Poor Home Maintenance = Increased Health Risks

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Executive Summary

MFAN (Military Family Advisory Network) survey data from 16,000 respondents living in privatized military housing are used to examine trends and linkages between environmental illness and home maintenance. The MFAN data was collected from 200 US facilities spread across North America and Hawaii in response to the MFAN organization's investigation of dissatisfaction in privatized military housing. Privatized military housing management firms self-report high satisfaction rates (80%) to the US military that conflicts with dissatisfaction reports received by MFAN from housing residents. We use the MFAN survey data as a reflection on rental housing in general, and assert that observed trends and relations are valid beyond privatized military housing.

Environmental illnesses are strongly linked to visible mold. Mold occurrence correlates with HVAC (comfort conditioning) systems, plumbing, and building structure problems. HVAC, plumbing and building structure issues are directly linked with survey respondents' dissatisfaction with maintenance. And, housing residents' dissatisfaction with maintenance is a strong factor in residents' overall housing satisfaction. In other words, improved maintenance practices that reduce HVAC, plumbing and building structure problems will significantly improve resident health and housing satisfaction.

Housing dissatisfaction increases as home occupant income decreases. Lower income housing residents receive poorer maintenance with a resulting environmental illness increase. In addition to higher levels of home occupant dissatisfaction and increased prevalence of environmental illness, lower income housing residents are taxed with higher out-of-pocket expenses related to self-remediated health problems, maintenance fixes, and elevated utility bills. A destabilizing set of circumstances forms in which the hidden expenses of lower cost housing cut disproportionately into a household's precious discretionary income.

Smart ventilation and comfort conditioning systems represent disruptive technologies that can improve housing maintenance efficiency and lower maintenance costs. Estimates of the value of smart housing technologies and potential environmental illness and energy savings are discussed.

Trends and relationships among survey topics and housing satisfaction are summarized below.

1) 1 out of every 4 homes reporting visible mold also report someone suffering from an environmental illness.
2) Approximately 40% of privatized military homes report mold and 10% report environmental illness.
3) Homes in warm, dry climates have less mold than homes in warm, humid climates, however, homes in all climatic conditions are susceptible to high levels of mold and environmental illness.
4) Mold occurrence is related to HVAC (comfort conditioning) issues and plumbing problems with nearly 0.8% increase in mold for every 1% increase in either HVAC or plumbing difficulties.
5) An increase of 0.6 to 0.7% in maintenance dissatisfaction occurs for every 1% increase in either HVAC or plumbing issues.
6) Overall housing satisfaction is directly related to income with a satisfaction grade of 2.4 for $2000 per month income earners and nearly 3.0 for incomes of $12,000 per month (based on a 5 point scale with 3.0 representing neutral, 1=very negative, 5= very positive).
    a. The overall satisfaction grade for 200 military facilities is 2.43.

7) Housing residents' "very negative" responses are twice as high (20% versus 10%) for low income households than high income households, while "very positive" responses to housing conditions are half as great (2.5% versus 5%) for lower income households.
8) For the military in particular, and rental management firms in general, improved maintenance practices that reduce HVAC (comfort conditioning), plumbing and structural problems will significantly improve resident housing satisfaction, decrease environmental illness, and decrease home occupant out-of-pocket expenses.
    a. Maintenance dissatisfaction has strongest cross correlation coefficient (-0.56) with overall housing satisfaction indicating the best way to improve housing satisfaction is improved maintenance.
    b. Other survey topics strongly related to housing satisfaction are: paying out-of-pocket expense (-0.37), management lying (-0.35), plumbing problems (-0.34), management issues (-0.3), weather damage to housing (-0.25), and climate control issues (-0.20).
    c. Maintenance is the key to improving correlation topics in b. Whether housing management is "lying", or disgruntled residents are interpreting excuses and lack of maintenance response as lying, residents will be more satisfied with more effective maintenance.
9) Environmental illness most strongly correlates to mold (0.69), HVAC (climate control, 0.42), out-of-pocket expenses (0.36), insect pests (0.35), building structure (0.34), and plumbing (0.27). "Praise" of housing comments decrease with increased environmental illness (-0.34).
10) The occurrence of mold is strongly related to building structure problems (0.50), plumbing (0.38), HVAC issues (0.34), and insect pests (0.35). Interestingly, mold occurrence is weakly correlated to maintenance, indicating a higher order or indirect linkage of maintenance dissatisfaction to mold through HVAC, plumbing and building structure problems. Note that building structure problems, as well, may be the result of damage from leaking HVAC and plumbing systems.

Rental housing residents suffer from poor maintenance practices as building owners seek to maximize profit by minimizing cost. Housing residents and the populace as a whole are affected by poor maintenance elevating health and energy costs. Today's "smart" technologies, such as CERV2 smart ventilation and comfort conditioning systems are disruptive technologies that can decrease maintenance costs while improving indoor environmental quality.

The results of this report identify pathways for the US military leadership to improve privatized housing problems. Improved maintenance coupled with smart ventilation and comfort conditioning technologies will provide the most bang for the buck in improved housing satisfaction and reduced operating costs. Military leadership would also gain direct access to privatized military housing performance through smart monitoring and control of ventilation and comfort conditioning.

Home owners also benefit by the lessons learned from the MFAN survey and this report's analyses. No matter how "green" you have designed and constructed a home, a poorly maintained home will make its occupants sick and increase energy usage.

Introduction

Home occupant comfort and well-being are dependent on good maintenance practices. Poorly maintained HVAC systems, leaky plumbing, and structural problems degrade indoor environment quality and increase environmental illnesses. Lower income households have higher maintenance dissatisfaction with a disproportionate increase of environmental illness, illness-related costs, and out-of-pocket expenses. Smart ventilation, a disruptive technology, can improve maintenance effectiveness at reduced cost with a resulting decrease in environmental illness.

We investigate the relationship between maintenance and environmental illness in homes using survey data from the Military Family Advisory Network (MFAN) (1, 2, 3). Primary maintenance issues are poor performing heating and cooling systems, and plumbing problems. Comfort conditioning and plumbing problems are found to be related to mold occurrence, which in turn, is strongly related to environmental illness. Building structure problems are also significant indicators of poor maintenance and environmental health problems. Building structure problems can also be a symptom of problems originating with HVAC moisture and plumbing leakage issues.

