, R., & Goldstein, N. (2008). Social Norms: An Underestimated and Underemployed Lever for Managing Climate Change. *IJSC*, *3*, 5–13.

Kaneda, D., & Jacobson, B. (2010). Plug Load Reduction : The Next Big Hurdle for Net Zero Energy Building Design, 120–130.

Mardaljevic, J. (2013). Variable Transmission Glazing: Is the Search for the “Holy Grail” (nearly) Over? [Powerpoint slides]. Retrieved from www.lboro.ac.uk.

Nye, M., & Hargreaves, T. (2009). Exploring the Social Dynamics of Proenvironmental Behavior Change. *Journal of Industrial Ecology*, *14*(1), 137–149.

Poll, S. (2011). NASA Ames Collaborative Support Facility (Sustainability Base) *THE NEXT GIANT LEAP* [Powerpoint slides]. Retrieved from http://www.nasa.gov/sustainability-base/.

Salter, C., Powell, K., Begault, D., & Alvarado, R. (2003). *Case Studies of a Method for Predicting Speech Privacy in the Contemporary Workplace*. *Center for the Built Environment*. Berkeley, CA.

Schuler, R., Grymes, R., Poll, S., & Wilmoth, K. (2012). NASA Ames Sustainability Base [Powerpoint slides]. Retrieved from http://www.nasa.gov/sustainability-base/.

Schultz, W. (1998). Changing Behavior with Normative Feedback Interventions : A Field Experiment on Curbside Recycling. *Basic and Applied Social Psychology*, *21*(1), 25–36.

CHAPTER 2

"Energy Conservation Behaviors and Social Norms in the Net-Zero Energy Workplace at NASA Ames Sustainability Base"

Introduction

High performance building standards have grown in popularity, flourishing in the public and commercial sectors in the U.S. over the past decade (Kok, McGraw, & Quigley, 2012; Brown & Vergragt, 2008). Due to the introduction of green rating schemes, green office space has doubled in some cities, and there are a few metropolitan areas where one quarter of the building stock is green (Kok et al. 2012). In 2009, the federal government generated legislation mandating high performance building standards for government buildings (Siedel & Ye, 2012), requiring that all new construction in design process by 2020 plan to achieve net-zero energy by 2030 (p.2). Apple, Hewlitt-Packard, and the Cities of Houston and Philadelphia are examples of industries and municipalities that have invested in net-zero energy technologies and policy-making within the past two years (ASHRAE, 2012). Currently, the federal government maintains just two net-zero energy buildings. The first is the National Renewable Energy Lab in Golden, Colorado, completed in 2009 (Lammers, 2009). The second is Sustainability Base at NASA Ames Research Center in Mountain View, California. Sustainability Base is a 50,000 square foot office facility and living test-bed for building operations and maintenance research (Schuler, Grymes, Poll, & Wilmoth, 2012). Completed in 2011, the building design achieved net-zero electricity by taking advantage of local solar and geothermal resources, and through the procurement of a 55% electric conversion efficiency solid oxide fuel cell (Schuler et al., 2012). NASA technologies applied to Sustainability Base included intelligent control modeling, database building, anomaly detection, systems prognostics and diagnostics for the purposes of improving operations and maintenance performance capabilities (Poll, 2010). The concept for a "*living test-bed"* took things a step further by inviting external research partners who wanted to test new building performance technologies on site by engaging with NASA research staff.

Sustainability Base integrated NASA technologies and living test-bed research into a working office facility for three "mission project" groups of research scientists. The building can house up to 200 occupants at capacity, and 139 NASA employees were selected to occupy the building by NASA administration prior to the building's completion in 2011. Since their selection, these individuals have been the focus of longitudinal research, which we conducted to examine the effects of relocation from traditional offices to the net-zero energy work environment. Specifically, we were interested in potential changes in the occupants' home energy conservation behaviors that may have been prompted by systems, protocols, and social norms in the new work environment.

RESEARCH OBJECTIVES

Post-occupancy evaluation gauges satisfaction, comfort, and productivity in green buildings. However, little has been studied about the social and behavioral implications of the high performance environment to individual occupants. Research has focused predominantly on assessing physical costs and paybacks of sustainable design for organizations (Heerwagen, 2000). The broader goal of our research is to examine the value-added potential of the workplace to function as a pedagogical and normative feedback tool for energy savings in the home. Organizations and the building industry as a whole need tools to clarify the effectiveness of high performance investments from a behavioral perspective, particularly those that are designed to educate occupants about energy consumption. Our research findings aim to clarify the role of the high performance building in changing perceptions of energy use by measuring changes in the following areas:

1) Energy use awareness in the workplace and at home
2) Knowledge of energy sources
3) Receipt of information in the workplace regarding energy use
4) Influences of workplace on home energy awareness, motivation, and behavior
5) Home energy conservation habits
6) Home investments in energy saving features
7) Workplace energy conservation norms and personal conservation norms

Literature Review

The federal government is leading by example to move the country in a sustainable direction (Siedel & Ye, 2012), and as part of this effort has begun to recognize the value of investing in post-occupancy evaluation (POE) as a tool for assessing building performance (Choi, Loftness, & Aziz, 2012; Peck, 2011). Post-occupancy evaluation studies typically measure occupant satisfaction, comfort and productivity in the workplace with regards to the performance of building systems and how well they have improved working conditions from traditional work environments (Abbaszadeh, Zagreus, Lehrer, & Huizenga, 2006). POE literature regarding green workplace buildings has concentrated on analysis of on-site occupant comfort levels and subsequent work productivity (Heerwagen, 2005) in response to H-VAC systems (Brager & Baker, 2008), lighting systems (Inkarojrit, 2005) and thermal conditions (Arens, Humphreys, De Dear, & Zhang, 2010). A series of POE studies called “PROBE” were conducted in the UK, one of which investigated the link between occupant satisfaction and a bias towards green buildings (Bordass & Leaman, 2007). Through a meta-analysis of 177 buildings, the study showed that users tended to tolerate deficiencies in green building systems more than traditional buildings, coining what they called “the forgiveness factor” (Bordass & Leaman, p. 664, 2007). A recent study by Deuble and de Dear (2012) expanded on the Bordass and Leaman study by linking satisfaction and forgiveness to environmental beliefs. They found that building users with higher satisfaction and forgiveness scores also scored higher for pro-environmental beliefs. However, POE has not yet been used to examine the effects of green buildings on norms and behavior change, and the mechanisms by which change may occur. Studies investigating pro-environmental behavior to date have been undertaken largely by using social psychological frameworks and theories. Our approach to post-occupancy evaluation affords the opportunity to merge architectural practice with social science methods in a new strategy—one that includes a baseline data set and that centers the inquiry on the occupant rather than the building systems. This enables analysis not only of the functionality of building systems to provide satisfaction, comfort, and productivity for its employees, but also of the potential implications of workplace feedback for social change.

Theoretical Framework

NORMS and NORMATIVE FEEDBACK

One of the prevalent frameworks used to study pro-environmental behavior is the Norm Activation Model, originally developed by Shalom Schwartz to explain altruistic behavior (1977). According to Norm activation, “behavior occurs in response to personal norms that are activated when individuals are aware of adverse consequences to others or the environment (awareness of consequences or AC beliefs) and when they think they can adverse these consequences (ascription of responsibility or AR beliefs)” (p. 416, Steg, Dreijerink, & Abrahamse, 2005). Beliefs about awareness of consequences and ascription of responsibility for a given behavior precede increased feelings of moral obligation to act (Degroot & Steg, 2011). The norm activation model has demonstrated substantive success as a predictor of behavior (Abrahamse & Steg, 2009; DeGroot & Steg, 2011, Stern, 2000), particularly in studies testing feedback effects targeting specific behaviors (Carrico & Riemer, 2011; Cotterill, John, & Nomura, 2009; Schultz, 1998). In a study testing Value-Based-Norm theory (see Stern, 2000 for an overview) and factors influencing the acceptability of energy use policies, Steg et al. (2005) examined mechanisms of norm activation as part of a causal chain that moved from general to specific beliefs. Their study distinguished four types of behavior, including

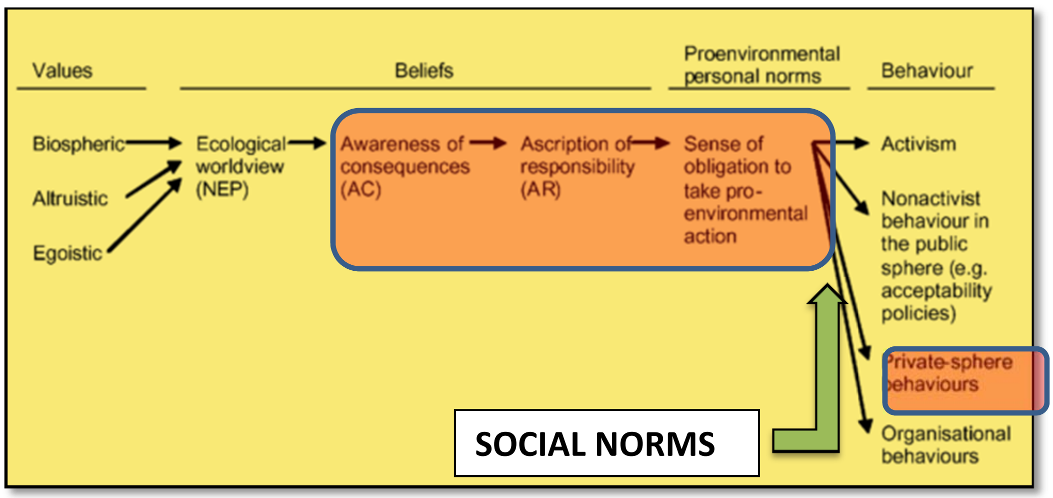


Figure 2.1: VBN Schematic developed by Stern (2000); adapted by Steg, Dreijerink, & Abrahamse (2005) to test the full VBN Theory and Factors Influencing the Acceptability of Energy Use Policies

environmental activism, non-activist behaviors in the public sphere, private-sphere environmentalism, and organizational actions (see Figure 1). Research findings implied that the predictive power of their model would be enhanced by the fine tuning beliefs and personal norms to specific behaviors (Steg et al., 2005). Our study draws on these findings to explore the influences of social norms in the work environment, specifically to generate behavior-specific feedback that enhances awareness of personal energy usage. We test the following hypotheses to gauge changes in awareness, knowledge, norms, and behavior in the workplace, and explore the role of social norms in the relationship between personal norms and behavior:

Hypothesis 1: *"Knowledge of workplace energy sources increases with Sustainability Base building occupation."*

Hypothesis 2: *"Receipt of normative information in the workplace regarding energy use increases with Sustainability Base building occupation."*

Hypothesis 3: *"The influences of the workplace on home energy awareness, conservation motivations, and home behaviors increase with Sustainability Base building occupation."*

Hypothesis 4: *"Home investments in energy saving features increase with 2 years of Sustainability Base building occupation."*

Hypothesis 5a: "*Personal energy use awareness in the workplace increases with 2 years of building occupation at Sustainability Base."*

Hypothesis 5b: "*Personal energy use awareness in the home increases with 2 years of building occupation at Sustainability Base."*

Hypothesis 6: *"Home energy conservation habits increase with 2 years of Sustainability Base building occupation."*

Hypothesis 7: *"Social conservation norms in the workplace moderate the relationship between personal conservation norms and conservation habits."*

Hypothesis 8: *"Social norms for workplace conservation increase with 2 years of Sustainability Base building occupation."*

SOCIAL NORMS AND ENERGY CONSERVATION

The influences of social norms have been substantiated in both the workplace (Lo, Peters, & Kok, 2012) and the home (Abrahamse, Steg, Vlek, & Rothengatter, 2005; Brandon & Lewis, 1999). A study of residential energy use conducted by Griskevicius, Cialdini, and Goldstein (2008) compared perceptions of personal reasons for conserving energy at home with the subjective social norm that others were conserving energy. Results showed that behavior correlated with social motivators twice as strongly as the personal motivators (p.7, 2008). Additionally, when comparing one's behavior to "others", the more similar the group was to the resident, the stronger the effect of the social norm. A study of behavior change in household energy use conducted by Harland, Staats, and Wilke (2004) showed the importance of experiencing group standards prior to individual decision-making, and highlighted the promotion of a supportive social environment as a vital condition necessary to encourage pro-environmental behavior that will last (p. 344, 2004). In a study on energy-related behaviors in office buildings, differences in organizational foci were linked to norm salience- the tighter the group, the stronger the effect (Lo, Peters, & Kok, 2012). Finally, a study conducted by Nye and Hargreaves (2009) assessed the effectiveness of team-based behavior change interventions in both work and home environments. They found that for both workplace and home environments, the context and the social dynamics of a given situation *"acts as the lynchpin for understanding what happens in the shifting milieu of social competencies, normative expectations, and roles and rules of conduct that the individual encounters when negotiating everyday life"* (p. 139, 2009). These studies suggest that the strength of identification with the work group (in our case the mission project) may play an important role in defining the social norm in the workplace.

Methods

SAMPLING

A census of a population of 139 NASA employees who were selected to move into Sustainability Base was taken for this study. Three distinct mission projects were represented in the population, including 33 earth scientists, 40 finance and marketing specialists, and 66 scientists and engineers dedicated to the NASA SOFIA (Stratospheric Observatory for Infrared Astronomy) mission. Survey research employed a longitudinal design for the purposes of tracking changes in energy conservation norms and behaviors from the time prior to employees moving into Sustainability Base through 2 years of building occupation (November 2011-2013). The survey was pilot tested by a group of 15 NASA scientists in the Human Factors Division (ARC-TH) at Ames Research Center to assess content validity and enhance reliability of the instrument. The pre-occupation survey was administered in November 2011 using Lime survey software, an online method available through the NASA server. Participants were invited via email to follow a link to take the survey, which was anonymous and voluntary. A second online survey was administered in November 2012, and a printed, hand-delivered exit survey was administered on site by the researcher in November 2013, accompanied by a personal thank you and an invitation to participate in a follow-up interview at a later date. Data sets were matched using a matched code tracking system, which was a required field for each survey. This enabled individual-level tracking of changes in response over time without compromising anonymity for the participant. The study produced three data sets, one for each sampling period, and a matched codes data set, which were used for hypothesis testing and analysis. Response rates at Time 2 were insufficient for probability testing (36%) due to incomplete responses and were omitted from the study. Total response rates at Time 1 (T1) were 64% and at Time 3 (T3) were over two thirds of the population at 67%. A matched code data set produced a 23% response rate, which was generated from responses at T1 and T3 to obtain results for longitudinal tests.

