IS GREEN HOUSING HEALTHY HOUSING? A QUESTION FOR SENIORS

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Abstract

With green building standards increasingly embedded in residential construction, the need to assess their impact on indoor environmental quality (IEQ) and human health becomes more critical "to ensure that green housing and healthy housing are in fact synonymous" (USDHUD, 2009, p. 8). There is little research to date that has systematically examined this, and none has focused on low-income seniors. Sponsored by a grant from the U.S. Department of Housing and Urban Development, this research incorporates a multidisciplinary team effort and perspective, involving social ecologist and housing researcher, nursing faculty, architect, energy specialist and environmental engineers, healthcare economist, and visual communication professional. The paper describes the research design and methodology of a quasi-experimental study spanning 36 months (and three data collection panels), examining the health and IEQ outcomes and healthcare benefits/costs of a green housing renovation for seniors in Phoenix, Arizona. Since data collection is ongoing, no statistical findings are presented. Lessons learned to date regarding the intervention and methodological process are discussed.

Keywords: Green Housing; Elderly; Aging; Health; Sustainable

When Does Green Housing Become Healthy Housing – Or Does It?

With energy efficiency and green building practices increasingly embedded in residential renovations, the need to assess their impact on indoor environmental quality (IEQ) and human health becomes more critical "to ensure that green housing and healthy housing are in fact synonymous" (USDHUD, 2009, p 8). Recent research (e.g. Wargo, 2010) suggests that the two do not *de facto* correspond and may even conflict, in part because few green building certification programs or standards mandate building materials, fixtures, appliances/systems, and other elements that directly correspond to potential health impairments or enhancements. Many green building practices emphasize energy efficiency practices to the neglect of indoor air quality.

This research study contributes to the nascent body of research examining green and energy efficient building practices on resident health, by focusing on a vulnerable residential population: low-income seniors living in assisted housing. While there are a number of research studies examining a single type of housing characteristic (e.g. lighting) on singular health outcomes (e.g. injuries), none examine the impact of multiple green building practices on prominent health concerns of seniors, particularly: respiratory ailments; joint and movement impairments; falls and injuries; sleep; mental health conditions; and functional limitations.

In theory, "green building" encompasses resource efficiency, energy efficiency, and healthy indoor and immediate outdoor environments (Wells and Laquatra, 2010). In practice, however, "green building" typically focuses on and implements only one of these: technologies and building practices that enhance energy efficiency. The extent to which conventional green building and renovation practices contribute to mitigating potentially harmful environmental conditions has recently been questioned, particularly among environmental scientists (Wargo, 2010). A study undertaken by the National Center of Healthy Housing (Morley and Tohn, 2008) examined standards and recommendations of four, nationally-known green housing programs, and found that green programs were missing a number of elements essential to healthy housing as reflected in the seven principles established by the US Department of Housing and Urban Development (HUD): dry, clean, ventilated, pest-free, safe, contaminant-free, maintained. As noted by Wells and Laquatra (2010), even though a number of indoor environmental problems have been linked to ventilation deficiencies in housing, the National Green Buidling Code does not require compliance with standards established by the American Society of Heating, Refrigerating, and Air-Condiitoning Engineers (ASHRAE) for mechnical ventilation in housing. As they also point out, safety features, such as bathroom grab bars and scald-protection faucets, are likely absent in all of the green housing programs examined by the National Center of Healthy Housing study, as were recommendations for avoiding building mateirals susceptible to mold growth.

With increasing public investment in green and energy-efficient housing improvements, it is important to assess the collateral impact such housing improvements may have in enhancing or diminishing health conditions of residents and, indirectly, healthcare costs.

The Green Apple Project (GAP)

The American adage "an apple a day keeps the doctor away" was appropriated for "branding" and naming this research study as the Green Apple Project (see Figure 1) – the effects of a *green* apple (i.e. green housing practices) on health. Supported by a HUD Green and Healthy Homes Technical Studies grant, a multi-disciplinary team of faculty, research professionals and graduate students are conducting a panel study examining impacts on indoor environmental and indoor air quality (IEQ, IAQ), and reported health conditions of senior residents following the green renovation of their apartment complex in Phoenix, Arizona.

Figure 1 Identity Mark of Green Apple Project

The building retrofit interventions that were undertaken in this project do not reflect those of leading green certification programs such as LEED or Green Globes. Since they reflect the ARRA Retrofit program (initiated by the US federal government on many of their properties and funded by the American Recovery and Reinvestment Act of 2009), we characterize these interventions as "baseline green" – what housing authorities and other agencies may typically incorporate in improving energy efficiency and other green housing improvements on a relatively affordable budget. More detail description of these building characteristics follow in a later section.

The health conditions and indoor environmental quality metrics that were examined in this study reflect key health-related concerns of elderly populations that could be exacerbated, or enhanced, by housing conditions and of climatic conditions of the American Southwest – an area with very little precipitation and humidity; dry and arid; high counts of outdoor air pollution, particularly particulate matter; and extreme outdoor temperatures for several months of the year.

Brief Overview of Housing and Health Issues of Seniors

While there are currently 39 million Americans who are age 65 or older (in this report, this age group will be referred to as "seniors"), that number is estimated to increase to 72 million Americans by 2030, representing 20% of the U.S. population (Federal Interagency Form on Aging Related Statistics, 2010). Demographic trends in the U.S. reflect those world-wide. The United Nation's Department of Economic and Social Affairs (2009) suggests that the number of older persons will grow from 700 million in 2009 to 2 billion by 2050.

Relatively little research has examined adverse health effects facing this population from potential environmental exposures and hazards in the residential environments where they live. Aging-related changes in behaviors and activities, in mind and body, and in financial and social assets, can alter exposure and susceptibility to environmental threats, resulting in potential health risks.