Improved maintenance in lower income rental housing is a difficult but important problem to solve. Beyond the direct cost of an environmental illness (doctor visits, medications, emergency room visits) are indirect effects such as missed days at work or school, and a decrease in one's work or school performance. For the military, environmental illness degrades military personnel preparedness and indirectly impacts military personnel readiness caused by worry about their family's well-being.

Housing maintenance is analogous to auto maintenance. A car's oil filter, air filter, and general preventive maintenance should occur at similar mileage periods regardless of car value. Likewise, a home's air filters should be changed regularly, plumbing leaks fixed, and comfort conditioning systems maintained regardless of house value.

Electric vehicles are disrupting the automotive market with significant reductions in maintenance expense in comparison to conventional cars with internal combustion engine technology. Oil changes are no longer required; transmissions, mufflers, and catalytic converters are no longer needed; and brake pad longevity is increased. "Smart" technologies are similarly disrupting the housing industry with improved indoor air quality and increased energy efficiency coupled with reduced maintenance expense. Autonomous vehicles are also disrupting the marketplace with technologies that improve accident avoidance. Similarly, we are entering a period of autonomous homes where our residences can avoid catastrophic breakdowns that degrade our health and well-being.

Build Equinox's CERV2 smart ventilation system has had online control, monitoring, and diagnostic capabilities since 2013. Our seamless OTA (Over-the-Air) upgrading capability ensures that all CERV's are operating on the most advanced algorithms. Housing management can be alerted to problems in a residential unit's air quality and comfort conditions before damage to the home and one's health occur. Unoccupied residential units can be remotely monitored and controlled, minimizing costs related to frozen pipes, gas leaks, mold (humidity), excessive energy bills from incorrect thermostat settings, or other problems normally undetected until the next occupancy occurs. For privatized military housing, smart technologies provide the military with a supervisory capability that minimizes inaccurate or misrepresented housing maintenance and administrative records.

Background

The MFAN (Military Family Advisory Network) conducted a survey from January 30 to February 6. 2019. US military families were asked for feedback on privatized military housing. Over 16,000 responses were received during the one week survey period, revealing multiple inadequacies and a high level of dissatisfaction. The Secretary of the Army apologized to US military families as a result of the survey. Hopefully a consistent path of remediation and improvement of privatized military housing ensues.

MFAN survey data reflects issues encountered with rental housing in general. The breadth of the MFAN survey in terms of geographic distribution, income, physical condition, and housing administration is remarkable. We analyze the MFAN survey results with a primary focus on tenant health related to their housing environment. Several studies have shown increased health problems in lower income housing environments. Our analyses of MFAN survey data provides an understanding of the linkage between housing maintenance and occupant environmental health.

The MFAN survey is a qualitative assessment of privatized US military family housing units geographically spread over the US, covering all service branches and military ranks. The survey asked respondents to describe various aspects of their housing experiences. MFAN personnel coded survey responses into several categories, and cross-checked categorization uniformity among survey assessment personnel. Detailed descriptions of the survey and survey analyses are included in the MFAN preliminary and final reports (1,2). An MFAN executive summary (3) itemizes key findings from the survey.

We use the survey data to analyze trends among respondent answers, and to assess cross-correlation relations between respondent survey categories. Many results are common sense. For example, higher levels of mold correlate with higher incidence of environmental illness. Others are not so obvious, such as an increased maintenance dissatisfaction has a positive correlation with a tenant's out-of-pocket expense. It is important to remember that correlation does not imply causation. Although mold is strongly related to environmental illness, mold is only one of several factors that can cause environmental health issues. More generally, mold is an indicator of other problems in the indoor environment that require attention.

A chain of events is evident as one examines relatively strong cross-correlations among the survey categories. For example, a lower income family is more likely to be dissatisfied with their housing than a higher income family. A primary reason for lower income family housing dissatisfaction is poor maintenance. HVAC comfort conditioning and plumbing leakage problems correlate strongly to poor maintenance. Mold correlates with HVAC comfort conditioning and plumbing problems. And, environmental illness correlates strongly with mold.

MFAN survey data covers nearly 200 military housing locations ranging from smaller facilities with one or two responses to larger facilities with more than 100 responses. We restrict our analyses to facility locations with 40 or more responses in order to reduce bias related to small sample sizes. Significant differences are expected for large base facilities due to variations in housing quality, climatic conditions, housing administration effectiveness, and other factors. These differences in larger facilities are important for examining general trends and correlation relations among survey responses.

MFAN collected data on overall housing satisfaction based on a 5 point scale (1=very dissatisfied, 2=dissatisfied, 3=neutral, 4=satisfied, and 5=very satisfied). A response weighted satisfaction grade was calculated by MFAN for each site. Figure 1 is a plot of the satisfaction grade as a function of number of responses for each facility. The wide variation of satisfaction grades at facilities with low response numbers is evident, and the reduced variation of satisfaction grades at facilities with 40 or more responses is also evident. Note that military housing respondents have an average satisfaction grade of 2.43, well below a neutral rating of 3.0.

Table 1 is a listing of military facilities with 40 or more MFAN survey responses, including each facility's satisfaction grade. Table 2 is a listing of survey topics. Color coding in Table 2 is used to define environmental illness, physical facility, administration, and financial survey topic areas.