INSTRUMENTATION

The survey (see Appendix C) was designed in collaboration with UI faculty and NASA human factors and administrative staff at Ames Research Center, and was approved by both NASA IRB (see Appendix C) and the University of Idaho IRB (Appendix D). Survey design and implementation utilized a modified Tailored Design Method (Dillman, 1978; Dillman, 2001; Salant & Dillman, 1984) to maximize response rates for the study. The survey contained 22 questions and incorporated a variety of formats for response, including closed and open-ended response options, but relied primarily on 7-point bi-directional Likert scales constructed using magnitude estimators to ensure true equivalence of intervals (Bass, Cascio & O'Connor, 1974). Primary constructs tested in the survey utilized scales that were validated by confirmatory factor analysis, and that had been administered successfully in previous studies.

PRIMARY CONSTRUCT MEASUREMENT

Primary constructs included personal conservation norms (Steg, Dreijerink, & Abrahamse, 2005), home conservation behaviors (Staatz, Wit, & Midden, 1996), and organizational identification (Mael & Tetrick, 1992), which was measured as a component of social norms. Personal conservation norms were measured using a scale adapted from Steg et al. (2005). Respondents were asked to rate their agreement with personal belief and norm statements on a 7-point bi-directional Likert scale (Table 1). Conservation behavior was measured using a voluntary behavior scale adapted from a study by Staatz, Wit, and Midden (1996), in which researchers evaluated the effectiveness of a mass

Table 2.1: Conservation belief and norm agreement statements;
Vanhoozer 2014 adapted from Steg et al., 2005

a. "Energy savings help reduce global warming"
b. "I feel morally obligated to save energy, regardless of what others do"
c. "My contribution to energy problems is negligible"
d. "I feel partly responsible for the exhaustion of energy resources"
e. "If I would buy a new washing machine, I would feel morally obligated to buy an energy- efficient one"
f. "I feel personally obligated to save as much energy as possible"
g. "I feel guilty when I waste energy"
h. "The exhaustion of energy resources is a problem"

media campaign in Holland to increase knowledge and awareness of the greenhouse effect. Respondents were asked to rate frequency of engagement in 15 conservation behaviors, such as turning electronic devices off when not in use, using heating systems sparingly, etc. on a 5-point uni-directional Likert scale. Social norms were measured using a scale adapted from Fishbein's subjective norm construct (Glassman & Fitzhenry, 1976). This scale traditionally defines the norm as the product of a normative belief, which is what one believes a referent group would approve of in a given situation, and a motivation to comply with the normative belief. This study measured a general normative belief about energy conservation, and operationalized the motivation to comply (Glassman & Fitzhenry, p. 479, 1976) as a measure of organizational identification with the work group (constructed by Mael & Tetrick, 1992).

SECONDARY CONSTRUCT MEASUREMENT

Secondary constructs included transfer behavior, or influences of the workplace at home, objective knowledge of workplace energy sources, presence of injunctive norms in the workplace, and awareness of personal energy usage both at home and work. Finally, self-reported investments in home energy savings features were generated from a list of commercially available products and captured nominal level data for investments in home energy savings. Survey data gauging changes in occupant satisfaction with building systems were analyzed in a separate study (Vanhoozer & Probert, 2014).

HYPOTHESIS TESTS AND RESULTS

Time 1(T1), Time 3(T3), and Matched code (MC) data sets were analyzed to describe the population sample and to conduct statistical tests. Variables used to describe the population included response by tenure, gender, age, and home ownership, type and age. Descriptions of each sample and differences observed between data sets are shown as proportions in Table 2.

Table 2.2: Population Sample Descriptive Statistics for T1, T3, and MC; Vanhoozer 2014

	% Male	*% Age Range 41-60 years*	*% Home Owners*	*% Single Family Dwelling Homes*	*% Homes > 40 years old*
T1	33%	59%	80%	70%	39%
T3	58%	59%	77%	77%	40%
MC	72%	60%	81%	60%	41%

Analysis of variance tests controlled for gender, age, tenure, office type change, home ownership, and mission project as potentially significant factors influencing outcomes for dependent variables in the study. Mission project was determined a significant factor influencing social norms, injunctive norms, workplace awareness of energy use, and transfer behavior. As mentioned, population sizes for mission projects included 33 earth scientists, 40 finance and marketing specialists, and 66 scientists and engineers dedicated to the SOFIA mission. Response rates dis-aggregated to mission project produced sample sizes insufficient for conducting probability analysis. Responses were therefore aggregated and post-hoc tests applied to explore sources of variance in significant test results.

Analysis of variance (ANOVA) was used to explore potential factors in population samples that might influence hypothesis test results. Significant factors included mission project, which influenced social norms $F(2,111)=9.79$, $p < 0.001$, receipt of workplace conservation messages $F(2,111)=3.21$, $p = 0.04$, and perceptions of workplace influences on home behaviors $F(2,102)=17.89$, $p < 0.001$. We conducted Tukey's multiple comparison tests to explore mission project influences on social norms, receipt of workplace messages, and workplace influences on home behaviors. We found that mean scores for social norms in the SOFIA mission project (M= 190.3, S.D. = 98.6) were significantly lower than Marketing (M=329.9, S.D.=64.4). Influences of workplace on home behavior were significantly lower for SOFIA (M=5.2, S.D=3.5) than both Marketing (M=9.8, S.D.=6.1) and Earth Science (M=7.8, S.D.=5.8). Message scores were not significantly different between mission projects in multiple comparison analysis.

The matched codes data set was used to analyze changes in the population over the 2-year sampling period. We tested eight hypotheses, each of which is listed below with a description of analysis and discussion of results:

Hypothesis 1: *"Knowledge of workplace energy sources increases with Sustainability Base building occupation"*

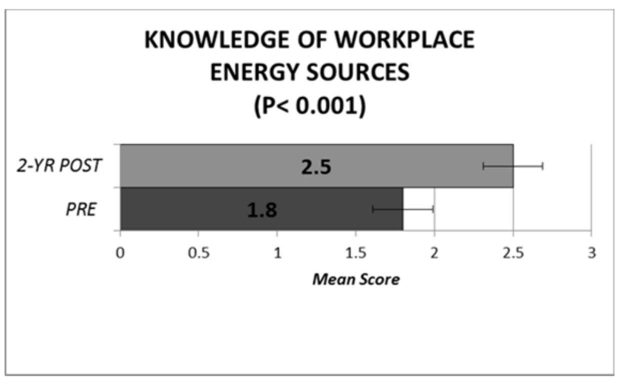


Figure 2.2—Knowledge Increase: Occupants were more knowledgeable about workplace energy sources after moving to Sustainability Base; Vanhoozer 2013

Occupants were instructed to select all the energy sources that they believed powered the building from a list of potential energy sources that powered their workplace. After working in Sustainability Base for two years (Fig. 1.2), survey data indicated that their knowledge of the identity of these sources had increased significantly, $t(31)=-3.67$, $p=.001$.

Hypothesis 2: *"Receipt of normative information in the workplace regarding energy use increases with Sustainability Base building occupation"*

Participants were given a list of conservation messaging sources to choose from (i.e. emails, building protocols, meetings, and seminars) and asked to check all that applied to their workplace (Figure 1.3). While it was apparent that there would be more conservation-oriented messages (injunctive norms) distributed in Sustainability Base, whether or not employees received messages was not

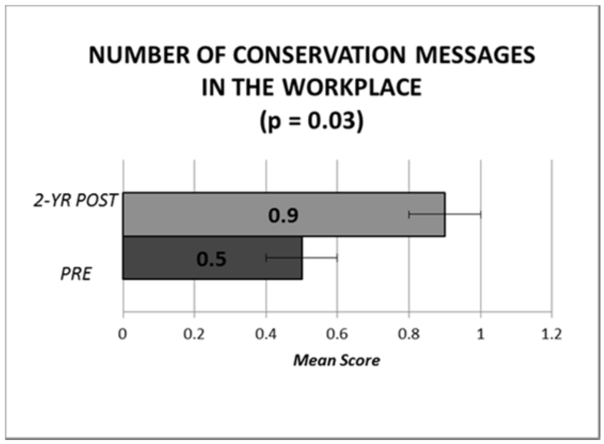


Figure 2.3—Information Receipt: Occupants in Sustainability Base reported receipt of a significantly greater number of conservation messages after 2 years in Sustainability Base than they had prior to building occupation; Vanhoozer 2013

known. Results indicated that occupant receipt of information increased at the 2-year mark of building occupation, $t(31)=-2.35$, $p=0.03$.

Hypothesis 3: *"The influences of the workplace on home energy awareness, conservation motivations, and home behaviors increase with Sustainability Base building occupation"*

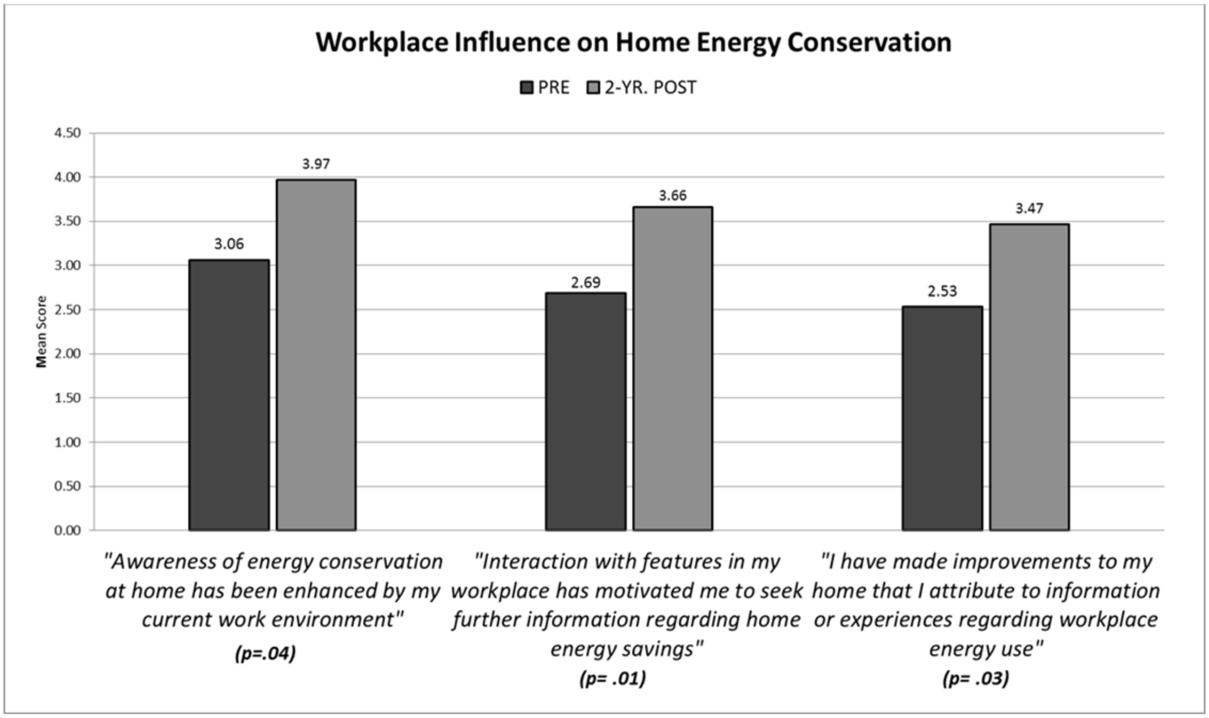


Figure 2.4—Influences of Workplace at Home: Occupants attributed increased home awareness, motivation, and home improvements to working in Sustainability Base 2 years after building occupation; Vanhoozer, 2013

Occupants maintained two years after relocation that Sustainability Base had influenced changes in their energy conservation at home (Figure 1.4). Occupants said that general awareness of energy conservation at home was enhanced by working in the building, $t(31)=-2.14$, p=.04. Additionally, features in the new workplace motivated occupants to seek information about home energy savings, $t(31)=-2.78$, p=.01, and they attributed improvements they had made in their homes to the new work environment, $t(29)=-2.23$, p=.03. Open-ended survey commentary, as well as personal interview data generated from a separate qualitative study (Vanhoozer & Sanyal, 2014) helped to clarify what occupants were more aware of at home because of Sustainability Base. Occupants frequently mentioned the use of geothermal water for both heating and cooling as a novel feature, though not necessarily one that would be transferable to their homes because of cost and feasibility issues. Interaction with the Enmetric plug load management system (see Poll, 2010) motivated occupants exposed to the pilot project to examine vampire power-draw for electricity use in their homes, and a few occupants mentioned plans to invest in xeric landscaping. Many occupants mentioned exploring solar panels for their homes, but discovered that economic payback wasn't likely due to the orientation of their homes to adequate sun. Several occupants also said they have requested electric vehicle charging capabilities at Sustainability Base.

Hypothesis 4: *"Home investments in energy saving features increase with 2 years of Sustainability Base building occupation"*

Survey data indicated investments in overall energy savings investments did not change, t(31) -.882, p= .38. Investments were limited to small energy-saving features, such as LED/CFL light bulbs, *t*(31)=-3.04, p=.005. The take-home message was that most of the small investments had already been made, and the larger savings exhibited in Sustainability Base (i.e. solar panels, bloom energy box) were simply not economically or residentially feasible. However, some pro-active occupants found ways to respond to inspiration from the building. For example, in a personal interview one occupant described how the building inspired the family rental of a "Green at Home" kit to improve home efficiency:

> "[A]t home I've been more aware, and one of the opportunities that the Cupertino Library offered in partnership with the City, the library and City Cupertino put together green at home kits that you could borrow from the library…they provided you with things to measure, to look for drafts, to measure the temperature of your refrigerator, to replace incandescent bulbs with high performing light bulbs. There were a few of these things that were a part of the kit that you returned to the library, but some of them that you got to keep like the thermometer that went in your refrigerator you got to keep. The light bulbs you got to keep and there were flow restrictors and things like that you got to install. I did that." (Occupant interview, 2/2014)

Hypothesis 5a: "*Personal energy use awareness in the workplace increases with 2 years of building occupation at Sustainability Base"*

Hypothesis 5b: "*Personal energy use awareness in the home increases with 2 years of building occupation at Sustainability Base"*

When we analyzed changes in knowledge of personal electricity use in the workplace, we did not find a significant result, t(29) -.812, p= .42. This change was anticipated based on proposed implementation of a personal energy use dashboard in each workstation, which is a feature of the Enmetric plug-load management system. The interface was designed to provide occupants with detailed feedback about personal energy use, however as of December 2013, the system had not yet been fully commissioned in the building. Additionally, awareness of home electricity use was high before people moved into the building, and an increase in this awareness was not indicated after working in Sustainability Base, t(30) -.329, p= .75.