Many seniors spend up to 90% of their times indoors, often at home (Simoni, Jaakkola, Carrozzi, Baldacci, Di Pede & Viegi, 2003), heightening their exposure to potential home containments and hazards. Susceptible to arthritis, muscular atrophy, osteoporosis, and visual impairment, many elderly can find it difficult to maintain sufficient cleanliness standards of their homes, to visually identify residential fixtures and features correctly (e.g. temperature control switches on stovetops), or to sufficiently grasp objects and move throughout their home safely and without injury (Davis 2007).

Compared to young adults, older adults have smaller airways and are therefore more likely to experience bronchial hyper-responsiveness (Yeatts et al, 2006), making them increasingly vulnerable to indoor air particulates and certain environmental toxins and contaminants. Diabetes is among the top leading cause of death in the U.S. for seniors. People living with diabetes are considered at high risk for adverse health effects from exposure to harmful particles or air pollution found both indoors and outdoors. Likewise, breathing in harmful particles from air pollutants may increase the risk of heart attack and stroke (Dominici et al, 2006; National Center for Healthy Housing, 2008).

Mold growth in high concentrates can cause severe health effects in the elderly. Seniors are particularly susceptible to influence of mold spores as the immune system weakens as people age, but the respiratory system, including the lungs, lose strength as lung tissue atrophies. Seniors are less capable of fighting off unwanted airborne contaminants because the systems that help to prevent infections – the cough reflex, mucus lining, and antibodies – lose their strength with age (Indoor Restore, 2012; Lippmann, 2002).

Thermal stress is increasingly problematic as people age. Heat stroke often occurs in outdoors settings, but it and other temperature-related health problems can be aggravated by indoor residential temperature conditions as well. Compared to younger people, seniors do not adjust as well to sudden changes in temperature; they are prone to impaired thermoregulatory control as they age; they are more likely to have a chronic medical condition that upsets normal body responses to heat; they have a lower activity level and thus metabolic rate; and they are more likely to take prescription medicines that impair the body's ability to regulate its temperature or inhibit perspiration. Given these physiological conditions and differences, van Hoof and Hensen (2006) question whether current thermal comfort standards and recommendations are appropriate when assessing and designing residential environments of older adults.

Being at higher risk for residential injuries especially falls (Sleet, Moffett & Stevens 2008), seniors are vulnerable to mishaps on steps and stairs, smooth and slick floor materials, and wet surfaces in the home (USDHUD OHHLHC 2009). Each year, over one-third of American adults 65 years and older fall at least once. Every 18 seconds, an older adult is treated in an emergency department for a fall, and every 35 minutes a senior dies as a result of their injuries. It is estimated that falls account for 33% of injury-related medical expenditures and cost Americans more than $38 billion annually (USDHUD OHHLHC 2009). While stairs, slippery floors, and hard surfaces (e.g. sinks) are often blamed for contributing to such residential injuries, inadequate lighting levels are also suggested as a contributor (Illuminating Engineering Society, 2007).

The American Association of Geriatric Psychiatry (2008) estimates that nearly 25% of people age 55 years and older experience some type of mental health concern, including anxiety, severe cognitive impairment and mood disorders. Dark, noisy, damp and dense living spaces can aggravate depression and dementia in elders (Guite, Clark & Ackrill 2004; Day, Carreon, & Stump, 2000).

All of these health conditions will grow in increasing prominence and medical expense as the number of people older than 65 years of age is expected to double in the U.S. between 2005 and 2030 (CDC & Merck 2007), and most seniors will want to live in non-institutionalized homes as long as possible (AARP 2000). As Selgrade and colleagues (2006) point out, the increase in the senior population living and aging in homes outside nursing homes and other institutionalized care facilities underscores the importance of addressing hazards and indoor environmental risk factors for housing-related illnesses and injuries among older adults.

The Research Site: Sunnyslope Manor, Phoenix, Arizona

Sunnyslope Manor (SSM) is a federally subsidized (i.e. Section 8) apartment complex in Phoenix, Arizona, owned and operated by the City of Phoenix Housing Department. The project consists of a single three-story, 116-unit building constructed circa 1970. All the apartment units within the building are of identical internal configuration. Residents are required to meet the requirements of the HUD Section 8 housing assistance program including the limitation on family gross income.

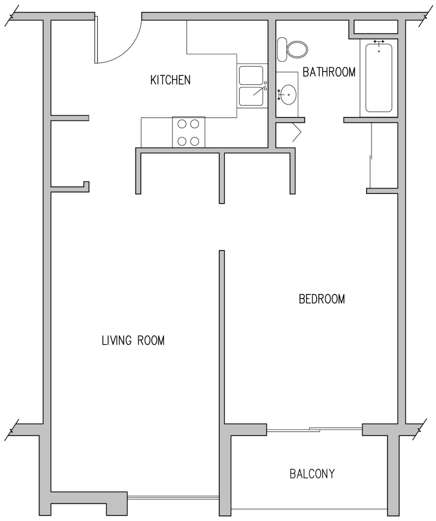
Sunnyslope Manor was selected as the site for this research because the timing of a $1.7 million American Recovery and Reinvestment Act (ARRA) grant from the U.S. Department of Housing and Urban Development for a green retrofit of Sunnyslope Manor made it possible to perform a panel (i.e. longitudinal) study of the effect of the green remodel on the IEQ/IAQ of residents' homes and on residents' health and assessments. Further, Sunnyslope Manor represents the building age and scale of many multi-unit residential complexes retrofitted in HUD's ARRA Green Retrofit Program.