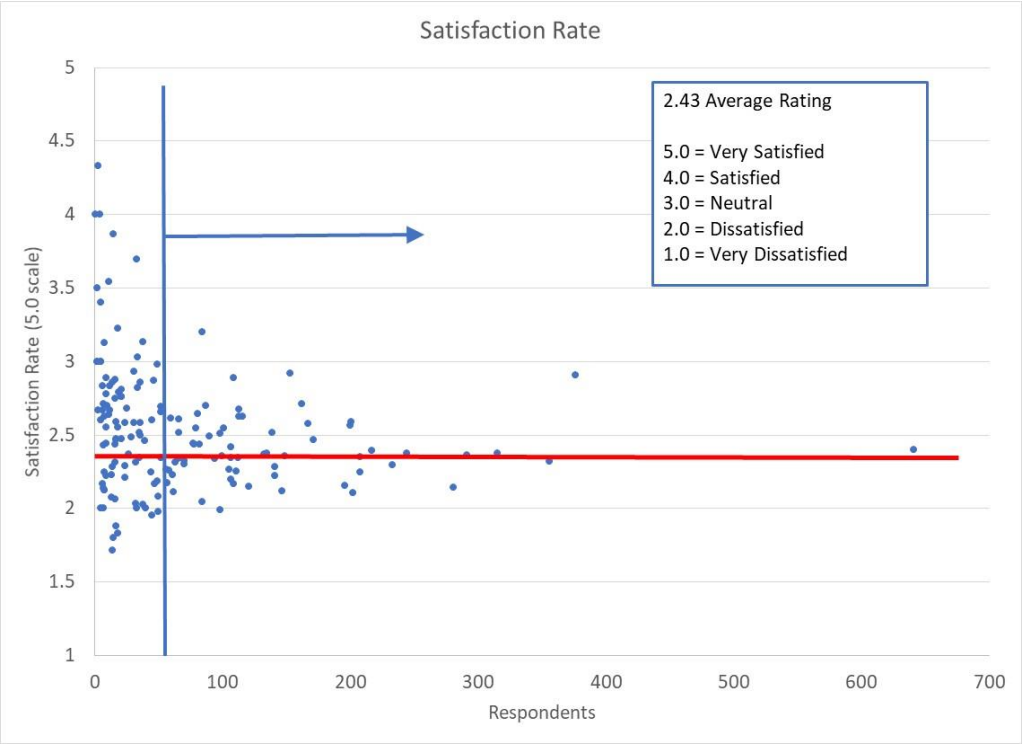

Figure 1 Satisfaction Rate versus number of survey respondents for each military facility with privatized housing. Facilities with 40 or greater responses are used for this report.

Environmental Illness and Mold

Our indoor environment should not make us sick, but too often, it does (4). Nearly 800 of MFAN survey respondents reported an environmental illness attributed to housing. MFAN coded survey results for environmental illness as:

"Families who described specific deteriorating health they attribute to issues inside their homes. This code was only applied to those respondents who made the direct connection from their homes to their illnesses. Some examples were: chronic illnesses, breathing and respiratory ailments, rashes, headaches and migraines, pneumonia, and fertility complications." (ref 1; MFAN Privatized Military Housing Final Report May 2019, p. 26).

The accompanying stories included in the MFAN reports are eye opening and disappointing that constrained maintenance budgets cause such large increases human illness and health care costs. As expressed by Florence Nightingale more than 150 years ago, if architects and building owners were charged for the health costs of their building's occupants, buildings would be designed and operated much differently (5).

The list below (from Table 6 of reference 4) describes many symptoms associated with environmental illness. The most common complaint in the building survey and analysis by Brightman, et.al (4) is a lack of ventilation air (54%), with other major complaints (too hot, too cold, too dry) centering around poorly operating HVAC systems. Poorly controlled indoor environmental quality increases sick days (6,7), causes poor sleep (8), and degrades cognition productivity (9,10, 11).

- Tired or strained eyes
- Dry, itching, or irritated eyes
- Unusual tiredness, fatigue, or drowsiness
- Headache
- Tension, irritability, or nervousness
- Pain or stiffness in back, shoulders, or neck
- Stuffy or runny nose, or sinus congestion
- Sneezing
- Sore or dry throat
- Difficulty remembering things or concentration
- Cough
- Dry or itchy skin
- Feeling depressed
- Dizziness or lightheadedness
- Chest tightness
- Nausea or upset stomach
- Shortness of breath
- Wheezing

A strong indicator of environmental illness is mold (12,13). Mold can directly impact home occupant health, and mold is an indicator of other environmental illness causes such as poor indoor air quality,

high humidity, and biological contaminations. Figure 2 is a plot of MFAN data for military facilities with more than 40 responses showing self-reported environmental illness versus percentage of respondents who reported visible mold.

Figure 2 shows that one out of every four homes with visible mold has one or more household members with an environmental illness. A least squares plot of environmental illness as a function of mold presence has a zero intercept. That is, eliminating problems that lead to mold growth eliminates environmental illness!

Some military facility data points in Figure 2 are highlighted to illustrate trends associated with climatic conditions. Eight warm, humid bases (5 in Florida and 3 in Georgia) and five warm, dry bases (3 in New Mexico, 1 in Nevada, and 1 in west Texas) show that more humid climates exacerbate mold occurrence as one would expect. High levels of outdoor humidity add to the moisture loading of internally generated moisture and the potential to grow mold. Dryer climates help reduce mold growth, however, significant levels of mold and environmental illness exist in poorly maintained, dry climate homes, too.

As previously mentioned, mold is not necessarily the cause of a home occupant's environmental illness, but can be a surrogate for poor air quality (carbon dioxide and VOCs), poor comfort conditions (temperature and humidity), and unhealthy microbiome (bacteria, viruses, endotoxins, etc). For example, high humidity levels increase dust mite activity, which can trigger asthma attacks, while carbon dioxide and VOCs impair cognition and sleep. Tiny concentrations (nanogram per cubic meter) of endotoxins significantly increase fatigue and cause inflammation and fever.