Hypothesis 6: *"Home energy conservation habits increase with 2 years of Sustainability Base building occupation"*

Home energy conservation habits were measured using a 15-question voluntary behavioral acts scale developed by Staats, Wit, & Midden (1996). Habitual home behaviors included recycling, water conservation such as turning off the faucet while doing dishes, and turning off lights and other electric devices when not in use (p. 7, 1996). Pre-occupation data results indicated ceiling effects for baseline home behaviors, and no significant change in habits was observed at the 2-year interval, t(31)= -.76, p=.45.

Hypothesis 7: *"Social conservation norms in the workplace moderate the relationship between personal conservation norms and conservation habits"*

Research on norms has found that social norms can moderate the relationship between personal norms and behavior (Bicchieri, 2002; Cook & Rousseau, 1988; Griskevicius, Cialdini & Goldstein, 2008; Nye & Hargreaves, 2009; Schultz, 1998). In the case of Sustainability Base, we predicted that if social norms in the new building would make relationships between occupant's personal norms and their conservation behaviors stronger. Social conservation norms for this study were measured as the sum of subjective normative beliefs about workplace conservation (Glassman & Fitzhenry, 1976), conservation messages or injunctive norms received in the workplace, and organizational identification (Mael & Tetrick, 1992).

Hierarchical multiple regression was conducted to determine if social workplace norms moderated the relationship between personal conservation norms and home conservation behaviors. Neither personal conservation norms nor social norms were significant predictors of conservation behavior in simple correlation tests. However, the interaction between personal norms and social norms was significant, $\beta = -.394$, $F(1,54) = -2.56$, $p = .01$, inc. $R^2 = 0.10$). The moderation of social norms on personal norms also explained a significant proportion of variance in personal norms and behavior, $R^2 = .17$, $F(3,54) = 6.56$, $p = .01$. The interaction between personal and social norms

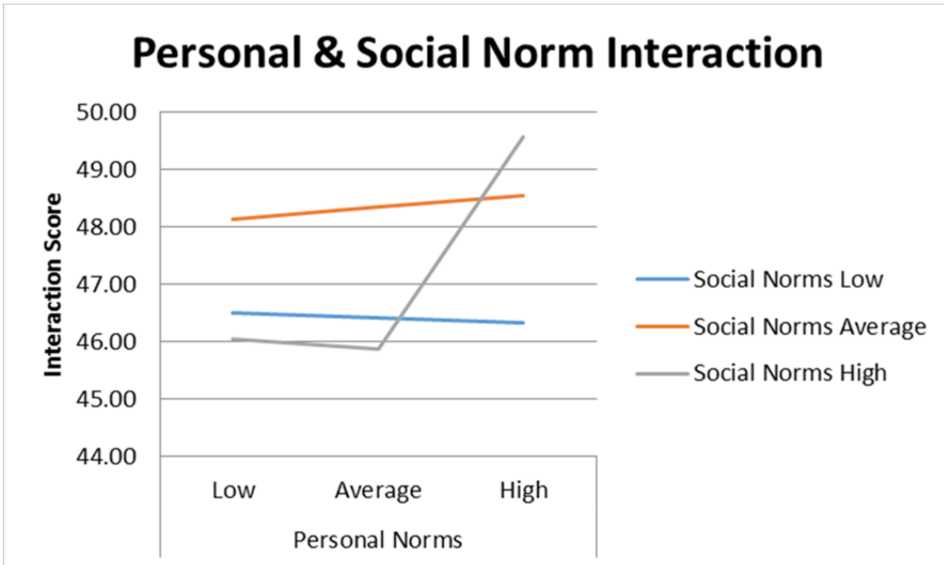


Figure 2.5: Personal & Social Norm Interaction plot: demonstrates significant interaction between high personal norm and high social norm scores; Vanhoozer & Thorsteinson, 2014

(Figure 1.5) was significant for participants who had high personal norm and social norm scores.

Hypothesis 8: *"Social norms for workplace conservation increase with 2 years of Sustainability Base building occupation"*

A statistically significant change in social norms was found between the old work environments and Sustainability Base after two years of occupation, $t(31) = -2.167$, $p = .04$. This finding, coupled with moderation results of hypothesis 7, suggests that increasing social conservation norms in the building may have a positive effect on personal conservation norms and conservation behaviors at home.

Discussion

POE has not to date documented the effects of green buildings on norms and behavior change, and the mechanisms by which change may occur. We examined the role of social norms in behavior change, and findings suggest that social conservation norms in the building may have a positive effect on relationships between personal conservation norms and home behaviors. This is encouraging news, given that NASA has made significant investments in an energy conservation showcase facility, which also houses test-piloting for building features to provide energy use feedback for occupants. Increases in social conservation norms in the building suggest that what people say they believe about conservation and what they actually do becomes more aligned due to a conservation-oriented social environment in Sustainability Base.

Increased knowledge of building energy sources and increased receipt of conservation messaging at work bodes well for the investments made in conservation communication in the building. Occupants maintained two years after relocation that Sustainability Base had influenced changes in general awareness of energy conservation at home, that features in the new workplace had motivated information seeking about home energy savings, and they attributed improvements they had made in their homes to the new work environment. However, larger savings exhibited in Sustainability Base (i.e. solar panels and a bloom energy box) were not feasible and/or economical in the home, which limited transfer in residential applications. Future research in workplace energy saving features that are also transferable to residential environments is an untapped niche in the building research and design field.

Findings for this study contribute empirical evidence to the value-added elements of building energy savings investments and forge general connections between energy use practices in work and home environments. We recommend future applications of these methods as a justification for investments in future building energy savings. However, high levels of general awareness and baseline home behaviors present researchers with challenges in measuring change. We recommend that future studies capture change by targeting specific conservation behaviors to specific workplace feedback.

LIMITATIONS

Obstacles encountered when conducting research revolved around the limitations of the sampling time frame in a building with considerable commissioning challenges, lack of matched codes through anonymous survey tracking, and lack of treatment to deliver occupant feedback necessary to measure significant effects.

The timeline for data collection included a pre-occupation sample and two post-occupation samples, both of which took place before the building was fully commissioned. The rule of thumb for POE is to avoid sampling prior to the two year mark, because the building commissioning process can skew research results, particularly with regards to satisfaction and comfort. In the case of Sustainability Base, building commissioning is an ongoing effort. Ideally, POE research for specialized high performance facilities would employ a sampling scheme with a longer time frame (i.e. pre, 2-year, and 5-year) in order to appropriately describe post-commissioning building effects.

Instrumentation limitations in the study included small sample sizes at the mission project level due to lack of viable matched codes for longitudinal sampling purposes. First, overall response was sufficient for conducting probability analyses however, lack of response to survey questions identifying a mission project prevented group-level analysis of the data. This presented challenges when addressing norm-related effects on behavior. Second, the matched code tracking method was designed to comply with the agency's request to preserve anonymity during survey participation. This method proved marginally successful, yielding only 32 matched codes for longitudinal analysis. Additionally, lack of confidential tracking prevented tracking non-response bias, which limited characterization of the sample. Future Studies should develop a confidential tracking method for longitudinal study that effectively follows the population from pre-occupation through commissioning and for the duration of the research. Finally, piloting a method to capture the effects of a treatment in the workplace domain on behaviors in the home presents the inherent challenge of lack of control over extraneous variables, particularly in the home environment. We recommend future studies formulate hypotheses that target highly specific home behaviors designed to be influenced by specific workplace innovations, and during sampling periods that include fully commissioned treatments. Additionally, we recommend higher specificity of inquiry when targeting workplace feedback mechanisms for home behavior change. Lack of treatment, specifically with the Enmetric plug load management system, affected the results of hypothesis testing for building feedback effects.

CONCLUSION

POE case study research generated data unique to the net-zero energy setting in a facility that is also pioneering living test-bed research at NASA Ames Research Center. Findings for Sustainability Base are unique to the living test-bed facility and not likely to generalize to other building models. However, the government has made a commitment to investment in future facilities like Sustainability Base, and the reliability of the methods we employed provide architects, post-occupancy evaluation researchers, and the building industry with great insights into the implications of high performance design for occupants of future facilities, not only in the workplace but also in their homes. This study offers valuable tools for behavioral research, particularly in instances where it is feasible for researchers to identify and track occupants before relocation to a new facility and after building commissioning is complete. We are confident that research at Sustainability Base offers insights into the behavioral implications of high performance building investments, and that the methods and lessons learned through our efforts provide novel strategies for designers and practitioners engaged in post-occupancy evaluation as a building performance evaluation tool.

References

Abbaszadeh, S., Zagreus, L., Lehrer, D., & Huizenga, C. (2006). Occupant Satisfaction with Indoor Environmental Quality in Green Buildings. *Buildings*, *III*(Figure 1), 365–370.

Abrahamse, W., & Steg, L. (2009). How do socio-demographic and psychological factors relate to households' direct and indirect energy use and savings? *Journal of Economic Psychology*, *30*(5), 711–720.

Abrahamse, W., Steg, L., Vlek, C., & Rothengatter, T. (2005). A review of intervention studies aimed at household energy conservation. *Journal of Environmental Psychology*, *25*(3), 273–291.

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, *50*(2), 179–211.

Arens, E., Humphreys, M. a., De Dear, R., & Zhang, H. (2010). Are "class A" temperature requirements realistic or desirable? *Building and Environment*, *45*(1), 4–10.

Bass, B.M., Cascio, W.F., & O'Connor, E.J. (1974). Magnitude estimations of expressions of frequency and amount. *Journal of Applied Psychology*, 59(3), 310-320.

Bamberg, S., Hunecke, M., & Blöbaum, A. (2007). Social context, personal norms and the use of public transportation: Two field studies. *Journal of Environmental Psychology*, *27*(3), 190–203.

Bicchieri, C. (2002). Covenants without Swords: Group Identity, Norms, and Communication in Social Dilemmas. *Rationality and Society*, *14*(2), 192–228.

Brager, G., & Baker, L. (2008). Occupant Satisfaction in Mixed-Mode Buildings. *Air Conditioning and the Low Carbon Cooling Challenge* (pp. 27–29). London: Network for Comfort and Energy Use in Buildings. Retrieved from http://nceub.org.uk

Brandon, G., & Lewis, A. (1999). Reducing Household Energy Consumption: a Qualitative and Quantitative Field Study. *Journal of Environmental Psychology*, *19*, 75–85.

Brown, H. S., & Vergragt, P. J. (2008). Bounded socio-technical experiments as agents of systemic change: The case of a zero-energy residential building. *Technological Forecasting and Social Change*, *75*(1), 107–130.

Carrico, A. R., & Riemer, M. (2011). Motivating energy conservation in the workplace: An evaluation of the use of group-level feedback and peer education. *Journal of Environmental Psychology*, *31*(1), 1–13.

Choi, J.-H., Loftness, V., & Aziz, A. (2012). Post-occupancy evaluation of 20 office buildings as basis for future IEQ standards and guidelines. *Energy and Buildings*, *46*, 167–175.

Cooke, R. a., & Rousseau, D. M. (1988). Behavioral Norms and Expectations: A Quantitative Approach to the Assessment of Organizational Culture. *Group & Organization Management*, *13*(3), 245–273.

Cotterill, S., John, P., Liu, H., & Nomura, H. (2009). Mobilizing citizen effort to enhance environmental outcomes: a randomized controlled trial of a door-to-door recycling campaign. *Journal of environmental management*, *91*(2), 403–10.

De Groot, J., & Steg, L. (2007). General Beliefs and the Theory of Planned Behavior: The Role of Environmental Concerns in the TPB. *Journal of Applied Social Psychology*, *37*(8), 1817–1836.

DeGroot, J., & Steg, L. (2011). Morality and Prosocial Behavior : The Role of Awareness , Responsibility , and Norms in the Norm Activation Model. *The Journal of Social Psychology*, *149:4*(August), 425–449.

Deuble, M. P., & De Dear, R. J. (2012). Green occupants for green buildings: The missing link? *Building and Environment*, *56*, 21–27.

Dillman, D.A. (1978). *Mail and telephone surveys: The total design metho*d. New York: John Wiley and Sons.

Dillman, D.A. (2001). *Mail and internet surveys: The Tailored design method*, 2nd Edition. New York: John Wiley Company.

Eagly, A. H., & Chaiken, S. (1998). Attitude Structure and Function (pp. 269–281).

Glassman, M., & Fitzhenry, N. (1976). “Fishbein’s Subjective Norm: Theoretical Considerations and Empirical Evidence”. *Advances in Consumer Research*, *3*, 477–480. Retrieved from http://www.acrwebsite.org/search/view-conference-proceedings.aspx?Id=9303

Griskevicius, V., Cialdini, R., & Goldstein, N. (2008). Social Norms: An Underestimated and Underemployed Lever for Managing Climate Change. *IJSC*, *3*, 5–13.

Harland, P., Staats, H., & Wilke, H. a. M. (2004). Effecting Durable Change: A Team Approach to Improve Environmental Behavior in the Household. *Environment & Behavior*, *36*(3), 341–367.

Heerwagen, J. (2000). Green buildings, organizational success and occupant productivity. *Building Research & Information*, *28*(5-6), 353–367.

Heerwagen, J. (2005). The Human Factors of Sustainable Building Design: Post Occupancy Evaluation of the Philip Merrill Environmental Center, Annapolis, MD.

Industry News. (2012).*ASHRAE Journal*, (July), 6. Retrieved from ashrae.org

Inkarojrit, V. (2005). Balancing Comfort: Occupants' Control of Window Blinds in Private Offices. *Unpublished Dissertation, University of California, Berkeley.*

Kok, N., McGraw, M., & Quigley, J. M. (2012). The diffusion over time and space of energy efficiency in building. *The Annals of Regional Science*, *48*(2), 541–564.

Lammers, H. (2009). NREL Tests Energy Saving Office of the Future. Retrieved from http://www.nrel.gov/news/features/feature_detail.cfm/feature_id=1921

Leaman, A., & Bordass, B. (2007). Are users more tolerant of "green" buildings? *Building Research & Information*, *35*(6), 662–673.

Lo, S. H., Peters, G.-J. Y., & Kok, G. (2012). Energy-Related Behaviors in Office Buildings: A Qualitative Study on Individual and Organisational Determinants. *Applied Psychology*, *61*(2), 227–249.

Mael, Fred. Tetrick, L. (1992). Identifying Organizational Identification. *Educational and Psychological Measurement*, *52*, 813–824.