Figure 2 shows a view of SSM from the street it fronts. The building is constructed of deformed concrete block load bearing walls (known in the American Southwest as "slump block") with wood framed floor, roof, and interior partitions. Vertical access within the building is by three stair towers and two elevators. Common area laundry facilities are located on the second and third floors near the center of the building's north side. Access to individual apartment units is via double loaded corridors that run the length of the building.

Figure 2 Street Façade of Sunnyslope Manor

Figure 3 depicts the typical SSM apartment floor plan prior to the green remodel; all units are the same interior layout although they may be "flipped" in orientation. Total livable area within each unit is 57.5 m^2 (or 619 square feet, or SF). The kitchen, bath, and closet areas of the unit are situated along the corridor side and the living and bedroom are adjacent to the exterior wall. Ceilings are flat at 2.4 m (or 8 feet) above the floor.

Figure 3 Apartment Floor Plan



Research Questions

Two overarching research questions directed this study. They are:

1. To what extent does indoor environmental and air quality of homes improve following housing renovations of the ARRA Green Retrofit Program?

2. To what extent do health outcomes of seniors improve following designated housing renovations of the ARRA Green Retrofit Program?

In addition to these, two ancillary research questions were addressed:

3. What is the benefit cost of these housing improvements in terms of both renovation costs and anticipated healthcare costs and savings, particularly related to falls and injuries?

4. What is the use and effectiveness of age-specific educational materials developed for this particular resident sample in informing and motivating residents to maintain their renovated homes in a healthy manner?

Methodology

Research Goal and Hypotheses

The overall goal of the research project was to assess the extent to which an array of building changes of the ARRA Green Retrofit Program resulted in improved indoor air/environmental quality and health of elderly residents living in an assisted housing development in Phoenix, Arizona. In so doing, several hypotheses and sub-hypotheses were proposed and tested (see Table 1).

Table 1 Study Hypotheses

1. **Indoor environmental quality** (<u>**IEQ**</u>) – as measured by ***temperature***, ***relative humidity*** and ***air exchange*** – will improve following ARRA Green Retrofit housing renovations. These changes will be <u>immediate</u> (first post-test) and <u>sustaining</u> (second post-test) for most IEQ indicators.
   - These changes will meet thresholds of ASHRAE and other industry standards
   - IEQ changes will be less in homes with certain resident characteristics/behaviors (i.e. resident moderating conditions) and building/design characteristics (i.e. building moderating characteristics) than without these characteristics.
   - Tighter air exchange levels after the retrofit will also result in greater changes in temperature and relative humidity

2. **Indoor air quality** (<u>**IAQ**</u>) – as measured by ***particulate matter*** and ***aldehydes*** (formaldehyde, acetone, and acetaldehyde) concentrations – will change following ARRA Green Retrofit housing renovations, both <u>immediate</u> and <u>sustaining</u> for most IAQ indicators.
   - PM levels are expected to increase and to exceed air quality standards due to the construction process.
   - Aldehyde levels are expected to improve; and formaldehyde levels following retrofit will meet thresholds of health/safety standards.
   - IEQ changes will be less in homes with certain resident characteristics/behaviors (i.e. resident moderating conditions) and building/design characteristics (i.e. building moderating characteristics) than without these characteristics.
   - Tighter air exchange levels after the retrofit will also result in greater changes in PM and aldehydes concentration.

3. Residents will **perceive and assess improved housing and IEQ/IAQ conditions** following ARRA Green Retrofit housing renovations.
   - Any non-improvements in actual IEQ or IAQ (i.e. hypotheses 1 and 2) may be mediating factor in resident perceptions.

4. **Seniors' reported health** at Sunnyslope Manor will improve following ARRA Green Retrofit housing renovations.
   - These changes will be <u>immediate</u> and <u>sustaining</u> for many health indicators of: (1) overall health status and life satisfaction; (2) respiratory-related conditions; (3) skin-related conditions; (4) joint-related conditions; (5) pain; (6) mental health related conditions; (7) sleep; (8) functional limitations; (9) heart-related conditions; (10) neurological or brain-related conditions; (11) diabetes; (12) vision; and (13) hearing.
   - Changes in health conditions at Sunnyslope will be greater than changes in health conditions in the general population, as measured by national health surveys

5. **Integrative model**: Changes in seniors' health conditions (hypothesis 5) will positively correlate or correspond with IEQ changes (hypotheses 1 and 2) and aldehyde changes, and negatively correlate or correspond with PM changes; but may be moderated by resident and building characteristics.

6. Changes made to reduce falls can result in major **healthcare cost savings**. Conversely, changes made that create opportunities for falls to occur may result in healthcare savings.

7. **Resident educational materials** designed and developed to this particular age group will effectively inform and motivate residents to maintain their renovated homes in a healthy manner.

Research Design

This research utilized a quasi-experimental design in examining the effects of green retrofit homes on IEQ and resident health. Key components include: (1) pre- and multiple post-intervention testing; and (2) proxy measures for comparison.

Three data collection periods, or panels, were undertaken: one prior to the intervention (i.e. retrofit) and two after renovation was completed. Given validity threats to one-group pre-test/post-test designs in health and social science research (Campbell & Stanley 1963), incorporating a non-randomized proxy comparison (not subject to the specific intervention) helps diminish these threats.

The research design of this study – Pre-test, Post-test, Non-Equivalent Comparison Group – is outlined in Table 2, using the nomenclature of Campbell and Stanley (1963), where "O" represents data collection of outcome measures, "X" represents the intervention. Outcome variables and measures – of health and indoor air/environmental quality – are the same in each data collection panel. Details about the intervention (i.e. renovation), outcome measures, and proxy comparison measures are described in detail in following sections.