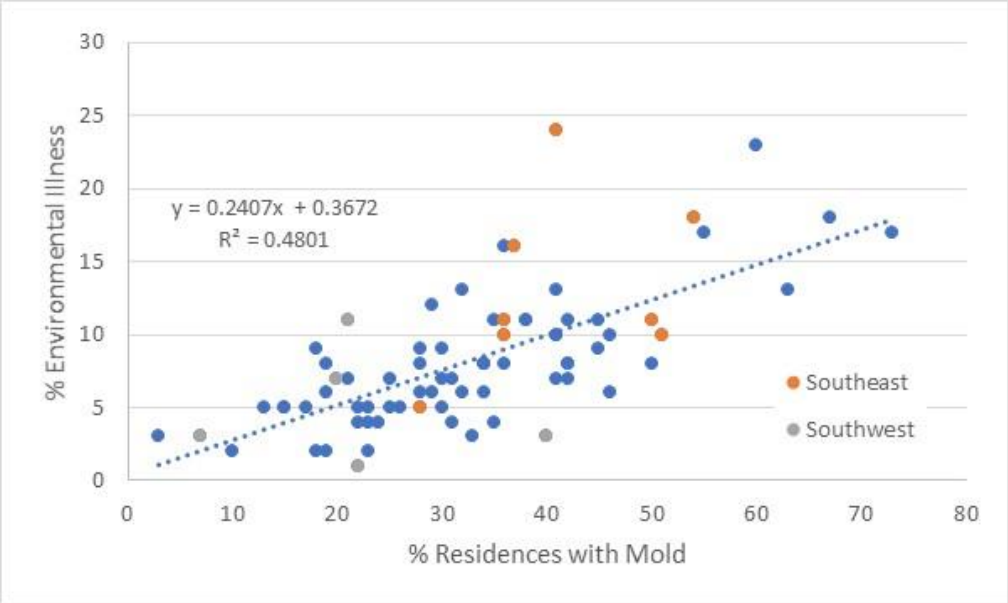

Figure 2 Relation between environmental illness and residences with mold. Some Southwest (dry climate) and Southeast (wet climate) housing data are highlighted.

Maintenance and Mold

The presence of mold is related to HVAC problems and plumbing leaks, and these problems are linked to home occupant dissatisfaction with maintenance services. Improved maintenance practices that minimize HVAC and plumbing problems will improve resident health and increase housing satisfaction.

Figure 3 is a plot of household mold versus HVAC system problems and plumbing problems. Significant data scatter occurs due to climatic variations and house construction as previously discussed. A more quantitative assessment of HVAC and plumbing problems within specific climatic zones would better define trends. The intent of this analysis is to provide guidance for more detailed studies. Within the framework of the current survey, the trend exhibited is evident. HVAC and plumbing are related to mold occurrence in similar manners. Every 1% increase in either HVAC or plumbing problems increases mold incidence by 0.8%, for a nearly 1-to-1 correspondence. Eliminating plumbing and HVAC problems would reduce mold incidence to 15 to 20% of homes rather than an average mold incidence of 30 to 40% military homes.

Mold is ubiquitous, and all homes have mold, however the survey focuses on visible mold. Water incursion through housing materials from rain and snow creates an environment for growing mold. Mold also forms within the structure of a leaky home as humid infiltrated and exfiltrated air condenses moisture as it passes through the building structure. Water condensation on windows during winter conditions and poorly vented bathrooms are other examples of mold growth factors. The large scatter in Figure 3 is indicative of multiple sources of mold growth.

Figure 4 plots MFAN respondent maintenance dissatisfaction versus HVAC and plumbing problems. Similar to Figure 3, HVAC and plumbing problems are quite similar, perhaps indicating that both develop maintenance issues at a similar frequency. Eliminating HVAC and plumbing problems would reduce maintenance dissatisfaction to 45%, which is still quite high. That is, HVAC and plumbing problems cause additional dissatisfaction with maintenance in combination with other maintenance issues. Mold, however, is more strongly associated with HVAC and plumbing problems than with other maintenance problems. We will also find that structural problems are linked to HVAC, plumbing and maintenance dissatisfaction through our discussion of cross-correlation relationships. Structural problems may be directly related to HVAC and plumbing issues because water is a frequent cause of structure deterioration.

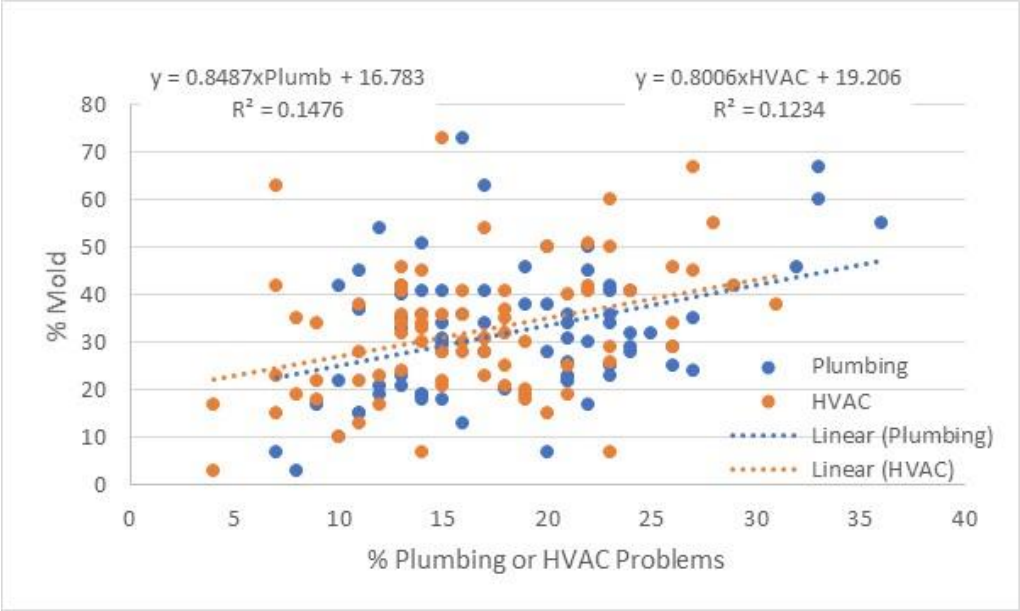

Figure 3 Percent mold occurrence versus plumbing and HVAC problems.