Nye, M., & Hargreaves, T. (2009). Exploring the Social Dynamics of Proenvironmental Behavior Change. *Journal of Industrial Ecology*, *14*(1), 137–149.

Peck, R. (2011). *Green Building Performance: A Post-Occupancy Evaluation of 22 GSA Buildings*.

Poll, Scott (2011). NASA Ames Collaborative Support Facility (Sustainability Base) *THE NEXT GIANT LEAP* [Powerpoint slides]. Retrieved from http://www.nasa.gov/sustainability-base/.

Salant, P., & Dillman, D.A. (1984). *How to conduct your own survey*. New York: Wiley.

Schuler, R., Grymes, R., Poll, S., & Wilmoth, K. (2012). NASA Ames Sustainability Base [Powerpoint slides]. Retrieved from http://www.nasa.gov/sustainability-base/.

Schultz, W. (1998). Changing Behavior With Normative Feedback Interventions : A Field Experiment on Curbside Recycling. *Basic and Applied Social Psychology*, *21*(1), 25–36.

Schwartz, S. H. (1977). Normative Influences on Altruism (Vol. 10, pp. 221–279). Madison: Univsersity of Wisconsin.

Seidel, S., Ye, J., & Solutions, E. (2012). Leading by example: using information and communication technologies to achieve federal sustainability goals, (September).

Staats, H. J., Wit, a. P., & Midden, C. Y. H. (1996). Communicating the Greenhouse Effect to the Public: Evaluation of a Mass Media Campaign from a Social Dilemma Perspective. *Journal of Environmental Management*, *46*(2), 189–203.

Thøgersen, J. (2008). Social norms and cooperation in real-life social dilemmas. *Journal of Economic Psychology*, *29*(4), 458–472.

Vanhoozer, A., & Probert, A., (2013). "*The Built Environment at Sustainability Base and the Occupant Experience."* Manuscript in preparation. College of Environmental Sciences, University of Idaho. Moscow, Idaho.

Vanhoozer, A.,(2014). *"Diffusion of Sustainability Base High Performance Building Technologies in the Workplace—Exploring Technological Innovations and Reinvention Potentials at NASA Ames Research Center".* Manuscript in preparation. College of Environmental Sciences, University of Idaho. Moscow, Idaho.

Van Vugt, M. (2009). Averting the Tragedy of the Commons: Using Social Psychological Science to Protect the Environment. *Current Directions in Psychological Science*, *18*(3), 169–174.

CHAPTER 3

"Adoption and Diffusion of NASA Green Building Technologies—Exploring Communication Channels and Perceptions of Innovation Characteristics at Sustainability Base"

Introduction: Green Building Innovation at NASA Ames Research Center

Sustainability Base at NASA Ames Research Center is a pioneer in green building innovation and net-zero energy technologies. Named after Tranquility Base, the site marking man's first landing on the moon, Sustainability Base demonstrates NASA's commitment to both space exploration and sustainable Earth systems (Siedel and Ye, 2012). The 50,000 square foot facility is located in Mountain View, CA, in the heart of Silicon Valley, and since 2012 has functioned as a working office and living test-bed research facility for net-zero energy technologies (Schuler, Grymes, Poll, and Wilmoth, 2012). The vision for the building was championed by Dr. Steven Zornetzer, Associate Center Director at Ames Research Center, who saw the opportunity to take the technologies used in creating livable conditions for space exploration and applying them to a showcase facility here on Earth:

> *"NASA had to build the highest-performing building in the federal government, embed NASA technology inside, and make a statement to the public that NASA was giving back to the people of planet Earth what it had developed for advanced aerospace applications"* (Steve Zornetzer, Siedel and Ye, 2012)

NASA has long been reputed for innovation and reinvention. Examples of NASA technologies adapted for terrestrial uses include Dustbuster vacuums, CAT scans, and high-tech sneakers, which use technology first developed for space suits (Baker, 2000). Sustainability Base adapted aerospace technologies to building information systems to maximize energy efficiency. The design for the building followed in the footsteps of the National Renewable Energy Laboratory Research Support Facility (NREL-RSF), the first government research and lab facility whose design called for a "net-zero" total energy footprint over the course of a year of building operations (Lammers, 2009). Sustainability Base's design achieved net-zero electricity by taking advantage of local solar and geothermal resources, and through the procurement of a 55% electric conversion efficiency solid oxide fuel cell called a Bloom Energy Box (Schuler et al., 2012). However, the building went beyond net-zero in two ways. The first was through adapting existing NASA technologies originally designed for advanced aerospace missions, such as intelligent control modeling and systems prognostics and diagnostics, to the study of building operations and maintenance performance capabilities (Poll, 2010). The second concept that took the building beyond net-zero involved the creation of the living test-bed model facility. Through this model, NASA engaged external research partners who wanted to test new building performance technologies with research staff on site. Technology partnerships for testing and research included building information modeling with Autodesk, Inc. and electric power demand sensing with Verdigris Technologies, as well as Integrated Building Solutions, Inc. (IBIS) and Enmetric Systems, both of which deployed customized interfaces for monitoring and analysis of systems from which occupants could obtain feedback about building-level and personal energy use (Schuler et al., 2012).

Our research at Sustainability Base explored the diffusion of technological innovations in a 3-year post-occupancy evaluation (POE) study. We employed a longitudinal research design that included survey research methods (see Appendix C), physical instrumentation, and qualitative case study procedures in the form of observation, journaling, and personal interviews. The over-arching objective of our study was to determine changes in occupant satisfaction and energy conservation norms and behaviors over a pre and post occupation time period that could be attributed to the building (Vanhoozer and Probert, 2014). Application of this research design to existing POE strategies contributed novel tools for evaluating quantitative changes in environmental behavior to the architectural research field. This paper concentrates on the qualitative component of the POE, which explored the dissemination of building technologies and the transference of sustainable behaviors from Sustainability Base to the homes of NASA employees. Through observation and semi-structured interview procedures, we sought to understand the experiences of building occupants and leaders at NASA and their responses to the adoption of the Sustainability Base building innovation at Ames Research Center. We used the Diffusion of Innovations Theory (DIT) framework (Rogers, 2003) as a lens for our inquiry, focusing on the relative advantages of the work environment for occupants, and the adaptability of the facility to Ames Research Center's organizational infrastructure from leadership perspectives. Additionally, we explored the potential for adaptation of ideas and practices implemented in the building to existing infrastructure at Ames Research Center and to the homes of employees.

According to DIT, innovations move through social networks via communication channels (Rogers, 2003). In the case of Sustainability Base, channels exist between occupants, managers, and researchers in the form of NASA's organizational infrastructure, Sustainability Base high performance building protocols, and employee interfacing with building systems. The research question that guided our inquiry was as follows:

How do communication channels in NASA social networks influence perceptions of the innovation characteristics and reinvention potentials in Sustainability Base? Sub-questions about the influences of communication channels on specific innovation characteristics included the following:

- *How is opinion leadership structured at Sustainability Base, and how does that structure affect access to communication* channels for building occupants?
- *"How do mission projects differ in terms of their needs in the building and the dynamics of their communication channels?"*
- *What role does the complexity of automated intelligent controls for building operations and maintenance play in perceptions of the building's overall function as a workplace?*
- *What are the relative advantages of building occupation for occupants in terms of satisfaction, comfort, and productivity?*
- *How compatible is the net-zero energy building with existing organizational infrastructure at Ames Research Center?*
- *How does trial-ability influence building functionality and occupant satisfaction?*
- *How effective is the observability of the building as a showcase for energy conservation? Does the building teach the occupants or affect their awareness of energy conservation?*
- *What reinvention potentials does the building offer for technology adaptation and sustainable behavior changes in the home? How has the building operations and maintenance model been adapted at Ames Research Center?*

Literature and Theory

"*Our problem is to learn why, given one hundred different innovations conceived of at the same time—innovations in the form of words, in mythological ideas, in industrial processes, etc.—ten will spread abroad while ninety will be forgotten*" (Tarde, 1903, p. 140). Diffusion of innovations began with the work of French sociologist Gabriel Tarde, and became popular as a theory during

WWII with the study of the adoption of technology for hybrid seed corn (Ryan and Gross, 1943). DIT was grounded in the communication field in the 1960's by rural sociologist Everett Rogers (Rogers, 2003; Srivastava and Moreland, 2012), and has since been used in a wide variety of applications, particularly in the area of information technology (Karahanna, Straub and Chervany, 1999; Baumann, 2008) to study the processes by which innovations are adopted and distributed through social systems.

An innovation is defined as an idea, practice, or object that is perceived as new by an individual or other unit of adoption (Rogers, 2003). The innovation decision is a process through which a decision-making unit passes from first knowledge of an innovation, to the formation of an attitude towards the innovation, to the decision to adopt or reject, to implementation and use of the new idea, and to confirmation of this decision. In the case of Sustainability Base, the adoption of the high performance workplace environment was an authority decision made by NASA Ames Associate Center Director Dr. Steven Zornetzer. As is often the case in organizational settings, the end users are not in the position to make adoption decisions. Innovation adoption is often accomplished through what Rogers (2003) coined opinion leadership. Opinion leadership plays a vital role in many innovations (see Nisbet and Kotcher, 2009 for an overview). Whether by means of organizational structuring, as was the case for NASA, or in the interest of simplifying the adoption process, administrators and professionals often function as filters in diffusion, and new technologies are screened for users who are either less informed or have less authority (Leonard-Barton, 1984). Depending on the innovation, it is common for lack of interest in on the part of individual recipients in being involved with the adoption decision process. "The more technically sophisticated is the innovation, the less inclined the intermediary is to share information with, or as he or she may perceive it, burden with information, the user (Nochur, 1982 as cited in Leonard-Barton, 1984). In fact, depending on the end user level of technical expertise and/or interest in a technology, the user may feel the greater need for information about the intermediary than they do the innovation itself. In the case of Sustainability Base, opinion leadership paved the way for innovation. Three separate mission projects were selected to move into the building, and occupant level of expertise and interest in building technologies varied according to mission, with engineering and science-oriented projects tending to express stronger opinions and greater interest in building technologies than administrative mission projects.

Innovation characteristics in DIT include relative advantage, compatibility, complexity, trial-ability, and observability (Rogers, 2003). We considered each of these, as well as reinvention, in terms of the communication channels present in the Sustainability Base context at NASA Ames Research Center. Relative advantage refers to the degree to which the innovation is perceived as better than the idea it supersedes, in the case of Sustainability Base defined as the perceptions of change from former work environments for NASA employees. Compatibility refers to the degree to which an innovation is perceived as being consistent with existing values, past experiences, and needs. In context, this was defined in terms of organizational values and mission project needs. Complexity, the third characteristic we considered, is the degree to which an innovation is perceived as difficult to understand and use. Because the building operated with automated controls, this characteristic pertained only to researchers and facilities management, and was defined as the navigability of systems operations and maintenance in Sustainability Base. Manual controls for occupants in Sustainability Base were limited, as the facility was commissioned with the following working hypothesis: *"Overall building performance can be improved, energy usage can be reduced, and individual occupant comfort can be better achieved through integrated building control utilizing intelligent, decentralized, and adaptive control strategies" (Poll 2010).* Trial-ability in DIT is defined as the degree to which an innovation may be experimented with on a limited basis, and referred to both researcher and occupant perceptions of their interactions with building systems. The fifth innovation characteristic explored for the study was observability, which refers to the degree to which the results of an innovation are visible to others. Observability was defined in terms of the showcasing abilities of Sustainability Base, as well as the perceived accountability or social norms generated by the building towards conservation-oriented behavior. Reinvention was the last innovation characteristic considered for this study, which refers in DIT to the degree to which an innovation is changed or modified by a user in the process of adoption and implementation. Our primary interest in this aspect of innovation involved the potentials for adaptation of systems encountered in Sustainability Base to implementation in home environments.

DIT & GREEN TECHNOLOGY DEVELOPMENTS

High performance building standards have grown in popularity, flourishing in the public and commercial sectors in the U.S. over the past decade (Kok, McGraw, and Quigley, 2012; Brown and Vergragt, 2008). Due to the introduction of green rating schemes, green office space has doubled in some cities, and there are a few metropolitan areas where one quarter of the building stock is green (Kok et al. 2012). In 2009, the federal government generated legislation mandating high performance building standards (Siedel and Ye, 2012), requiring that all new construction in design process by 2020 plan to achieve net-zero energy by 2030 (p.2). Apple, Hewlitt-Packard, and the Cities of Houston and Philadelphia are examples of industries and municipalities that have invested in net-zero energy technologies and policy-making within the past two years (ASHRAE, 2012). DIT has been used to study investments in energy savings in the green building sector (Kok et al., 2012), particularly the adoption of green office space in relationship to the introduction of rating schemes such as LEED and BREEAM (DeGroot, Verhoef, and Nijkamp, 2001). From a rating perspective, there has been concern that current rating systems may actually pose as impediments to more extensive future energy reductions. In a case study of residential net-zero energy in relation to building standard developments, Brown and Vergagt projected that if current standards level off “[they] could possibly become no more than a checklist for developers seeking public recognition and government subsidies” (p. 109, 2008). Communication channels have been studied in the diffusion literature in the context of local government adoption of climate change technologies over time (Pelz, 1983; 1985). In a study of municipal public services provided for conservation practices, impersonal or one-way channels (i.e. lectures, printed reports, journals, newspapers, radio, TV) were found to be effective at generating awareness, while personal or two-way channels were effective at persuasion and implementation (Pelz, 1983). Unfortunately, investments in implementation have been and remain to this day under-funded in federal research and development. Roberts-Gray and Gray (1983) pointed out the lack of funding allocated to implementation, where “only one-half of one percent of federal research and development dollars are dedicated to phases of innovation beyond diffusion” (p.213, 1983). As we interviewed leaders, researchers, and occupants in Sustainability Base, we discovered communication and funding were the greatest barriers to implementation.

Procedures and Analysis

Diffusion of Innovations provided an a priori theory to guide qualitative inquiry in deductive categorization of data. Data was categorized according to the innovation characteristics specified in Rogers theoretical framework (2003), which are relative advantage, compatibility, complexity, trial-ability, observability, and reinvention. Categories of data were then coded for emergent themes within each innovation characteristic using a thematic analysis approach.

SAMPLING

Purposive sampling methods (Miles and Huberman, 1994) utilized critical case and criterion subjects for the study. Critical cases included opinion leadership roles specific to the Sustainability Base innovation at NASA Ames Research Center. Criterion subjects were selected by mission project and sampled to theoretical saturation in order to explore group dynamics as affected by innovation characteristics in the work environment. Interview participation was solicited as a voluntary follow-up to survey research for the quantitative portion of the Post Occupancy Evaluation, which took place in November 2013. At that time, each occupant in the building was approached individually, thanked personally for their time, and given the opportunity to participate in a printed exit survey. During survey solicitation, occupants were directed to an insert in the survey, which provided information about follow-up interviews. Semi-structured personal interviews were conducted with a total of 19 participants in February/March 2014.