Table 2 Quasi-Experimental Research Design

	Pre-Test (Panel 1)	Intervention	Post-Test #1 (Panel 2)	Post-Test #2 (Panel 3)
Study Site	O	X	O	O
Proxy Comparison	O		O	O

Panel 1 data collection occurred June-July 2010; Intervention occurred between Feburary and July 2011; Panel 2 data collection occurred between April and September 2011, one to three months after the resident's unit was renovated; and Panel 3 will occur in May-June 2012.

Description of Study Participants

Working with the property manager of SSM, we established a multi-pronged recruitment procedure. In this manner, 77 residents from 74 units agreed to participate in the study; and all 77 participated in Panel 1. Attrition occurred by Panel 2. Being a panel study, residents who did not participate in Panel 1 were ineligible to participate in Panel 2. The sample in Panel 2 consisted of 55 units, and 59 residents who had participated in panel 1 (see Table 3). Of those no longer participating in Panel 2, eight had moved from Sunnyslope Manor, three had died, and seven said they were no longer interested in participating. As of this writing, data collection for Panel 3 has not begun.

Table 3 Demographic Profile of Residents Participating in Both Panels 1 and 2 (n=59)

Gender	32% Male, 68% Female
Age	Mean = 74 (sd = 8.12); Range from 62 to 92 years
Race and Ethnicity	80% White; 3% Black/African American; 3% American Indian; 2% Asian Indian; 17% Some Other Race; 15% Hispanic or Latino
Retired from working	88%
Have pets	17%
Smokes	17%
Lives alone in apartment	86%
General health, as rated on 5-point scale, with "1" being excellent and "5" being poor	Mean = 2.78 (sd = 1.12)
Number of days in past 30 days when health not good	Mean = 2.04 (sd = 1.10) (n=57)
Reports at least one respiratory health problem	41%

While the homes were all the same size, layout, and with the same lighting, appliance and system fixtures, they were in different locations of the building. Because sun load may have had a potential contributing factor to some of the IEQ/IAQ conditions and assessments in the study, we also identified each unit along these building location characteristics: north or south facing unit; east or west wing; floor level. Table 4 profiles the units in the sample along these building orientation dimensions.

Table 4 Building Location of Residential Units (n=55)

Orientation: North-south facing unit	49% facing north, 51% facing south
Wing: East-west	47% in east, 53% in west
Floor level	29% on first, 42% on second, 29% on third

Intervention: Green Retrofit of Sunnyslope Manor

The City of Phoenix did not move residents and their belongings from Sunnyslope Manor during the renovation, believing it would be too disruptive for their population. Instead, the renovation scheduling procedure involved having each resident box up his/her possessions for 5-7 days, spend the daytime hours in "The Green Room" (an unoccupied apartment unit in the building that was renovated and furnished), and return to their under-construction apartment each evening to sleep on their bed which was re-installed each day.

The following briefly describes retrofit <u>changes</u> made to the residents' units.

Systems. The HVAC system for each apartment includes 5 components: (1) a through-wall package terminal air conditioner package (PTAC) unit, (2) a bathroom exhaust fan, (3) a range hood exhaust fan, (4) a bedroom ceiling fan, and the (5) doors and windows. Of these, the front door and PTAC unit remained the same with no changes; replacements were made for both exhaust fans and the exterior windows and door; and a new ceiling fan was added.

The *bathroom exhaust fan* was replaced with a Broan Ceiling/Wall Fan Model 784 -Energy Star unit specified to fit the existing duct size. Three to six apartment units shared a common vertical exhaust duct which extends vertically through the roof where the air is exhausted. Accordingly, variances in apartment unit positive and negative air pressure can cause air to communicate between units, rather than always being exhausted to the roof.

The *kitchen range hoods* are very similar. They are standard residential units exhausted to common vertical ducts extending up through the roof. Like the bathroom exhausts, the kitchen range hood exhaust air can also communicate between units depending on positive and negative air pressure differentials between units and floors.

A new *bedroom ceiling fan unit* was installed in each unit: Royal Pacific Model 1051-L-ES Energy Star ceiling fans with light kits. Residents operate the fan speed and light kit on/off by means of pull chains hanging from the ceiling fan itself. In most cases observed, the residents place their bed under the ceiling fan.

In the course of the remodel, each apartment unit was equipped with a new arcadia-style *sliding balcony door* with sliding screen and a new living room sliding *window*. In both cases, the extant units were replaced with new Paramount Titan Series sliders, aluminum framed, double pane, low-E coat with green cool tint units in thermally broken sash and frames.

Kitchens. The kitchens of each apartment unit were entirely remodeled including new cabinets, appliances, flooring, sink/faucets, light fixtures, and paint. In the renovation, the appliance locations remained approximately the same to minimize the expense of relocating utilities. The primary difference in the remodeled version was the inclusion of a large shallow vertical cabinet for dry goods storage and the provision of a desk in the short hallway leading from the kitchen to the living room. A small hallway closet was eliminated to make room for the desk.

Appliances installed during the remodel were Energy Star compliant.

Cabinets installed during the remodel were specified to be of low VOC materials and construction technique. The cabinets were of typical face frame residential grade featuring natural oak product kiln dried sold hardwood doors and frames with engineered wood boxes and shelving with melamine surfaces applied with a low VOC adhesive. Hardwoods used in the manufacture of the cabinetry were Collins FSC certified forest products. *Countertops* installed over the base cabinets were also specified to be of low-VOC materials and construction technique. The countertops installed were residential grade Pionite laminate post-formed over particle board with integral splash and bullnose front edge using low VOC adhesives that were Greenguard Indoor Quality Certified.

Plumbing fixtures installed in the kitchen incorporated low-flow controls.