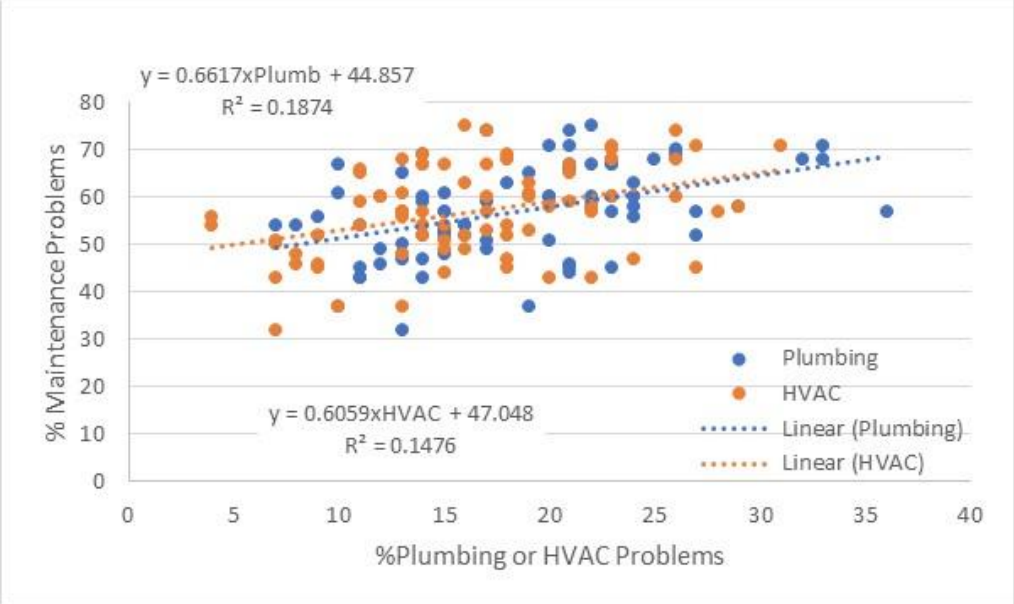

Figure 4 Maintenance dissatisfaction versus household plumbing and HVAC problems.

Housing Satisfaction Ratings Related to Income

Military pay grades provide a means to examine rental housing satisfaction in relation to income. The MFAN survey collected paygrade data relative to housing satisfaction. The trend in housing satisfaction relative to paygrade is very clear. The more income, the better (and more satisfying) the housing. Figure 5 shows a plot of military pay levels based on mid-pay schedule rates over the range of military paygrade ranks represented by the MFAN data. A 0.6 difference (25% difference) in satisfaction rating exits between the lowest paygrade and highest paygrade.

Figure 6 provides an additional view of satisfaction trends related to monthly salary. "Neutral" ratings are relatively constant at 30% across all paygrades. "Very Positive" satisfaction ratings increase significantly with increases in pay while "Very Negative" satisfaction ratings decrease with salary increase. The highest salary levels have twice as many very positive ratings than the lowest paygrade, and half as many very negative ratings.

Figure 7 is an estimate of maintenance dissatisfaction relative to overall satisfaction grade. Notice that southeast (warm, humid) and southwest (warm, dry) military housing facilities have similar levels of maintenance dissatisfaction variations. Two points are drawn on Figure 7 that correspond to the overall satisfaction grades for the highest and lowest military paygrades. We do not have survey data details for quantitative comparison, but estimate 15% maintenance dissatisfaction for the highest salary level in comparison to 60% maintenance dissatisfaction for the lowest paygrade.

Figure 8 estimates trends in environmental illness relative to maintenance dissatisfaction. Qualitatively the trends indicate that higher salary is related to reduced environmental illness. Many issues impact maintenance dissatisfaction resulting in significant data scatter. Projecting environmental illness trends from high to low military paygrades indicates 5% of high salary households to have environmental illness relative to 8% of lower military paygrades. Warm, humid locations tend to be higher in environmental illness than warm, dry climates with a 10% or more higher level of illness incidences in warm, humid climates.

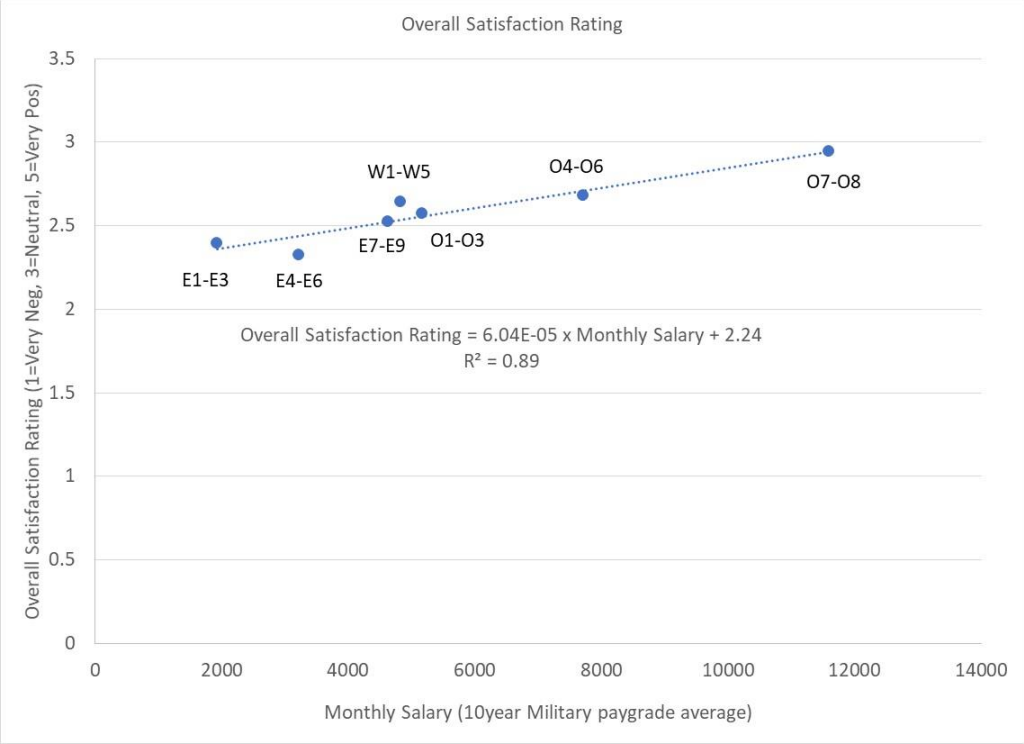

Figure 5 Housing satisfaction rating as a function of military income.

Figure 6 Trends in "very positive", "neutral", and "very negative" satisfaction ratings with monthly salary.