ANALYSIS

A priori codes were developed for interviews using Diffusion of Innovations theory constructs. Thematic analysis procedures (Braun and Clarke, 2006) engaged the primary researcher in an active role of inductive development of emerging themes from the data. Descriptive data points that had been initially grouped into DIT a priori categories were collated into unique attributes to generate themes. Inter-rater agreement between the primary researcher and principle investigator validated homogeneity of themes that emerged.

Thematic analysis is a qualitative research procedure that is used to identify patterns across data sets that are associated to a specific research question. Procedural emphasis is placed on organizing and describing data sets through codification of raw data prior to interpretation. Processes of interpretation vary, but generally follow the concept of supporting assertions with data from grounded theory (Strauss and Corbin, 1990). As mentioned, our research employed a priori categories from DIT literature as codes for interview data (Lewins, Taylor, and Gibbs, 2010). We interpreted codes with the objective of developing themes useful for highlighting similarities and differences between mission projects and leadership roles across data sets. This generated insights related to communication channels within the DIT framework, which were suitable for informing high performance building design and operations.

Results and Discussion

We asked the question “*How do communication channels in NASA social networks influence perceptions of the innovation characteristics and reinvention potentials in Sustainability Base?* Communication channels in diffusion of innovations refer to the message content exchanged concerning new ideas. The nature of the information exchange relationship in this fundamentally social process determines the conditions under which transfer will occur (Rogers, 2003). In the case of NASA, authority decision-making determines organizational functions, and the adoption of the Sustainability Base building innovation resulted from opinion leadership in the Executive Branch, the Office of Strategic Infrastructure, and the Associate Center Director at Ames Research Center. However, successful implementation of high performance building objectives requires existing infrastructure at Ames to adapt to new functions, adopt new methods of communication, and create new channels in order to achieve conservation-oriented goals. Results of this study highlight the successes and challenges experienced during implementation communication processes at Sustainability Base, and discuss implications for future innovations.

OPINION LEADERSHIP AT SUSTAINABILITY BASE

“How is opinion leadership structured at Sustainability Base, and how does that structure affect access to communication channels for building occupants?” Key innovation leadership roles at Ames Research Center included the Associate Center Director, Research Coordinator and technical support staff, Facilities Services Manager, and Mission Project Management, all of which have been instrumental in the ongoing building operations and maintenance communications at Sustainability Base. Associate Center Director Dr. Steven Zornetzer was primarily responsible for instigating change in development decisions regarding new building plans at Ames Research Center. In 2008, he attended a 30% design review for the proposed new facility at Ames, and described his reaction to what he saw presented:

> *“I saw a building that was a very conventional building that could have been built in 1990, that had nothing exceptional about it. It didn’t embrace energy efficiency and sustainability in any way. This was our first new building in 25 years, being proposed to be built here at NASA, in the heart of Silicon Valley in the 21st century. I stood up in the room with 50 people and basically just called time out. I said we should not build this building. We will not build this*

building. We have to build the building that's much more representative of what NASA can do in the 21st century in the heart of Silicon Valley. We need to be more innovative" (Steven Zornetzer, Personal interview, March 2014)

From that point forward, the design for what would become Sustainability Base began under Dr. Zornetzer's direction. Research coordination and technical support roles that developed along with the building involved the creation of supportive infrastructure that would integrate building objectives with federal regulations and facilitate external research partnerships. Rosalind Grymes, lead Research Coordinator for Sustainability Base, described her vision for building operations research as follows:

"In a habitat it's important that you use and reuse all of your resources maximally all the time and manage them in an integrated fashion. All of those mission critical research areas are also relevant to managing a building, for building energy use, the building's optimization strategy, and the building's resource dynamics. They can all be applied and that's the way we win" (Rosalind Grymes, Personal Interview, February 2014).

The Facilities Services Manager (FSM) role at NASA traditionally acts as a liaison between operations personnel (information security and facilities operations and maintenance) and the occupants for a given building. This role was filled by Krisstina Wilmoth, who was tasked with FSM duties, as well as managing the logistics of building commissioning and occupation for external research partnerships and the mission projects selected to move into the building. Management from three mission projects including an Earth Science research group, marketing and finance administrative group, and the Stratospheric Observatory for Infrared Astronomy (SOFIA) mission, worked with the FSM to transition their groups into the building.

PRE-OCCUPATION PLANNING OUTCOMES FOR MISSION PROJECTS

"How have mission projects differed in terms of their needs in the building and the dynamics of their communication channels?" Planning and communications between opinion leaders and mission project management prior to occupancy made a big difference in how much information and inputs managers had as they coordinated transition to the new building. This set a precedent that continued to affect the dynamics of the work environment post-occupancy. Mission project transition began anywhere from 18 months to just a few months prior to occupation for each group,

depending on when the decision to move into the building was finalized. This scenario presented group managers who committed to moving early in the planning process with an advantage, as they were given more information and opportunity to provide inputs to the FSM and construction teams regarding their group needs. The FSM designed center-wide informational meetings to engage mission projects in the occupancy planning process, and commented in a personal interview on the positive impacts of attendance for the groups who moved into Sustainability Base:

> *"It was always good because our all-hands, typically they're organizational wide meetings, and a lot of the people attended who were moving into the building from these groups. For example, for our Earth Sciences group who sit in my wing, not only were they and all of their peers engaged in that early on, they then got to down select from their organization which people would actually move into the building, so they had a very different level of motivation, interest, and connection based on that. The other group, the financial and travel folks who were moving in, they didn't get a say per se whether or not they were moving into the building, but they were engaged early on and got to be a part of that process. Then as I said, the first floor occupants missed out on all that, nearly 18 months of work with them"* (Krisstina Wilmoth, Personal Interview, February 2014).

In general, occupant pre-disposition towards the new work environment resulted from the degree of change from their previous work environments and from communication with management, specifically access to personal channels and feedback. Pre-occupation Center-wide meetings generated positive interest at Ames and were well attended by future occupants, however, communications specific to building protocols after the building was commissioned were not funded. Training for occupants in terms of manual overrides for automated systems and regarding appropriate conduct in the cubicle environment was left to mission project managers, who were instructed to contact the FSM in the event of a building-related issue. For occupants, this meant that personal access to communication with their management was important to their perception of successful transition to the new work environment. Marketing and finance mission staff retained a dedicated position within their mission project to interface with occupants, management, and the building FSM, resulting in effective communication channels. Additionally, the previous work environment for their group had been a cubicle environment. For the Earth Sciences group, the change in work environment was greater, as most staff transitioned from private offices into cubicles. This transition was largely successful due to availability of personal communication channels between management and a much smaller number of staff than the marketing and finance mission project. However, a number of occupants have struggled to overcome the distractions of the cubicle environment in order to maintain focus for research-related work productivity. This has been an issue particularly when visitors or new occupants who are unaware of noise level sensitivities have come to the building. Finally, the SOFIA mission project faced the greatest challenges for occupant transition to Sustainability Base, because their group had the least amount of preparation time for the move, a marked change in work environment for many staff, and the least amount of personal communications with management. For many staff, particularly scientists who struggled with the distractions the cubicle environment imposed on their work productivity, these factors set a negative precedent for communication in the building.

COMMISSIONING AUTOMATED INTELLIGENT CONTROLS

"What role does the complexity of automated intelligent controls for building operations and maintenance play in perceptions of the building's overall function as a workplace?" Opinion leaders at Ames Research Center chose an automated approach to systems controls during the building design process, knowing that there were trade-offs, but believing that because of the software strength at NASA, *"we would be able to create a control system for the building, create the software for that control system that would enable the autonomous control of the building to operate very effectively, without having to rely on manual control"* (Steven Zornetzer, Personal Interview, March 2014). Automated control strategies have been marginally successful since the building has been occupied for a number of reasons. First, agendas between facilities operations and maintenance personnel and research staff are different. Second, data management and administrative control in the building has not been clearly articulated, and operations and maintenance resources are not available to address communication barriers through dedicated systems administration staffing. Finally, communication obstacles have slowed progress in realizing the building's vision for occupants.

In the absence of a dedicated systems administration position, building operations became the responsibility of facilities operations and maintenance personnel, whose objectives for the building differed from research staff interested in testing new systems and integrating intelligent controls into automated systems:

> *"The facility's folks have different culture and they speak and respond in that different culture. They tend to be more deliverable and contract oriented. When you ask them for*

something it's not an open ended thing it's a thing that you need by Wednesday and a specific thing and if it's not done it has a consequence. They're used to that and they're less used to the open ended let's try this. If it works, if it doesn't work there's no harm we'll try something else" (Rosalind Grymes, Personal Interview, February 2014).

Research and technical support staff have struggled to establish a working relationship with both operations and information security personnel groups. One technical support employee commented feeling like he could be in "read-only" mode when it came to conducting building related research:

"Basically, as a researcher, I haven't really been ultimately involved with the administration of that machine. It's really been someone else from Code J. because there's this disconnect about who is actually the steward of this, is it the researcher? Is it operational? It ends up, by default, going to the operator. So I say, "Okay. Don't touch anything until we get it ... it's basically, firewalled, until we can figure it out properly. It puts a halt on research completely because I can't collect data for our external research partners" (Technical Support Interview, March 2014).

The request for at least one dedicated central point of contact (POC) position in the building to manage automated systems, monitor data, and direct systems integration processes has been brought to the attention of opinion leaders. However, resources are not available to create the role, and would not solve obstacles related to differences in organizational culture. Cultural barriers have thus far been overcome through authority and personal communication channels:

"It was more personal connections… and a system administrator over here that I really got a lot of stuff done. Going forward, we actually are still hitting on our systems group to help us out a lot, but it is also … it's still not paid. These guys are doing it because we have a personal relationship with them and we've told them, "Hey, if we start asking more than you guys feel that you can do, because you have to work on your other projects, you can push back and just let us know." But they're enthusiastic about it because we've been communicating to them, "Hey, this is really cool. Will you do this? Will you do that?" they're doing it because they want to do it" (Technical Support Interview, March 2014).

The challenges of building systems operations management have been noted by disappointed occupants who have sought out information from advertised sources in the building and gotten no feedback:

> *"I tried going to the website for the building and could never find anything there. I wrote to the website for the building, what happened to this and this and this and never got any reply. None. When I went to talk to people, the answer was well, we're pretty busy. So guess what? I don't use that site. Not only does nobody care, but how do I know they've been resolved? They never told us. If they told us by the way, this feature's now available, I'd go look. I went and looked for months after I moved in, they weren't available, I gave up.* (Occupant Interview, March 2014).

RELATIVE ADVANTAGES OF THE WORK ENVIRONMENT

What are the relative advantages of building occupation for occupants in terms of satisfaction, comfort, and productivity? When occupants were asked to compare Sustainability Base as a work environment to their previous work environments, opinions varied according to mission project dynamics, however, several general themes emerged from interview data. Themes pertained to two factors, including spatial dynamics and building systems features in the work environment (see Table 1). Spatially oriented themes included isolation vs. collaboration in the cubicle environment, personal space and privacy, and unintended dynamics in open spaces.

Occupants from all mission projects described both advantages and disadvantages to having more direct contact with co-workers. Most enjoyed no longer feeling isolated in private offices, and felt their productivity was enhanced by proximity to co-workers, as well as having social cues as to whether or not someone was available in the open plan work space:

> *"…the open environment I thought was a fairly good one in the sense that it made it easier to know when people were perhaps available for conversation, or not. You had the cues of whether somebody was already having a discussion with someone else. Or if they were making a phone call, or some other activity that otherwise you might, you know, traipse down to their office and then wait and go back and forth"* (Occupant interview, March 2014)

Drawbacks of the open space involved noise, visual distractions, and a general lack of privacy, which led to difficulty concentrating for some. Telephonic communications were particularly distracting to neighboring cubicles, and occupants reported that line of sight visibility, particularly through glass walls in huddle spaces and private offices, made it impossible to find space for privacy anywhere in the building. When asked about use of huddle spaces and conference rooms for confidential conversations, occupants reported a pervasive lack of speech privacy in the building. Glass partitions compounded this issue. Noise, and in many cases lack of visual privacy, made huddle spaces ineffective. One occupant commented, *"It's awkward to go into a huddle space that's right next to somebody's work area unless it's yours. Unless it's your work area. You're in there, you're having a conversation and they can hear you and they can see you"* (Occupant Interview, February 2014). Unintended dynamics of public spaces were not limited to huddle and conference rooms. Because of the awkwardness of line of sight and sound to adjoining work areas, break areas and collaborative meeting spaces were almost never used at all.

Three themes emerged for relative advantages of building systems in the new work environment. The first was a resounding positive response to natural daylight and windows in the space. The building was oriented to capture both wind and light in an optimal fashion, and operable windows at occupant desk heights provided manual controls. One occupant commented on appreciating the building's connection to the natural environment:

> *"In summer, when the windows are open, it feels like you're sort of connected to the outside, which is really nice. It's mostly birds and occasional cars going by. I think it's nice to feel connected to the environment around you. The sun comes up… you realize it's going down as you're leaving"* (Occupant Interview, February 2014).

The second building systems theme was a preference for manual controls over automated systems. Many studies have shown that occupants want some degree of autonomy when it comes to their workspace (Goins & Moezzi, 2011; Federspiel & Villafana, 2003; Bauman, 1999). This was particularly true for occupants in Sustainability Base who were part of a mission that occasionally required them to work at night, during which time automated systems made it very difficult to continue working:

> *"I'm here at seven and the building says it's time to go home. Of course, we work in an observatory that works at night. It's really silly to have the heat and the light go off. While night-time operations don't happen here, the people that support them still work here. I might be here at nine or ten o'clock at night doing work supporting people who are down*

south doing night-time operations, and every hour I have to get up and turn the lights back on. I can't turn the heat back on; it's off" (Occupant Interview, March 2014).

The third systems theme that emerged from interviews was a pervasive lack of speech privacy in the building. This issue resulted in a speech privacy analysis to physically document the location and severity of noise problems throughout the building (Vanhoozer & Probert, 2014).