Flooring in the kitchen was specified to be low-VOC in manufactured and material. Congoleum Air Steps - Autumn Glow was installed over the existing subfloor using leveling compounds and the manufacturers' recommended flooring adhesive. *Paint* in the kitchen (as in all other rooms) was specified to be Sherwin Williams Zero VOC - Harmony and was roller and brush applied over existing gypsum wallboard.

Light fixtures in the kitchen included a replacement of the ceiling fixture and the integral range hood fixture. The replacement ceiling light fixture was a surface mounted 4 foot NULITE #WAP2285T5-UNV with 2-T5 lamps providing approximately the same lumen output as the T8 prior fixture but with less energy consumption.

Bathroom. The remodel of the bathroom followed the same general scope of the kitchen remodel – the cabinetry, plumbing fixtures, and flooring were removed and replaced. The *cabinetry and countertop* specifications and procurement were identical to the kitchen, as was the flooring. *Plumbing fixtures* were specified to be "low-flow."

The flooring and baseboard for the bathroom was the same as the kitchen and was applied with the same adhesives and technique.

Bedroom/Living Room. The bedroom and living/dining rooms received new *paint* and *carpet*. The paint was low-VOC acrylic and the carpet and *pad* were also specified to be low-VOC. The carpet was Mohawk Towncenter 30 Alladin and the installation technique was the typical stretch method to perimeter tack trips over a Mohawk Commercial Lifeloc pre-attached pad. *Baseboard* throughout the units was Roppe rubber base adhesive applied to the walls utilizing a Roppe product.

Miscellaneous Sealants and Adhesives. A variety of construction adhesives and sealants were used throughout each apartment unit, depending on application and location. Only one – trim wood to gympsum wallboard – was specified low VOC.

Accessibility Units. Two apartment units at Sunnyslope Manor are designated as Type A accessible per the Americans with Disabilities Act (ADA). They received the same general scope of green remodeling. However, the configuration of the units was modified and certain features such as full ADA grab bars in the toilet and shower areas were incorporated (non-ADA units are equipped with a single vertical grab bar in the shower only). The appliance package was also modified, particularly the kitchen range. Figures 4 and 5 depict the ADA kitchen layout.

Figure 4 and Figure 5 Kitchen in ADA-Designated Units

Common Areas. In addition to the apartment unit remodeling described above, the overall complex was remodeled including corridors, stairwells, and common spaces. The corridors received new low-VOC carpet over pad and soundproofing underlayment. Higher-traffic common areas such as the elevator lobbies, main lobby and day rooms received a Pergo Pro Laminate flooring adhesive applied vinyl floor. Common area paints were specified to be low-VOC.

Procedures for Data Collection

Residents who indicated their willingness to participate were contacted by phone or in person to set up a time for the interview and air/environmental sampling of their residences.

The scheduling of the in-home interviews and most of the air sampling tests was combined so to minimize disturbance of the resident. At the scheduled appointment time, two GAP researchers would meet the resident in his or her apartment. One technician would set up and operate the air sampling equipment (for aldehydes, particulate matter) in the unit for an hour. He would also set up the temperature/RH sensors in the unit that would remain there for 5 days of data recording. The other technician, a trained interviewer, sat with the resident and conducted the health interview; this generally took 45 minutes to complete. In those instances where the resident felt uncomfortable or unable to speak English, a translator accompanied this team. Translators were provided for those speaking Romanian, Spanish, Farsi, and Russian. Human subjects protocol was followed, and signed consent forms received from all participants.

Five days after the interview and air sampling, a GAP researcher stopped by the unit to pick up the temperature/RH sensors. At this time or shortly thereafter, another technician visited the unit to conduct a blow-door test.

When all tests had been completed, a GAP research member stopped by the resident's home, picked up the completed menu card, and gave the resident a $25 gift card for a local grocery store in appreciation for participation.

Measuring Environmental and Air Quality Outcomes

The instrumentation, metrics, and duration of measurement for the IEQ (temperature, relative humidity, air exchange) and IAQ (particulate matter, aldehydes) outcome measures are listed in Table 5.

Table 5 Measurement of Environmental and Air Quality Outcomes

IEQ and IAQ Factor	Instrumentation and Location	Metrics	Duration of Measurement (Per Data Collection Panel)
Temperature (Temp)	Three HOBO temperature data loggers in each unit: kitchen, bedroom, living room locations	Mean Unit Temp* Minimum Unit Temp* (minimum recorded) Maximum Unit Temp* (maximum recorded temperature) Temp Variability* (standard deviation) Temp Above 81* (# of data points above 81^o) Temp Below 68* (# of data points below 68^o)	Every 15 minutes for 5 days, for total of 480 data points for each unit
Relative Humidity (RH)	One data logger in living room	Mean RH RH Variability (std. deviation)	Every 15 minutes for 5 days, for total of 480 data points for each unit
Air Exchange	Blower Door Test	Air exchanges per minute	Once, for 3 minutes
Particulate Matter	Dustrack 8533 Sampler, in kitchen, living room and balcony	PM2.5 in unit# PM10 in unit#	One hour
Aldehydes	Commercial samplers containing CNPH-coated silica gel, in kitchen, living room and balcony	Acetone concentration in unit# Acetaldehyde concentration in unit# Formaldehyde concentration in unit# # times Formaldehyde levels exceeded CA 8-hour ref. exposure level (27 ppb) #	One hour

* Composite variable constructed from taking mean of data collected in the three rooms
\# Composite variable constructed from taking mean of data collected in kitchen and living room

Measuring Health Outcomes and Resident Assessments of IEQ/IAQ

The *Health at Home* questionnaire for the resident interview that was created and used in this study contained 108 multiple choice questions at Panel 1 and 148 questions (including open-ended ones) at Panel 2. Most of the health question items were taken from standardized surveys of National Institute of Health (NHIS) and Centers for Disease Control (BFRSS) that have been undertaken on an annual basis for several years. Not all questions were pertinent to each study participant. For the most part, questions in the two panels were the same except when the item was unnecessary to re-ask in Panel 2 (e.g. age, race/ethnicity) or was inapplicable to ask in the first panel (e.g. questions about new appliances and fixtures). For health questions in Panel 1, the time frame for recalling health ailments was primarily 30 days, and on occasion 12 months, the same time periods as those in the national surveys being used as proxy. In Panel 2, these health questionnaire items were rephrased to replace the 30-day and 12-month time references with "since your unit was renovated" to ensure that their responses reflected health conditions post-renovation.