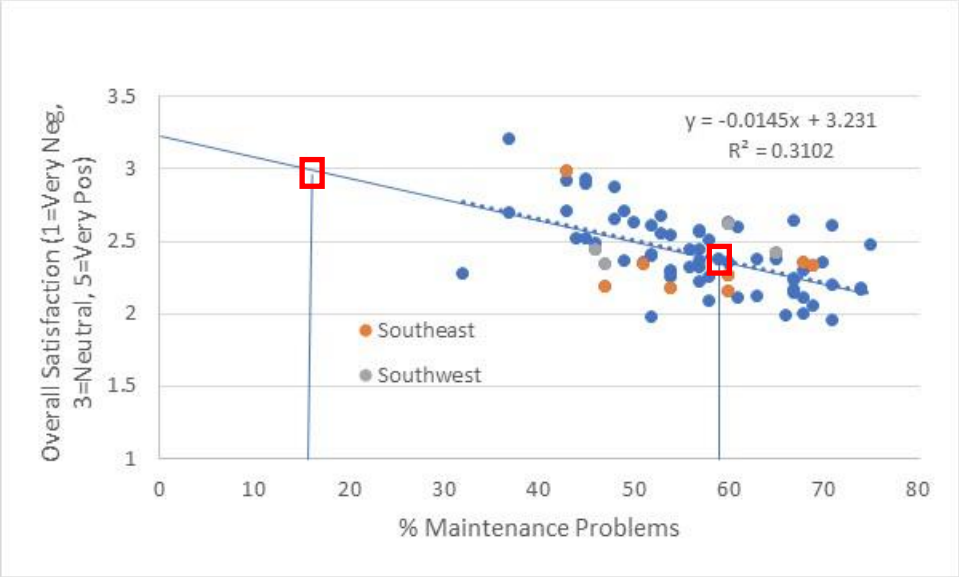

Figure 7 Plot of overall satisfaction versus maintenance dissatisfaction.

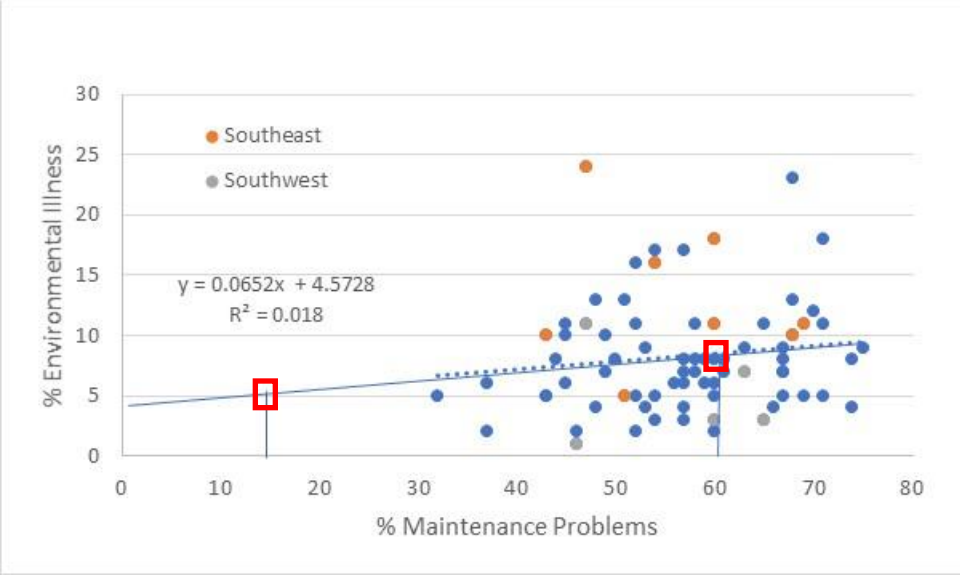

Figure 8 Estimated trend of environmental illness and maintenance dissatisfaction.

Cross Correlation Matrix and Survey Topic Interrelationships

Cross correlations between survey topics further identifies the strength or weakness of relations between survey items. In addition, cross correlations indicate whether an increase in one topic is related to an increase or decrease in another topic. Terms that have reasonably strong cross correlations can be used as to understand which housing improvements improve housing satisfaction. It is important to remember that correlation does not mean causation.

We apply Excel's cross correlation function with survey topic data for military facilities that have 40 or more responses. We also correlate the overall satisfaction grade with the survey topics in order to assess which survey topics seem to be most strongly related to satisfaction. A perfect cross correlation would have a value of 1, indicating a positive sloped correlation, or -1, indicating a negative sloped correlation. A correlation of 0 indicates no correlation, and values between 0 and 1, and 0 and -1 are varying levels of correlation. For the MFAN data, a correlation coefficient between -0.1 and 0.1 are weak, and correlations greater than that are increasingly related.

Tables 3 and 4a/4b display the cross correlation results. Tables 4a and 4b are enlarged views of Table 3 for easier viewing of results. We will discuss only a few of the survey topics that are most relevant to environmental illness while noting that many other interesting topic interrelations exist in the table. Our discussion is in the spirit of explaining possible relationship paths that impact housing resident satisfaction. Other explanations, including simple happenstance and randomness, may also be valid. Quantitative investigations exploring these topics can more firmly establish relationships.

<u>Overall Satisfaction Grade:</u>

Almost all survey topics negatively correlate with satisfaction. Positive praise for the facility is positively (and strongly) correlated with satisfaction with a correlation coefficient of 0.80. That is, when a survey respondent praised their housing, they were also likely to give housing a high satisfaction grade as one would expect. Water quality issues correlate positively with satisfaction grade (0.27), which is the opposite of what one would expect. Very few survey respondents (fortunately) reported water quality problems (several facilities reported no problems), which makes the correlation less meaningful.

Survey topics with a negative correlation greater than -0.2 in descending order to correlation strength are: maintenance (-0.56), paying out-of-pocket expense (-0.37), management lying (-0.35), plumbing problems (-0.34), management issues (-0.3), weather damage to housing (-0.25), and climate control issues (-0.20).

<u>Environmental Illness Relationships:</u>

Survey topics that are most strongly related to environmental illness are mold (0.69) and climate control problems (0.42). Plumbing problems are positively correlated to environmental illness (0.27) along with structural problems (0.34), which may the result of water damage due to plumbing and HVAC problems. Maintenance (0.13) and "filth" at move-in (0.04) are weakly correlated to environmental illness in a direct manner. Insect pests are strongly correlated (0.35) to environmental illness while rodent pests (0.08) are not.