TABLE 3.1: Thematic Analysis: Diffusion of Innovations Communication Channels at NASA Ames Sustainability Base

CATEGORY	THEME	DESCRIPTIVE ATTRIBUTES
RELATIVE ADVANTAGES: SPATIAL DYNAMICS	***ISOLATION VS. COLLABORATION***	
		●LESS NEED FOR FORMAL MEETINGS ●MORE DIRECT CONTACT WITH STAFF FOR MANAGERS ●COWORKERS IN IMMEDIATE WORK AREA VS. BEHIND CLOSED DOORS ●IMMEDIATE AVAILABILITY CUES VS. WALKING TO AN OFFICE AND WAITING ●PROXIMITY TO WORK GROUP ●ENHANCED ACCOUNTABILITY TO STAY ON TASK ●NOISY ENVIRONMENT CAN HINDER CONCENTRATION ●NO PRIVATE DISCUSSIONS AT INDIVIDUAL DESKS ●PRODUCTIVITY AFFECTED FOR SOME ROLES
	NO PERSONAL SPACE/PRIVACY	
		●DIFFICULT TO FILTER OUT DISTRACTIONS WHEN ONE NEEDS TO CONCENTRATE ●CONCENTRATION INHIBITED BY NOISE AND LINE OF SIGHT ●BROADCASTING- EVERYTHING ONE SAYS/DOES IS PUBLIC ●LACK OF WALL SPACE AFFORDS VERY LITTLE OPPORTUNITY TO PERSONALIZE WORK AREA
	UN-INTENDED DYNAMICS IN OPEN SPACES	
		●HUDDLES ADJACENT TO CUBICLES FEEL AWKWARD AS THEY LACK VISUAL AND ACOUSTIC PRIVACY ●SEMI-OPEN MEETING AREAS RARELY USED/DISRUPTIVE WHEN USED ●HUDDLES ARE BEING CONVERTED INTO PRIVATE OFFICES
RELATIVE ADVANTAGES BUILDING SYSTEMS	***WINDOWS ARE THE BUILDING'S BEST FEATURE***	

		●EVERYONE RESPONDS POSITIVELY TO NATURAL DAY-LIGHT AND FRESH AIR ●WHILE WORKING IN THE BUILDING ONE FEELS CONNECTED TO THE NATURAL ENVIRONMENT ●OPERABLE WINDOWS ARE A GREAT FEATURE ●SOUTH-FACING WORK SPACES EXPERIENCE SEASONAL GLARE DUE TO LACK OF SUFFICIENT SHADING CONTROLS
	MANUAL CONTROLS ARE PREFERRED	
		●ADJUSTABLE DESK HEIGHTS AND SEATS ARE GREAT FEATURES ●OPERABLE WINDOWS ARE GREAT FOR PEOPLE WHO SIT NEXT TO THEM ●RADIANT HEAT RESPONSE IS TOO SLOW AND INSUFFICIENT ●OVERHEAD LIGHTING SYSTEM MANUAL OVERRIDES ARE NOT USER FRIENDLY
	SPEECH PRIVACY IS NON-EXISTANT	
		●PRIVATE OFFICES, CONFERENCE ROOMS, HUDDLES PARTITIONS DO NOT EXTEND TO THE CEILING; SOUND CARRIES INTO ADJACENT SPACES ●WALL THICKNESS INSUFFICIENT TO BLOCK ADJACENT NOISE ●VISITORS UNAWARE OF ACOUSTIC PROTOCOLS CAN BE VERY DISRUPTIVE
AGENCY COMPATIBILITY WITH GREEN BUILDING	***INCOMPATIBLE POLICIES***	
		●APPROVED SPACE HEATERS VIOLATE OSHA REQUIREMENTS ●GREEN EXTERIOR VERTICAL SHADING VIOLATES OSHA MAINTENANCE REQUIREMENTS ●RECEPTION FACILITATION REQUEST DENIED DUE TO NASA CIVIL SERVANT POLICY
	DIFFERING CODE AGENDAS	
		●PERSONAL CONNECTIONS BETWEEN CODES ARE KEY TO ACCOMPLISHING BUILDING GOALS ●RESEARCH AND PUBLIC VISIBILITY OBJECTIVES HAVE TO LEARN TO SPEAK TO NASA IT SECURITY AGENDA ●DELIVERABLE/CONTRACT ORIENTED FACILITIES CULTURE VS. OPEN-ENDED, EXPLORATIVE ENGINEERING RESEARCH CULTURES MUST COLLABORATE TO ACHIEVE BUILDING GOALS ●DATA OWNERSHIP AND MANAGEMENT IS UNCLEAR
		●RESOURCES ALONE DON'T SOLVE DIFFERENCES IN ORGANIZATIONAL CULTURE
TRIAL-ABILITY	***TEST-BED MODELING***	

		●SUSTAINABILITY BASE IS NASA's BUILDING TECHNOLOGY DEMONSTRATION SITE ●RESEARCHERS WANT OCCUPANT FEEDBACK IN THEIR TRIALS ●PROPRIETARY TOOLS IN BUILDING INDUSTRY LIMIT ADAPTABILITY ●DATA OWNERSHIP AND MANAGEMENT ISSUES HAVE PLACED RESEARCHERS IN READ-ONLY MODE
	FEW MANUAL CONTROLS FOR OCCUPANTS	
		●RETROFITS FOR MECHO-SHADE MANUAL CONTROLS ARE IN PROGRESS ●AUTOMATED CONTROLS NEED TO RELY ON MANUAL OVERRIDES TO ACHIEVE OCCUPANT COMFORT ●MANUAL OVERRIDES ARE NOT AVAILABLE OR NOT WELL COMMUNICATED TO OCCUPANTS ●NIGHT TIME OBSERVATIONS FOR FIRST-FLOOR MISSION PROJECT ARE HINDERED BY LACK OF MANUAL CONTROLS
OBSERVABILITY	***PUBLIC SHOWCASE***	
		●NASA IS TAKING THE LEAD ON BUILDING INNOVATION, ON PAR WITH GOOGLE, ADOBE, AND ORGANIZATIONS KNOWN FOR INNOVATION ●NASA HAS AN UNBIASED REPUTATION AND IS WELL-SITUATED TO PROMOTE ENERGY EFFICIENCY IN BUILDINGS ●NASA THOUGHT LEADERSHIP IN THE CLIMATE CHANGE ARENA MAKES SENSE, AS THE AGENCY SUPPORTS MUCH OF THE EARTH SCIENCE CLIMATE CHANGE RESEARCH IN THE USA
	NORMATIVE INFLUENCES	
		●GREEN PROTOCOLS HAVE MADE OCCUPANTS MORE AWARE OF ENERGY CONSERVATION IN THE BUILDING ●CONVENIENCE IS A MOTIVATOR TO BE GREEN ●SALIENCE OF NORMS VARIES ACCORDING TO MISSION PROJECTS ●BUILDING DESIGN SHORT-COMINGS(I.E. NO CEILING-HEIGHT PARTITIONS, WASTED PAPER TOWELS, NO FOYER IN THE MAIN ENTRYWAY) CONFUSE OCCUPANTS
REINVENTION: WORK TO HOME TRANSFER	***HOME AWARENESS***	
		●BUILDING ENHANCED AWARENESS OF PLUG LOAD USE AT HOME ●OCCUPANTS NOTICED THE BUILDING LANDSCAPE PLANTINGS AND LOW WATER USE STRATEGIES

		●BUILDING USE OF WATER FOR HEATING AND COOLING INSPIRED INFORMATION SEEKING AT HOME ●MOST HOME INVESTMENTS IN HIGH TECH. SYSTEMS ARE COST PROHIBITIVE
	HOME BEHAVIORS: INVESTMENTS AND HABITS	
		●LOW HANGING FRUIT HAS ALREADY BEEN PICKED VIA ENERGY SAVING APPLIANCES, BULBS, MODIFICATIONS TO REMOVE PHANTOM POWER DRAW ●PASSIVE HEATING AND COOLING STRATEGIES ARE MORE APPARENT AT HOME ●INFORMATION SEEKING SPECIFIC TO ELECTRICITY AND WATER SAVINGS IS ON THE RISE ●KNOWLEDGE IS BEING PASSED ON TO OCCUPANT'S CHILDREN
REINVENTION: BUILDING AND NASA INITIATIVES	***BUILDING INITIATIVES***	
		●AUTOMATED INTELLIGENT CONTROLS THAT ADAPT FOR INCREASED ENERGY EFFICIENCY OVER TIME IS THE BUILDING'S OVERARCHING GOAL ●ALGORITHMS USED IN NASA's INTELLIGENT SYSTEMS DIVISION FOR SPACE PROPULSION AND AVIATION SAFETY ARE RE-DEPLOYED FOR SUSTAINABILITY BASE BUILDING OPERATIONS AND MAINTENANCE
	AGENCY INITIATIVES	
		●CENTER-WIDE RECYCLING ADOPTION ●COMPOSTING CONVERSATION ●ELECTRIC VEHICLE CHARGING CONVERSATION

BUILDING COMPATIBILITY WITH NASA INFRASTRUCTURE

How compatible is the net-zero building with existing organizational infrastructure at Ames Research Center? As a living test-bed facility and working office space for an occupant population with diverse functions at NASA, Sustainability Base faced unique operational challenges. Two themes involving policy compatibility and agenda compatibility between NASA functions emerged from interviews (see Table 1). Agenda compatibility, discussed earlier, referred to differing objectives between operations personnel and research staff in the building. Compatibility with regards to government policy and adaptation for the living test-bed facility presented several challenges. For example, green building policy for a LEED Platinum facility specifies provision of approved space heaters for occupants experiencing thermal discomfort. When occupants requested space heaters in Sustainability Base, they encountered the following obstacle:

> *"We were told that we couldn't have heaters unless they were the approved heaters. I'm like, okay, that's fine I'll take an approved heater. Then they said but you can't have a heater unless it's at least four feet away from any flammable surface. My cubicle is too small to actually have any heater in it anyway. There is no way for me to ever have a heater. Yes, you've approved a heater but I can't have it because my cubicle is not large enough for it in order to pass their safety criteria…you are approved to have a heater but you can't have a heater within so many feet of any wall or something like that, which completely excluded every cubicle space"* (Occupant Interview, March 2014).

The second obstacle involved Civil Servant status requirements at NASA, which prevented the SOFIA mission's Public Education and Outreach Department from attempts to facilitate reception in the building for visitors. If organizational hurdles can be overcome, this feature could greatly enhance communication in what was designed to be the Federal Government's showcase facility for net-zero energy technology.

BUILDING TRIALABILITY

How does trial-ability influence building functionality and occupant satisfaction? Trial-ability in DIT is the ability to experiment with systems on a limited (trial) basis. As a living test-bed for building technology research, this innovation characteristic in Sustainability Base is vital to the success of building operations. The first theme that emerged from this category was the test-bed model vision. Despite organizational compatibility obstacles and the complexities inherent with automated intelligent controls, opinion leadership at Ames is confident that, with the right partners and resources, the building will *"demonstrate certain things that only NASA can, and bringing NASA aerospace technology back into this building to show how certain kinds of control systems or closed-loop systems can operate within the building to save water, energy, and maximize efficiency"* (Steven Zornetzer, Personal Interview, March 2014). Since 2012, NASA has contracted with several partners in ongoing research efforts. One such partner is Autodesk, a world leader in 3-dimensional design software, who began research and testing at Sustainability Base in 2012 called Project Dasher. Project partners are currently working with NASA scientists to build modeling software that can visualize systems in N232 and monitor real time and historic use patterns in the building. The

Interactive Building Information Model (BIM) under construction will be capable of visualizing architectural, mechanical, plumbing, power, controls and interior design. The software is designed to monitor real-time and historic use patterns, and to interact with NASA's knowledge-based filters to provide information regarding maintenance, upgrades and facilities operations. At the occupant level, electrical plug loads are the fastest growing segment of commercial energy demand (Kaneda, Jacobson and Rumsey, 2010). Anticipating this, NASA partnered with Enmetric Systems to pilot a plug load management system in the North wing of the building. The Enmetric system allows loads to be turned off when not in use, eliminating wasted electricity. In addition to monitoring, Enmetric systems enable occupant viewing and control of their personal electricity usage. This feature has not yet been fully activated in the building.

Another aspect of trial-ability for research partners in Sustainability Base is the opportunity to engage occupants in building research. For example, when a potential research partner, View Glass, approached Sustainability Base research staff in 2013 with a proposal for a dynamic glazing installation, the opportunity to address a known glare issue in the Southwest facing offices helped research staff and external partners select the location for the installation. The relationship is reciprocal, in that *"…what View wants out of the relationship is just occupancy feedback. They're not interested in the energy modeling; they've done all of that. They have their charts, but they would like to have NASA people saying this is a more comfortable space"* (Rosalind Grymes, Personal Interview, February 2014).

A major obstacle currently facing research and technical support staff as they work to integrate building systems has to do with the proprietary nature of building industry tools:

> "*The industry and all the vendors that create products for buildings are still operating in a proprietary 20th century model and this building I thought, mistakenly, could operate in a 21st century model. That and specifically what I'm referring to is the inability for us to easily get the subsystems of the building to talk to one another and to communicate with the major control system, the Siemens control system, for the building. None of those systems really work seamlessly together. They're all proprietary software, they all talk to themselves and no one else and it's very difficult"* (Steven Zornetzer, Personal Interview, March 2014).

BUILDING OBSERVABILITY

How effective is the observability of the building as a showcase for energy conservation? Does the building teach occupants or affect their awareness of energy conservation? Two categories of observability themes emerged from Sustainability Base—the building as a showcase to the public, and the building as a normative tool for enhancing energy conservation awareness for building occupants. NASA has two observability advantages pertaining to public showcasing for energy conservation initiatives. First, the agency has an unbiased reputation in the public eye.

> *"NASA is a very trusted organization, I think. I don't think people see NASA as a politically-motivated organization or one that's biased in any way. We deal with data and we share data and we interpret data. That's what we do. If we can do that with this building and be very objective in terms of being able to evaluate new technologies that are tested in this building, do they work, how well do they work, do they not work, this one worked better than another, then I think people can take advantage of what we've learned and be able to then take that information and use it in other applications"* (Steve Zornetzer, Personal Interview, March 2014).

Second, NASA has developed and operated much of the technology in the United States used for observing climate, and as such has supported the research related to climate change. *"…for NASA that an idea, probably an initiative, across the federal government that was likely to take hold had to do with sustainability at large, whether it was greenhouse gasses or water or resource management cradle to cradle…It made a lot of sense for us to be a leader, a thought leader in that arena"* (Rosalind Grymes, Personal Interview, 2014).

The building generated awareness of energy conservation for occupants through green protocols. Occupants reported changes in awareness of energy use, though salience of norms varied between mission projects (Table 1). Social norm influences in the net-zero energy work environment were examined in detail in survey research for the Sustainability Base post occupancy evaluation case study (Vanhoozer, Sanyal, Heinse, & Thorsteinson, 2014).