The questionnaire for Panel 3 will be similar with a additional questions regarding resident assessment of IEQ/IAQ, of certain health conditions (activity restrictions resulting from falls and injuries), of smoking frequency in the unit, of the usefulness of the resident education booklet, and of certain household activities and products (e.g. household cleaning) that may help clarify interpretation of IEQ/IAQ results.

In addition to health questions, the survey also addressed residents' assessments of environmental quality of their apartments; these items were derived from two sources. The University of California Berkeley's Center for the Built Environment (CBE) has developed the *Occupant IEQ Survey* for multiple building types. Survey items from the Residential version of the IEQ survey, pertaining to dormitories and multi-unit residential buildings, was used in this study. The second source was the *Healthy Housing Inspection Manual* (HHIM), developed by the Centers for Disease Control (CDC) and HUD. Questionnaire items pertaining to relevant housing conditions (pests, moisture in home) were included in the *Health at Home* questionnaire of this study.

Measuring Moderating Factors

Prior research has indicated behavioral, physiological, and social factors that may mediate or moderate the impact of housing conditions on residents' health and indoor air quality. There are also key building conditions that may differentially affect indoor environmental quality. Accordingly, this study examines whether the following variables acted as moderating factors (also see hypotheses in Table 1).

Behavioral/personal factors included: whether resident smokes; whether resident has pet in the home; use of kitchen and bathroom fans; use of air sprays (for pests, odor) in the home; manner of cleaning home; length of time living at Sunnyslope Manor; and age. This data was collected from items on the *Health at Home* interview.

Building factors that may act as moderating factors are those pertaining to sun load, identified by the location of the unit in relation to: south-facing orientation; east-west orientation; and higher floor level.

Proxy Measures

An optimal quasi-experimental research design would entail a non-randomized comparison group measured on the same outcome variables, but not exposed to the same intervention. Because there was no "non-green" renovation being done on a low-income seniors housing development in Phoenix at the same time as this study, alternative proxy measures were used.

For Health Outcomes, data of seniors (i.e. over the age of 64) from the national samples of annually-administered National Health Interview Survey (NHIS) and Behavioral Risk Factor Social Survey (BRFSS) surveys – both administered by the Centers for Disease Control – constitute the proxy comparison. Survey items from these instruments were used in the interviews at Sunnyslope Manor. At this time, only 2010 data from NHIC and BRFSS is available. Data for 2011 is expected in summer 2012; this will be used to assess whether the trend in changes noted in the research site (SSM) from Panel 1 to Panel 2 are of similar or dissimilar trend as the national samples. The same will be done for all panels once the national data for 2012 is available (likely summer 2013).

For IEQ Outcomes, air and environmental quality standards and thresholds are used for proxy comparisons. ASHRAE-55 2010 standards for temperature/thermal comfort and ASHRAE 62.2 for indoor air exchange will be compared with SSM's temperature measurements. ASHRAE-55 2010 absolute recommended thresholds for all seasons that will be used are: (1) High - 81 degrees Fahrenheit; (2) Low - 68 degrees Fahrenheit.

For particulate matter, the US Environmental Protection Agency has set National Ambient Air Quality Standards (NAAQS) for both PM2.5 and PM10. The NAAQS for PM10 is set at 150 micrograms per cubic meter over a 24-hour averaging period and the PM2.5 standard is set at 35 micrograms per cubic meter over a 24-hour averaging period. While sampling in the resident households only occurred for a period of one hour, there is no reason to expect significant temporal variability in the PM levels indoors, justifying the comparison of the one-hour average indoor PM levels to the NAAQS set over a 24-hour averaging period.

For formaldehyde, several health-based exposure levels have been established by various regulatory agencies in the US and other countries. We chose as a threshold criterion for formaldehyde the reference exposure level (REL) for chronic exposure in California: 27 ppbv (Salthammer et al, 2010).

Measuring for Benefit Cost Analysis

The renovation of SSM included reductions in risks associated with *ergonomic* attributes of the building such as lighting, grab bars, floor coverings and the design and location of certain fixtures, appliances and controls. These changes can affect the quality of life and, in some instances, reduce the risks of injuries and improve the mobility of residents. The other important group of renovations is those that improve the *environment* in which the residents live, including heat and air pollution which affect both the quality of life and, in some instances, individual health conditions such as asthma, chronic obstructive pulmonary disease, and other respiratory conditions that can also contribute to cardiac problems. Some of the parameters to be used in the benefit cost analysis include the following.

Costs. The costs will be measured as the accounting costs recorded in the construction budgets that are part of the contracts between the builders and the City of Phoenix. The challenge is how to best allocate the costs of an alteration among the multiple objectives to which it contributes.

Duration. Given the advanced ages of the Sunnyslope residents, the period of time over which benefits will be received by a resident may be small although the benefits will apply to multiple cohorts of residents over time. The challenge here is to define a duration that could capture the benefits among multiple cohorts of residents without introducing excessive uncertainty into the analysis. We assume a duration equal to the duration of the project plus five years. Although the alterations are capital improvements with longer useable lives, the considerable uncertainty surrounding the characteristics of the residential population over time suggests the need to be conservative.