Out-of-pocket expenses increase with environmental illness (0.36) while "praise" decreases (-0.34). Out-of-pocket expenses illustrates the destabilizing influence of environmental illness for lower income

housing residents. They suffer the effects of housing imposed environmental illness and must pay more out-of-pocket expenses for self-remediation of the poor housing. Decreasing environmental illness will improve housing residents' satisfaction and reduce their out-of-pocket expenses.

Mold:

Mold occurrence is weakly correlated to maintenance issues (0.10), however it is strongly related to structure problems (0.50), plumbing problems (0.38) and comfort control issues (0.34). Although the direct correlation of mold with maintenance issues is weak, as we will observe with maintenance correlations, mold and maintenance are strongly linked through higher order relations involving plumbing, comfort conditioning and structural issues. Mold, similar to environmental illness, has a stronger relation to insect pests (0.35) than rodent pests (0.11).

Maintenance Issues:

As previously noted, overall satisfaction is most strongly related (negatively) to maintenance issues. Improved maintenance practices will improve house resident satisfaction. Environmental illness and mold, however, have weak direct associations with maintenance. The most important factors related to environmental illness and mold are structural issues, plumbing problems, and comfort conditioning.

The strongest maintenance correlation topics are structural problems (0.30), plumbing problems (0.43) and comfort conditioning issues (0.38). Weather damage is also reasonably related to maintenance (0.28). We see that maintenance issues align with the most important factors related to environmental illness and mold.

The maintenance correlation table also indicates a very strong negative correlation with praise (-0.50) and a positive relation to management issues (0.33). When someone's maintenance problems are not being resolved, dissatisfaction with management is likely. We also see that unsatisfactory maintenance is related to out-of-pocket expenses (0.24). Poor maintenance practices cause additional expenses on housing residents.

Structural Issues, Plumbing Problems and HVAC (comfort control) Issues:

As we have seen, these three topics tend to go hand-in-hand with poor maintenance and are strongly related to environmental illness and mold. Structural issues are strongly related to plumbing problems (0.63) and comfort conditioning issues (0.42). These relations make sense because plumbing leaks and HVAC system problems (duct sweating, condensate leaks) often cause rot and building material degradation.

Plumbing problems and HVAC issues are strongly related (0.46), which indicates that poor maintenance of one also results in poor maintenance of the other. It is also interesting to note that climate control issues positively correlate with utility fees issues (0.26) and out-of-pocket expenses (0.33). Again, we see that increasingly poor maintenance in lower cost housing causes additional utility fees as well as out-of-pocket expenses by housing residents.

Cost Implications

Ideas regarding the value of improving occupant health and housing energy efficiency are presented. Studies have shown that "green" construction practices in new construction reduces environmental illness (14), however, longterm studies are needed to determine whether a so-called "green" building stays green if it has the same maintenance as neighboring non-green buildings.

The capability of smart ventilation and home comfort control to improve air quality and reduce energy usage have been investigated and demonstrated by many researchers (15, 16, 17). The importance of frequent home monitoring was illustrated by a study in which 34% of the study homes required adjustments and repairs to their ventilation systems (18). With smart, online home ventilation and comfort conditioning monitoring, degraded performance can be detected quickly and repairs scheduled before problems grow in expense and create health issues.

A continuing difficulty in buildings has been linking health effects to building maintenance costs. Facility managers are rewarded for reducing their maintenance costs at the expense of building occupants' health and productivity. Health and human productivity costs far exceed energy costs by an estimated 100 to 1 value (10). In the workplace, poor health and degraded human productivity due to poor maintenance practices are invisibly passed on to the HR department. Students in poorly maintained and operated schools suffer from degraded learning. Military personnel in poorly maintained homes and facilities lack peak cognitive and physical capabilities, endangering mission success.

Asthma is estimated to cost $3000 per afflicted person per year. Some MFAN survey facilities reported as much as 20 to 25% environmental illness. MFAN survey data does not provide information on how many in a household have an environmental illness, and more quantitative data should be collected to better define household environmental illness cost. Using the estimated cost for asthma as a rough guideline, and assuming an average household size similar to US households (2.5 occupants per household), we estimate a household cost $3000 to $12,000 per year for 1 to 4 house occupants (2.5 average occupancy +/-1.5 occupants) impacted by environmental illnesses.

Residential utility costs would be expected to range from $2000 to $3000 per household for older homes, with the potential of being reduced to $1000 to $1500 per year per household with conversion to a smart ventilation system, upgraded comfort control (high efficiency "minisplit" heat pumps), and heat pump water heaters. Combined cost for these systems is $10,000. Structural repairs and improvements (insulation and infiltration sealing) are estimated to be $10,000 per unit, based on $1 to 2 per cubic foot of insulation for ceiling/roof, and $4 per cubic foot for wall insulation and infiltration sealing.

A 2000 square foot floor area ranch home has approximately 2000 sqft of ceiling ($2000-4000 insulation cost) and 1000 sqft of wall area ($4000 insulation cost). Assuming a 10 to 20 year lifetime for the ventilation, comfort conditioning and water heating systems (note that these three systems work in a synergistic manner), the annualized equipment cost (on a simple basis with no inflation/escalation rates assumed) would be $500 to $1000 per year. Improved building structure with an assumed extended building lifetime of 50 years would be an additional $200 per year. Overall, improving indoor air quality and comfort in an energy efficient manner could result in a net savings of $300 to $1000 per year per residence based on energy performance enhancements. These energy savings can be applied to improved maintenance practices.

Beyond energy related savings, improvements in home occupant health is even greater. With a CERV2 smart ventilation system automatically managing air quality and comfort, sick days are reduced by 35% (6) and cognition productivity boosted 10% (10). Decreases in chronic environmental illnesses such as asthma and allergies further improve home occupant health with an associated decrease in health cost, perhaps as much as a 50% reduction in costs, or $1500 to $6000 per afflicted household. With nearly 10% of the general populace impacted by asthma alone, one out of four homes have someone with asthma in their household. Stress is also relieved in home occupants with respiratory sensitivities because their home is the one place where they can confidently breathe without being on guard for an attack.