BUILDING REINVENTION POTENTIALS

What reinvention potentials does the building offer for technology adaptation and sustainable behavior changes in the home? How has the building operations and maintenance model *been adapted at Ames Research Center?* Reinvention is the adaptation of an innovation during the diffusion process. Themes emerged via transfer of behaviors to home environments from Sustainability Base and as ideas diffused to Ames Research Center (Table 1). Occupants described several building features that generated increased awareness of electricity use at home. *"When we first moved in, they had some of our computers on an automatic shutdown cycle. I thought, okay, that would be a good thing to do, for certain times later if someone at home forgot and left on a computer"* (Occupant Interview, March 2014). Occupants also became more aware of water use strategies for thermal controls in the building, such as hot water radiators, and water savings through native landscape features. Home habits and energy-saving investments were characterized by low hanging fruit that had already been picked (i.e. energy star appliances, light bulbs, and passive heating and cooling strategies), and retrofits that were either unfeasible or cost prohibitive in the home.

In many ways, Sustainability Base embodies reinvention, as the building's primary objective is one of adaptation.

> *"A lot of different algorithms that we have are just easily translatable to two different applications. You can work a lot on years for, like developing an algorithm and recognize that this can clearly tap into a different domain entirely…you're using this [technology] in the built environment, even though it was originally intended for a completely different application. You're having that knowledge of, not just what we're doing here, space related missions in OTI, but also knowing something about building technologies area. It's really coming full circle from my perspective"* (Technical Support Interview, March 2014).

Investment in the building has initiated Center-wide initiatives and conversation amongst opinion leadership at Ames Research Center. Single stream recycling has been adopted Center-wide and is in implementation stages. Conversations about composting and adoption of electric vehicle charging have also been circulating, with long term objectives for an agency-wide initiative to implement electric vehicles.

LESSONS LEARNED & THOUGHTS FOR FUTURE STUDY

NASA is taking the lead on energy efficiency in building design technology, demonstrating commitment to their role through investment in the Sustainability Base innovation. Diffusion of innovations theory serves as a focusing lens to evaluate the effectiveness of their mission, and has provided a wealth of useful information through this study that can be applied to future innovations in building design and operations. By framing the characteristics of the innovation at NASA Ames in terms of communication channels and the social network in which it has been applied, we begin to understand the fundamentally social processes through which these ideas have taken shape and mobilized. We also obtain a clearer picture of where efforts might be concentrated so that future innovations can diffuse more efficiently.

This study has provided insights that can improve NASA operations and architectural planning and design efforts. First, NASA as an organization needs to not only anticipate, but to celebrate the human element of sustainability in building operations. This can be accomplished through DIT implementation planning strategies, which include establishing vested contractual relationships during planning phases, anticipating building-related policy incompatibilities, and addressing differing operational agendas. From an architectural planning and design perspective, celebrating the human element means balancing efficiency gains from collaborative spatial design with occupant privacy needs, integrating manual controls and overrides into building design, and incorporating workstation-level feedback that is specific enough to be useful to the occupant.

Implementation planning strategies are vital to the success of innovation diffusion. In the case of the Sustainability Base innovation, opinion leaders recognized once the building was commissioned that the contractual relationship with designers and the agency did not invest designers in operations and maintenance procedures. This type of relationship generated issues with incompatibility in design specifications and government regulations for health and safety that created problems for building operators (see Table 1 “incompatible policies”). Another component of implementation addresses organizational agendas and potential barriers to implementation (see Roberts-Gray and Gray, 1983, for a model of implementation of innovations in organizational settings). Barriers typically involve ineffective communication channels and lack of resource allocation to the implementation stages of an innovation. Ineffective communication channels are usually impersonal channels (i.e. email). Impersonal communications have been shown to be effective in generating awareness, however, personal channels are the key to innovation implementation success (Pelz 1983).

Architects designing to high performance industry standards should celebrate the human element in design. Building models need to balance the efficiency gains associated with collaborative spatial design (i.e. increased light and air flow) with consideration for occupant privacy needs. In Sustainability Base, the greatest disadvantage for occupants was a lack of speech privacy, which occurred even in areas designed for privacy due to lack of ceiling-height partitions and adequate wall thicknesses. Appropriate construction for acoustic privacy requires ceiling-height partitions and STC ratings for wall thicknesses that prevent excess noise greater than 6 decibels from intruding in spaces designed for privacy. Lack of traditional heating, cooling and ventilation and associated “white” noise also made open plan areas very quiet. This was exacerbated by large areas of highly reflective surfaces on glass walls and radiant chill panels suspended from the ceiling. Building operators were left with the recourse of retro-fitting spaces with acoustic panels and exploring options for closing the gaps between the walls and ceiling between private offices, huddles, and conferencing spaces and the open plan work areas (white noise machines were not an option). However, these measures could not remedy the unintended lack of privacy generated by the glass walls in huddle spaces, private offices, and dividing spaces between cubicles. Occupants complained not only of conversational noise, but also line of sight distractions in spaces where partitions were made of glass. This finding presents a challenge to designers who want to satisfy clients without sacrificing natural light.

Post-occupancy evaluation studies have determined a preference for integrating manual controls into building designs (Goins & Moezzi, 2011; Federspiel & Villafana, 2003; Bauman, 1999). This is particularly important in Sustainability Base, because of on-going experimentation with automated systems. Implementation of manual controls is not only preferable, but installation of work-station level data monitoring through a design such as the Personal Environmental Module (PEM) could provide data for building researchers about occupant needs and preferences (see Bauman, Baughman, Carter, and Arens, 1997 for an overview). Research partners such as View Glass, who are currently experimenting in the building, have already indicated a primary interest in occupant feedback in their trials. This presents an untapped opportunity for both research partners and occupants.

Lastly, occupants reported increased awareness of electricity behaviors and passive strategies for thermal control at home that they attributed to experiences with the systems in Sustainability Base. This awareness could be enhanced and solidified by full commissioning of the Personal Energy Use Dashboard feature, which was advertised, but has not yet become operational, as a workstation component for occupants. Additionally, occupants benefit from and respond the most to feedback that is specific and engaging to the individual. The IBIS system in the lobby provides building-level data, which enhances the building’s showcasing visibility, however, does not engage occupants in dynamic interfacing to monitor personal energy use. One occupant's vision for feedback was described in an interview as follows:

> *"I know that when Prius's came out, people started affecting their driving habits trying to get that miles per gallon number up because they could see it. I thought that the same thing would happen here, that we'd have people going around turning off lights and doing things to see if they could be ahead of the curve and be more efficient than other people. That's never happened. That's the biggest excitement on my part, but the biggest disappointment as well"* (Occupant Interview, March 2014).

Occupant interfacing that engages them in the energy use equation, rather than removing them from it, is the balance designers should strive for as they envision the building of the future. NASA is uniquely positioned to lead in the design and implementation of sustainable environments here on Earth. To that effect, despite the inconveniences and obstacles ahead, the sentiment of the majority in the Sustainability Base is well captured by this occupant's statement:

> *"I actually think this is a really good thing for the government to be doing. A NASA facility is one of the organizations making this investment. Where else do I see it? I see it at Adobe and I see it at Google, and I see it at other places that are known for innovation. When you look around this place, you see a bunch of eighty year old buildings that use a lot of power, and I'm proud of my corporation, I work for NASA, and I'm proud of them for taking the lead in that" (Occupant Interview, March 2014).*

References

Baker, D. (2000). *Scientific American Inventions From Outer Space: Everyday Uses For NASA Technology*. New York: Random House.

Baumann, J. (2008). From Corn to Computers: Diffusion of Innovations. *Conference Papers -- National Communication Association* (pp. 1–21).

Bauman, F. S. (1999). Giving Occupants What They Want : Guidelines for Implementing Personal Environmental Control in Your Building. *World Workplace 99*. Los Angeles: Center for the Built Environment.

Bauman, F. S. (1999). Giving Occupants What They Want : Guidelines for Implementing Personal Environmental Control in Your Building. *World Workplace 99*. Los Angeles: Center for the Built Environment.

Braun, V., & Clarke, V. (2006). Using Thematic Analysis in Psychology. *Qualitative Research in Psychology*, *3*(2), 77–101.

Brown, H. S., & Vergragt, P. J. (2008). Bounded socio-technical experiments as agents of systemic change: The case of a zero-energy residential building. *Technological Forecasting and Social Change*, *75*(1), 107–130.

De Groot, H., Verhoef, E., & Nijkamp, P. (2001). Energy saving by firms : decision-making , barriers and policies. *Energy Economics*, (23), 717–740.

Federspiel, C. C., & Villafana, L. (2003). Design of an Energy and Maintenance System User Interface for Building Occupants. *ASHRAE Transactions*, *109*, 665–676.

Goins, J., & Moezzi, M. (2011). Case Study of CALSTRS Headquarters West Sacramento, California. *Center for the Built Environment*.Leonard-Barton, D. (1984). Diffusing Innovations When the Users A re Not the Choosers: The Case of Dentists. *Science Communication*, *6*(1), 89–111.

Industry News. (2012).*ASHRAE Journal*, (July), 6. Retrieved from ashrae.org

Kaneda, D., & Jacobson, B. (2010). Plug Load Reduction : The Next Big Hurdle for Net Zero Energy Building Design, 120–130.

Karahanna, E., Straub, D., & Chervany, N. (1999). Information Technology Adoption Across Time: A Cross-Sectional Comparison of Pre-Adoption and Post-Adoption Beliefs. *MIS Quarterly*, *23*(2), 183–213.

Kok, N., McGraw, M., & Quigley, J. M. (2012). The Diffusion Over Time and Space of Energy Efficiency in Building. *The Annals of Regional Science*, *48*(2), 541–564.

Lammers, H. (2009). NREL Tests Energy Saving Office of the Future. Retrieved from http://www.nrel.gov/news/features/feature_detail.cfm/feature_id=1921

Lewins, A., Taylor, C., & Gibbs, G. (2010). Qualitative Analysis: How and What to Code. Retrieved from onlineqda.hud.ac.uk

Miles & Huberman (1994). Qualitative Data Analysis: An Expanded Sourcebook (2nd Ed). Sage Publications.

Nisbet, M. C., & Kotcher, J. E. (2009). A Two-Step Flow of Influence?: Opinion-Leader Campaigns on Climate Change. *Science Communication*, *30*(3), 328–354.

Nochur, K. (1982). "Diffusion Intermediaries." Cambndge. Sloan School of Manage- ment, MIT. (unpublished).

Pelz, D. C. (1983). Use of Information Channels in Urban Innovations. *Science Communication*, *5*(1), 3–25.

Pelz, D. C. (1985). Innovation Complexity and the Sequence of Innovating Stages. *Science Communication*, *6*(3), 261–291.

Poll, S. (2011). NASA Ames Collaborative Support Facility (Sustainability Base) *THE NEXT GIANT LEAP* [Powerpoint slides]. Retrieved from http://www.nasa.gov/sustainability-base/.

Roberts-Gray, C., & Gray, T. (1983). Implementing Innovations: A Model to Bridge the Gap Between Diffusion and Utilization. *Science Communication*, *5*(2), 213–232.

Rogers, E. (2003). *Diffusion of Innovations* (5th ed.). New York: Free Press.

Ryan, B., & Gross, N. C. (1943). The Diffusion of Hybrid Seed Corn in Two Iowa Communities. Rural Sociology, 8, 15-24.

Seidel, S., Ye, J., & Solutions, E. (2012). Leading by Example: Using Information and Communication Technologies to Achieve Federal Sustainability Goals, (September).

Schuler, R., Grymes, R., Poll, S., & Wilmoth, K. (2012). NASA Ames Sustainability Base [Powerpoint slides]. Retrieved from http://www.nasa.gov/sustainability-base/.

Srivastava, J., & Moreland, J. J. (2012). Diffusion of Innovations: Communication Evolution and Influences. *The Communication Review*, *15*(4), 294–312.

Strauss, A. and Corbin, J. (1990). Basics of Qualitative Research: Grounded Theory Procedures and Techniques. Newbury Park, CA: Sage.

Tarde, G. (1903). The Laws of Imitation. (E. C. Parsons, Trans.). New York, NY: Henry Holt.

Vanhoozer, A., Sanyal, N., Heinse, R., & Thorsteinson, T. (2014). “Energy Conservation Behaviors and Social Norms in the Net-Zero Energy Workplace at NASA Ames Sustainability Base”. Manuscript in preparation. College of Environmental Sciences, University of Idaho. Moscow, Idaho.

Vanhoozer, A., Probert, A., & Haglund, B., (2014). *“The Built Environment at Sustainability Base and the Occupant Experience.”* Manuscript in preparation. College of Environmental Sciences, University of Idaho. Moscow, Idaho.

APPENDICES

Appendix A: University of Idaho IRB Approval

University of Idaho

Office of Research Assurances
Institutional Review Board
PO Box 443010
Moscow ID 83844-3010

Phone: 208-885-6162
Fax: 208-885-5752
irb@uidaho.edu

To: Robert Heinse
Cc: Angie Vanhoozer

From: Traci Craig, PhD
Chair, University of Idaho Institutional Review Board
University Research Office
Moscow, ID 83844-3010

IRB No.: IRB00000843

FWA: FWA00005639

Date: Approved as Exempt September 12, 2011

Project: 11-044 has been approved as Exempt under Cat 2
'Behavioral Impacts of Net-Zero Energy Facilities: NASA Ames Sustainability Base Case Study'

On behalf of the Institutional Review Board at the University of Idaho, I am pleased to inform you that the above-named project is approved as exempt from review by the Committee. Please note, however, that you should make every effort to ensure that your project is conducted in a manner consistent with the three fundamental principles identified in the Belmont Report: respect for persons; beneficence; and justice.

Should there be significant changes in the protocol for this project, it will be necessary for you to resubmit the protocol for review by the Committee.