Discount Rate. The costs of the intervention are capital expenditures, invested in housing at a point in time but generating benefits over much longer periods. It is necessary, therefore, to compare the benefits measured during the period of the proposed project to the portion of the total investment that is distributed to the years in which the benefits are received. Otherwise the ratio of benefits to costs will be understated. Projections beyond the life of the proposed study in which benefits are measured must be converted to present values using a discount rate. We will use a real discount rate of 2%, approximately the real rate of interest in the United States for nearly a century. Current real rates of interest are negative so the use of the historic rate understates the present value of the benefits relative to discounting using current real rates.

Benefits. This portion of the analysis focuses on the health or health related benefits of the project and does not consider the other objectives of the project. The benefits discussed here can, therefore, be assumed to be additions to benefits such as the efficiencies associated with the use of more eco-friendly materials and designs. We first consider the potential benefits of ergonomic alterations and then the potential benefits of the environmental alterations.

The benefits from the ergonomic alterations include: reductions in the risk of injuries and increases in resident mobility including the ability to perform activities of daily living. In addition, we focus on reduction in the risk of injuries with special emphasis on injuries related to falls and injuries typically classified as: "struck by/against." These types of benefits can be measured in both natural units (incidence of falls) and monetary units in terms of the averted healthcare costs for reductions in the number and severity of falls.

Procedure for Development and Assessment of Resident Education Booklet

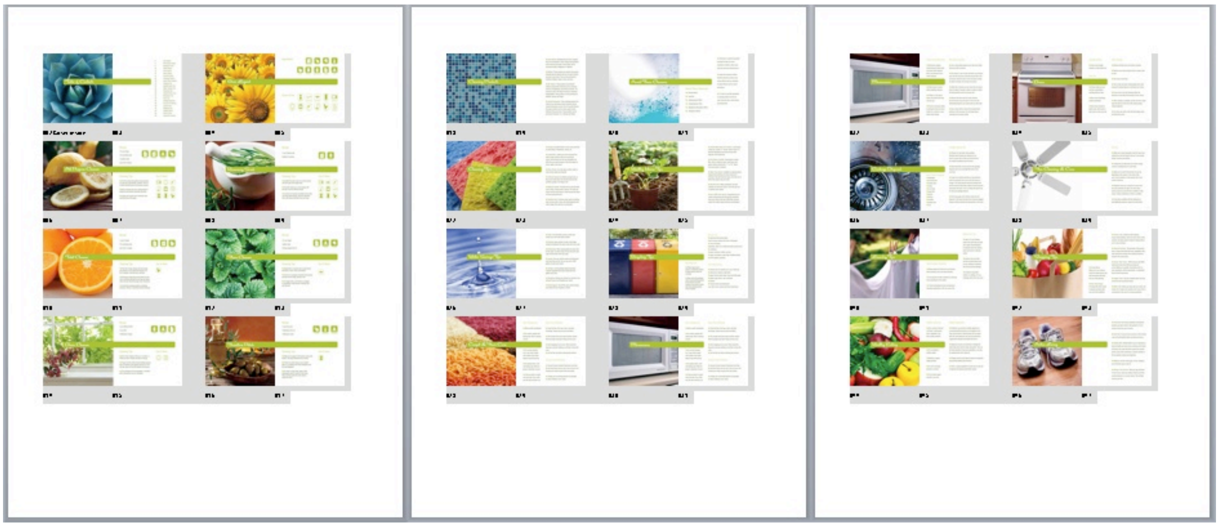
Researchers and housing providers acknowledge that resident behavior is a key component of healthy home practices as well as green practices such as energy efficiency (USDHUD 2001; Wener & Carmalt 2006). While a number of educational programs and brochures have been developed and implemented for promoting healthier and more efficient operation and maintenance of one's home, many of these lack age-appropriate communication strategy for the elderly. Further, there is little research evaluation of their effectiveness. It is our premise that resident communication materials that are specifically designed for and targeted to different populations groups may be more effective in informing and motivating residents to maintain and operate their homes in healthy-efficient ways.

When talking with the SSM residents during social and resident events, we recognized that, by and large, these older residents were quite energy conscious even though they did not pay their own utility expenses (except for phone and cable). Some shared stories of how they had changed light bulbs in their homes (and even the hallways) to CFL bulbs, or how they had encouraged property management to increase the recycling efforts and bins in the complex. This prevailing "green behavior" of SSM residents reflects the findings of a survey conducted by the marketing firm I-COM (Environment News Service, 2008) that showed that consumers over the age of 55 were the greatest users of green products. Accordingly, the GAP team believed the educational materials should reflect cleaning efforts and products for maintaining the healthy nature of their renovated homes, rather than energy efficient behaviors.

Third-year undergraduate students in ASU's Visual Communication Design studio course undertook a 6-week project in Spring 2011 to create educational materials for the residents. The students were supervised by their instructor Lisa Peña as well as members of the GAP team (Patel, Sinclair, Ahrentzen). Divided into 10 teams of four students each, the students examined conventional healthy homes educational materials (e.g. "Help Yourself to a Healthy Home," USDHUD 2001) to familiarize themselves with existing products. They then visited SSM, saw the renovated homes, observed use of the space, and spoke to several residents and the property manager.

Each team then developed a set of different materials (e.g. calendar, handbook, magnets, place mats, cleaning products, etc.) intended to inform residents of practices and products for maintaining the fixtures, furnishings, appliances, and other features of their renovated homes that would be healthy and green. The prototypes were also responsive to physiological, social and cognitive conditions of this older resident population. After these prototypes were developed, the student teams held a 2-hour meeting with approximately fifteen SSM residents, demonstrating the materials and getting feedback from them. Each prototype was refined based on this feedback, and presented to a few members of the GAP research team and the studio instructor. One prototype was selected for further development, which was carried out by four students in Fall 2011 (Figure 6).