Traci Craig

Appendix B: NASA IRB Approval

From: Timm, Elaine M. (ARC-D)[Lockheed Martin Space OPNS] **Sent:** Wednesday, July 13, 2011 4:30 PM **To:** Vanhoozer, Angie **Cc:** Smith, Nancy M. (ARC-TH); Pelligra, Ralph (ARC-QH); Young, Ernle W. (ARC-D)[Lockheed Martin Space OPNS] **Subject:** Exemption for Protocol HR-EX-11-02

The following message is sent on behalf of Ernle W. D. Young, Chief, Office for the Protection of Research Participants (OPRP): Dear Ms Vanhoozer: Your request for exemption of the protocol, "Residential Transference Effects of Changes in Occupant Awareness, Autonomy and Motivation," was reviewed and approved by the Chief, Office for the Protection of Research Participants (OPRP) on July 5, 2011. The NASA Ames Research Center Human Research Institutional Review Board (HRIRB) ratified the approval at the monthly meeting on July 7, 2011. The exemption was approved on the basis of Title 45 Code of Federal Regulations Part 46, Protection of Human Subjects (the Common Rule), paragraph (2) (ii).
For tracking purposes only, the protocol is assigned number **HR-EX-11-02**. You may proceed without further reference to Ames Procedural Requirements (APR) 7170.1, Human Research Planning and Approval, but in accordance with the confidentiality requirements of the Privacy Act. Any change to protocol HR-EX-11-02 must be submitted for re-approval of exemption status prior to its implementation. If you have questions, contact me at 650.604.5492 or by e-mail, Ernle.W.Young@nasa.gov. Immediately notify Dr. Ralph Pelligra, Chair, HRIRB, at 650.604.5163, or by e-mail, Ralph.Pelligra-1@nasa.gov, of any injury to a human participant, whether or not it was considered a risk inherent to the research. Injury includes, but is not limited to, bodily harm, psychological trauma or release of potentially damaging personal information.

Good luck in your research efforts.

Ernle W.D.Young, Ph.D. Chief, Office for the Protection of Research Participants (OPRP)

By Elaine Timm Recorder, Human Research Institutional Review Board Assistant to Dr. Ernle Young Office for the Protection of Research Participants, M/S 243-2 NASA Ames Research Center Bldg. 243, Room 120 P.O. Box 1 Moffett Field, CA 94035-0001 voice: 650.604.0119 fax: 650.604.6233 E-mail: Elaine.M.Timm@nasa.gov

Appendix C: Questionnaire

This survey takes about 10 minutes to complete. Participation in the survey is voluntary. You are free to skip questions that you don't want to answer and to end participation at any time.

Thank you for your participation

UNIQUE CODE:

In order to track information from this survey with other questionnaires, you will need to create a unique code as an identifier. This code will not be associated anywhere with your name or email address, and data will be kept anonymous. The following prompt will help you create a code that maintains anonymity and is easy for you to remember:

- **What are the first three letters of the town where you were born?**

AND

- **What is the two-digit number of the month you were born (e.g. March = 03)?**

AND

- **What are the first three letters of your mother's first name?**

*Please write your answer here:*____

SECTION 1: These questions ask about characteristics of your work environment in Sustainability Base at NASA Ames Research Center.

2. How satisfied or dissatisfied are you with the following systems and features in your workplace? *(Please **choose only one answer** for each of the following):*

BUILDING SYSTEM/FEATURE	STRONGLY DISSATISFIED	MODERATELY DISSATISFIED	SOMEWHAT DISSATISFIED	NEITHER DISSATISFIED NOR SATISFIED	SOMEWHAT SATISFIED	MODERATELY SATISFIED	STRONGLY SATISFIED
A. Artificial overhead lighting	1	2	3	4	5	6	7
B. Natural day-lighting	1	2	3	4	5	6	7
C. Heating system	1	2	3	4	5	6	7
D. Cooling system	1	2	3	4	5	6	7
E. Ventilation system	1	2	3	4	5	6	7
F. Acoustics (sound quality)	1	2	3	4	5	6	7

3. Overall, how much does satisfaction with systems and features in your workplace **add to or detract from** productivity? ***(Please choose only one answer)***

- ☐ Significantly detracts
- ☐ Moderately detracts
- ☐ Somewhat detracts
- ☐ Neither detracts nor enhances
- ☐ Somewhat enhances
- ☐ Moderately enhances
- ☐ Significantly enhances

4. Do you know about how much electricity per month your workspace uses? Rate your awareness of workspace energy needs: ***(Please choose only one answer)***

- ☐ Yes, I pay attention to my workspace energy use each month
- ☐ I have an idea of how much energy my workspace uses each month, but couldn't tell you exactly
- ☐ No, I don't know how much energy my workspace uses

5. Within the past year, have you received any messages about workplace energy or resource conservation in your current workplace? *(**Please choose all that apply**)*

- ☐ Emails
- ☐ Pamphlets
- ☐ Special tours
- ☐ Seminars
- ☐ LCD screen display in lobby
- ☐ Earth day dedication
- ☐ Workshops
- ☐ Other, write your answer here: ______________________

6. Where does the energy come from that provides power for your current work building? ***(Please choose all that apply)***

- ☐ Utility grid (hydro-electric, natural gas, coal)
- ☐ Solar panels
- ☐ Solid oxide fuel cell
- ☐ Don't know
- ☐ Other, write your answer here: _________________________

7. How strongly do you personally agree or disagree with the following statements?

(Please circle only one answer per statement)

STATEMENT	STRONGLY DISAGREE	MODERATELY DISAGREE	SOMEWHAT DISAGREE	NEITHER DISAGREE NOR AGREE	SOMEWHAT AGREE	MODERATELY AGREE	STRONGLY AGREE
a. "Energy savings help reduce global warming"	1	2	3	4	5	6	7
b. "I feel morally obligated to save energy, regardless of what others do"	1	2	3	4	5	6	7
c. "My contribution to energy problems is negligible"	1	2	3	4	5	6	7
d. "I feel partly responsible for the exhaustion of energy resources"	1	2	3	4	5	6	7
e. "If I would buy a new washing machine, I would feel morally obligated to buy an energy-efficient one"	1	2	3	4	5	6	7
f. "I feel personally obligated to save as much energy as possible"	1	2	3	4	5	6	7
g. "I feel guilty when I waste energy"	1	2	3	4	5	6	7
h. "The exhaustion of energy resources is a problem"	1	2	3	4	5	6	7

8. Which of the following best describes the degree to which collaboration takes place in your work group? ***(Please choose only one answer)***

- ☐ My work group functions as a team to accomplish project tasks
- ☐ Individuals in my work group function independently, but meet regularly to accomplish project tasks
- ☐ Individuals in my work group function independently; achieving project goals requires little collaboration

9. How closely do you identify with NASA Ames and the people you work with? ***(Please choose only one answer for each of the following statements)***

STATEMENT	STRONGLY DISAGREE	MODERATELY DISAGREE	SOMEWHAT DISAGREE	NEITHER DISAGREE NOR AGREE	SOMEWHAT AGREE	MODERATELY AGREE	STRONGLY AGREE
a. "I'm very interested in what others think about NASA Ames Research Center"	1	2	3	4	5	6	7
b. "If a story in the media criticized NASA Ames, I would feel embarrassed"	1	2	3	4	5	6	7
c. "When I talk about my work group, I usually say 'we' rather than 'they' "	1	2	3	4	5	6	7
d. "When someone criticizes my work group, it feels like a personal insult"	1	2	3	4	5	6	7
e. "My work groups' successes are my successes"	1	2	3	4	5	6	7

10. In your opinion, how important is energy and resource conservation to the following groups?

(Please choose only one answer per question)

	1	2	3	4	5	6	7
a. Your Work Group	VERY UNIMPORTANT	MODERATELY UNIMPORTANT	SOMEWHAT UNIMPORTANT	NEITEHR UNIMPORTANT NOR IMPORTANT	SOMEWHAT IMPORTANT	MODERATELY IMPORTANT	VERY IMPORTANT
b. NASA Ames Research Center	VERY UNIMPORTANT	MODERATELY UNIMPORTANT	SOMEWHAT UNIMPORTANT	NEITEHR UNIMPORTANT NOR IMPORTANT	SOMEWHAT IMPORTANT	MODERATELY IMPORTANT	VERY IMPORTANT

SECTION 2:_This section of the survey pertains to energy-related behaviors in your home environment. Please tell us how energy is used in your home by answering the following questions.

11. Which of the following features are present or not present where you live? For features that are present, which did you personally upgrade or have upgraded?

	Present in home?			If present	
FEATURE	Yes	No	Don't know	Present when I moved in	I upgraded or had upgraded
a. Programmable thermostat	Yes	No	DN	☐	☐
b. LED/CFL (compact fluorescent)	Yes	No	DN	☐	☐

lights

c. Solar panels	Yes	No	DN	☐	☐
d. Energy Star appliances	Yes	No	DN	☐	☐
e. Energy Star windows	Yes	No	DN	☐	☐
f. Insulation in exterior walls or ceiling	Yes	No	DN	☐	☐
g. Locally produced building materials (within 100 miles)	Yes	No	DN	☐	☐
h.Low VOC (volatile organic compound) paints	Yes	No	DN	☐	☐
i. Dual flush or low-flow toilets	Yes	No	DN	☐	☐
j. Low-flow shower-heads or faucets	Yes	No	DN	☐	☐
k. Rainwater catchment system	Yes	No	DN	☐	☐
l. Exterior shading devices for house	Yes	No	DN	☐	☐

12. How important are each of the following factors when deciding whether or not to make energy-efficient improvements where you live? ***(Please choose only one answer per factor)***

FACTOR	VERY UNIMPORTANT	MODERATELY UNIMPORTANT	SOMEWHAT UNIMPORTANT	NEITHER UNIMPORTANT NOR IMPORTANT	SOMEWHAT IMPORTANT	MODERATELY IMPORTANT	VERY IMPORTANT
a. Money to invest in improvement	1	2	3	4	5	6	7
b. Time to invest in improvement	1	2	3	4	5	6	7
c. Skills/information necessary to undertake improvement	1	2	3	4	5	6	7
d. Physical characteristics of the home/ feasibility issues	1	2	3	4	5	6	7
e. Ownership control of the home	1	2	3	4	5	6	7

13. Do you know about how much electricity per month your home uses? ***(Please choose only one answer)***

- ☐ Yes, I pay attention to my home energy use every month
- ☐ I have an idea of how much energy my home uses each month, but couldn't tell you exactly
- ☐ No, I don't know how much energy my home uses

Is there anything else you'd like to add about energy use in your home? **Please write your comments here:**

14. Please indicate how frequently you engage in each of the following behaviors in your home.
(Please choose only one answer per behavior)

BEHAVIOR	NEVER	RARELY	SOMETIMES	OFTEN	ALWAYS
a. I use the heat system sparingly	1	2	3	4	5
b. I use air conditioning sparingly	1	2	3	4	5
c. I leave electronic devices (pc's dvd players, etc.) on or on stand-by when I'm not using them	1	2	3	4	5
d. I open windows when possible to take advantage of fresh air	1	2	3	4	5
e. I take advantage of natural daylight instead of turning on lights	1	2	3	4	5
f. I turn lights off in unoccupied rooms	1	2	3	4	5

g. I throw away things that could be recycled	1	2	3	4	5
h. I turn electronic devices (pc's, dvd players, etc.) completely off when I'm not using them	1	2	3	4	5
i. I save dirty laundry until I can load my washing machine fully	1	2	3	4	5
j. I drive when I could bike or walk	1	2	3	4	5
k. I turn off the faucet while doing dishes, brushing teeth and washing my hands	1	2	3	4	5
l. I use public or alternative modes of transportation to and from work	1	2	3	4	5
m. I take long showers	1	2	3	4	5
n. I am in the habit of recycling	1	2	3	4	5
o. I turn TV's and radios off in unoccupied rooms	1	2	3	4	5

SECTION 3: These questions pertain to the influences of Sustainability Base on both work and home perceptions.

15. Within the past year, has Sustainability Base affected your perceptions of home energy use? ***(Please choose only one answer per statement)***

STATEMENT	STRONGLY DISAGREE	MODERATELY DISAGREE	SOMEWHAT DISAGREE	NEITHER DISAGREE NOR AGREE	SOMEWHAT AGREE	MODERATELY AGREE	STRONGLY AGREE
a. "Awareness of energy conservation at home has been enhanced by my current work environment"	1	2	3	4	5	6	7

b. "Interaction with features in my workplace has motivated me to seek further information regarding home energy savings"	1	2	3	4	5	6	7
c. "I have made improvements to my home that I attribute to information or experiences regarding workplace energy use"	1	2	3	4	5	6	7

16. To what degree do you think Sustainability Base is a positive or negative work environment in terms of the following factors? ***(Please choose only one response per factor)***

FACTOR	VERY NEGATIVE ENVIRONMENT	MODERATELY NEGATIVE	SOMEWHAT NEGATIVE	NEITHER NEGATIVE NOR POSITIVE	SOMEWHAT POSITIVE	MODERATELY POSITIVE	VERY POSITIVE ENVIRONMENT
a. Employee satisfaction for building occupants	1	2	3	4	5	6	7
b. Productivity of building occupants	1	2	3	4	5	6	7
c. Building energy savings	1	2	3	4	5	6	7
d. Building as showcase for energy conservation	1	2	3	4	5	6	7

SECTION 4: The final section ask a few general questions to help us describe your experiences with energy use in Sustainability Base. Thank you for taking time to complete the survey!

17. Which of the following best describes your current work station? ***(Please choose only one answer)***

- ☐ Private enclosed office
- ☐ Shared enclosed office
- ☐ Cubicle with high partitions (greater than 5')
- ☐ Cubicle with low partitions (less than 5')
- ☐ Workspace with no partitions (just desks)
- ☐ Other, *please answer here*: ____________________

18. How long have you worked at Ames Research Center?
Please round up to the nearest year __________

19. What is your gender?

- ☐ Male
- ☐ Female

20. What is your age? ***(Please select the appropriate range)***

- ☐ 18-25 years
- ☐ 26-40 years
- ☐ 41-60 years
- ☐ 61 years and older

21. Describe your living situation by answering the following questions.
(Please choose only one answer per question)

TYPE OF HOME	AGE OF HOME	OWN OR RENT
☐ Single family dwelling	☐ 0-10 years	☐ Own
☐ Duplex	☐ 11-20 years	☐ Rent
☐ Condominium	☐ 21-30 years	
☐ Apartment complex	☐ 31-40 years	
☐ Other, please describe: _____________	☐ 41+ years	

22. We look forward to sharing results with you once the study is complete. The last portion of our research at Sustainability Base involves conducting personal interviews with occupants in February 2014. If you would be willing to participate in an interview, please indicate so in the space below and write your name and email address on the **enclosed interview contact card**. Place the card in the exit interview envelope next to the exit survey envelope when you submit the survey. Thank you for participating in this research!

☐ Yes, I would be happy to visit with you about my experiences working in Sustainability Base. You may contact me to schedule an interview.

☐ No thank you, I'd prefer not to participate.

Are there any other comments you would like to make?

Thank You

If you have any questions about the Sustainability Base study,
please feel free to contact me:

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