Figure 6 Resident Education Booklet for Sunnyslope Manor



Printing and distribution of this document is underway as of this date. It will later be distributed to all SSM residents; and its use and effectiveness will be assessed in future focused group interviews.

Lessons Learned to Date

As of this writing, only preliminary data analyses of the first two panels has been undertaken; full-scale data analysis is planned for late summer and early Fall of 2012 when the third and final panel of data will be collected and assembled.

Nonetheless, the preliminary data analyses and our own impressions when visiting the site after the renovation have suggested several lessons relevant to our study's purpose and hypotheses. These are described briefly below for discussion during the ENHR "Residential Context of Health" workshop.

The Devil May be in the Details

This American slogan suggests that while we often focus on big-ticket items, such as energy upgrades or unit flooring, it may be that less visible and less prominent items may affect health and IEQ in ways seldom considered. Too often these small details are neglected when renovating homes or when documenting physical interventions in research studies. These details may also include non-technical elements such as cleaning solutions used, or non-environmental elements such as residents' cleaning habits and frequency.

Aldehyde levels, for example, measured during pre-renovation were quite high in several units. Given the duration of time since the cabinetry and much of the flooring had been installed in the apartments (over 20 years for the cabinetry), we found surprisingly high amounts of formaldehyde concentrations in several of the units, some exceeding threshold levels by a factor of two or three. In the second panel, we again found rather high amounts of formaldehyde concentrations in several units even though the cabinetry, paint, and flooring were all specified as low or no VOC materials. When we went to visit many of the apartments after the renovation, the lingering odor suggested the presence of aldehyde concentrations. One hunch we had was that this odor may be emitted from the adhesives, caulking and sealants for installing the low-VOC flooring and cabinetry. We made many efforts to gather information about these adhesives from the contractors and housing staff, who were surprised at our interest in such details. It turned out few of these adhesives were no- or low-VOC.

Another possibility is that such aldehyde concentrations may have come from cleaning products that residents used. In one of our tests in the second panel, a resident was using the cleaning mechanism on his oven. We took aldehyde readings during this time; and then came back at a later day when he was not operating the cleaning mechanism. (The latter data is the one recorded and used in our statistical analyses.) We were able to compare the high concentration of emissions during the mechanized oven cleaning process to that of his apartment days after it operated. (This particular comparison will be presented to residents at the completion of the study when study results are presented to them, to better inform them of the air toxicity that may occur during the oven cleaning operation.) As discovered during our Panel 2 interviews, nearly half of the residents use products to change the odor of their apartment (e.g. air fresheners), that may be reflected in the higher than expected aldehyde concentrations in those apartments. Preliminary comparative analyses of IAQ of units with smokers and units without further suggest how resident behavior may aggravate indoor air quality regardless of renovation changes.

Accordingly, we have made adjustments in our third panel questionnaire to gather additional information about resident behaviors and use of cleaning solutions.

Green Renovation is a Process, not Just a Product

Given the more delicate physiological conditions of older adults, short-term health impacts may be quite significant regardless of air and environmental improvements in the apartment months or years later. The staged scheduling process for this renovation – in which seniors remained in the building during renovation and returned to their under-construction units to sleep at night – may have exacerbated health conditions. Our preliminary findings of particulate matter in units show slightly higher levels of PM2.5 one to three months after the renovation. To investigate the relationship between in-filtration of particles (i.e. particles originating outdoors that enter into the home) versus particles generated indoors, the ratio of indoor to outdoor particles was determined. Preliminary findings demonstrate a sizeable number of units with indoor concentrations of particles that are lower than outdoor levels, suggesting that elevated concentrations of PM inside the home arise from indoor sources, not infiltration of PM from ambient (outdoor) sources.

In addition, the moving and renovation process itself may have been a distressful one for residents. In questions asking about dissatisfied aspects of their renovated units, one of the leading responses was the unpredictability of the move and renovation, and the constant inconvenience of having to "relocate" at night back to the under-construction apartment for sleeping.

"Baseline Green" Needs a Foil

Given costs and funding requirements, several physical changes intended to enhance environmental and air quality of the units were not implemented, most noticeably that of replacing the existing PTAC system with a more efficient and better ventilated HVAC system, or even something as small as a remote wall switch to operate the ceiling fan which would eliminate the need for elderly residents – many with muscle and joint impairments – to stretch overhead to reach the fan's pull cords.

Yiance Hernandez (2012), Deputy Director of Enterprise Communities Partner, a national affordable housing intermediary that helps finance and direct green and healthy building practices in the US, claims that most of the builders using their Green Communities building guidelines balk at employing the "healthy living environment" criteria of these (e.g. for mold prevention, ventilation), and are more prone to incorporate the energy and water efficiency criteria instead.

In our study, discovering significant health and IEQ/IAQ outcomes from SSM's "baseline" green retrofit changes may not turn out to be meaningfully significant given the lack of more effective ventilation, lighting and ergonomic systems in the renovation. Fortunately, a similar research study examining the health and IEQ/IAQ impacts of a green renovation of seniors' housing in Minnesota was funded by HUD at the same time and duration as our study. Their renovation involved moving the residents out of the building for nearly a year while substantial green renovation (using Enterprise Green Communities Criteria, 2011) occurred. We are sharing information on testing, measurement and, eventually, results with the researchers of this study (National Center for Healthy Housing).

In doing so, the findings and implications of this multidisciplinary research project will be further enhanced by taking into account, comparing, and starting to synthesize empirical results across studies – and eventually contributing to the knowledge base of understanding whether “green housing and healthy housing are in fact synonymous.”

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