A smart ventilation system, such as a CERV2, with online monitoring and control capabilities reduces maintenance costs by providing housing administration personnel with residence indoor air quality, comfort and energy performance information. Diagnostic tests can be remotely conducted and maintenance issues efficiently identified, saving maintenance technician labor. And, as improved algorithms and control features are developed, CERV2 OTA (over-the-air) upgrading capability ensures that a home's air quality and comfort systems are never out-of-date.

Privatized military housing facilities will benefit with smart house monitoring technology by providing the military with a capability to directly assess the performance of housing management contractors. Efficient, direct communication with service personnel home performance will alert both privatized housing management and military leaders with information to improve the health of military personnel at lower cost.

Tables

Table 1 Response number and Satisfaction Grade for large (40 or greater survey responses) military privatized housing facilities.

	Military Family Assistance Network Report N=10,861 respondents		
State	Location	Response	TotalGrade
AK	Anchorage-Elmendorf-RichardsonBase	233	2.296
AL	Maxwell AFB Gunter Annex	70	2.3
CA	Camp Pendleton	641	2.402
CA	Ft Irwin	141	2.284
CA	Lemoore NAS	109	2.89
CA	Miramar-MCAS	101	2.545
CA	Monterey	77	2.442
CA	Naval Base Ventura County	87	2.701
CA	San Diego Naval Complex	376	2.91
CA	Travis AFB	52	2.346
CA	Twentynine Palms-Marine Corps	113	2.673
CA	Vandenberg AFB	112	2.348
CO	Ft Carson	147	2.122
DC	Joint Base Anacostia-Bolling	107	2.196
FL	Eglin AFB	49	2.98
FL	Jacksonville-NAS	57	2.175
FL	MacDill AFB	105	2.267
FL	NAS Key West	49	2.186
FL	Tyndall AFB	121	2.149
GA	Ft Benning	149	2.356
GA	Ft Gordon	65	2.338
GA	Ft Stewart	70	2.328
HI	Kaneohe Bay Marine Base	196	2.158
HI	Joint Base Pearl Harbor - Hickam	244	2.377
HI	Schofield Barracks	139	2.518
ID	Mountain Home AFB	79	2.544
IL	NAS Great Lakes	98	1.99
IL	Scott AFB	107	2.346
KS	Ft Leavenworth	167	2.575
KS	Ft Riley	291	2.361
KY	Ft Cambell	66	2.515
LA	Barksdale AFB	56	2.268
LA	Ft Polk	100	2.36
MA	Hanscom AFB	82	2.439
MD	Andrews AFB	98	2.51
MD	Ft Meade	202	2.104

MD	Patuxent River NAS	84	2.048
MO	Ft Leonard Wood	113	2.628
MO	Whiteman AFB	46	2.87
MS	Keesler AFB	111	2.252
MT	Malmstrom AFB	66	2.606
NC	Camp Lejeune	315	2.378
NC	Cherry Point Marine Corps Air Station	63	2.317
NC	Ft Bragg	281	2.146
ND	Minot AFB	133	2.368
NE	Offutt AFB	47	2.17
NJ	Joint Base McGuire-Dix-Lakehurst	84	3.2
NM	Cannon AFB	78	2.436
NM	Holloman AFB	60	2.617
NM	Kirtland AFB	107	2.42
NV	Nellis AFB	94	2.34
NY	Ft Drum	153	2.922
NY	West Point	208	2.351
OH	Wright-Patterson AFB	44	2.25
OK	Ft Sill	116	2.629
OK	Tinker AFB	40	2
RI	NAS Newport	45	2.6
SC	Joint Base Charleston	50	1.98
SC	Shaw AFB	52	2.692
TX	Dyess AFB	81	2.642
TX	Ft Bliss	135	2.378
TX	Ft Hood	217	2.392
TX	Joint Base San Antonio-Ft Sam Houston	200	2.565
TX	Laughlin AFB	62	2.113
TX	Sheppard AFB	45	1.956
UT	Hill AFB	90	2.489
VA	Ft Lee	52	2.654
VA	Ft Belvoir	171	2.468
VA	Joint Base Langely-Eustis	208	2.245
VA	NAS Oceana	50	2.08
VA	Norfolk NAS	201	2.592
VA	Quantico	162	2.71
VA	Virginia Beach-Jnt ExpedBase-Little Creek	109	2.165
WA	Fairchild AFB	58	2.259
WA	Joint Base Lewis-McChord	356	2.32
WA	Naval Base Kitsap-Bangor	141	2.22
WY	FE Warren AFB	61	2.23

Table 2 Correlation categories consist of the overall satisfaction grade, environmental illness reports, maintenance related survey topics, administrative survey topics, and financial survey topics.

Overall Grade
EnvIllness
Mold
Maint
Filth
Struct
PoorQualMatl
DilapOutdate
WeatherDamage
Plumb&Leaks
ClimCntrl
ApplReplace
FaultyWiring
Lead
WaterQual
PestInsects
PestRodents
PestTotal
Landscap
UnsafePlaygrnd
FireHaz
Management
Praise
LongWaitlist
MoveOutIssues
TooSmall
DisrespectMgt
RankIssues
Security
RulesNotEnforced
LiedtobyMgt
BasAllowHous
FeeDisputes
UtilFeeIssues
PaidOutofPock

Table 3 Cross correlation matrix of MFAN total satisfaction grade and MFAN survey topics.

Cross Correlations	Overall Grade	EnvIllness	Mold	Maint	Filth	Struct	PoorQualM	DilapOutd	WeatherD	Plumb&Le	ClimCntrl	ApplRepl	FaultyWir	Lead	WaterQua	PestInsect	PestRoden	PestTotal	Landscap	UnsafePla	FireHaz	Managem	Praise	LongWaitl	MoveOutI	TooSmall	Disrespec	RankIssue	Security	RulesNotE	LiedtobyM	BasAllowH	FeeDisput	UtilFeeIss	PaidOutof
Overall Grade	1	-0.3248	-0.23245	-0.55697	-0.15623	-0.17848	-0.07136	-0.06642	-0.24915	-0.34338	-0.20488	-0.18268	-0.06752	-0.15344	0.278286	-0.17093	-0.16039	-0.19281	-0.01134	0.004289	-0.14533	-0.30131	0.797409	-0.03295	-0.15576	-0.00034	-0.17427	0.081722	-0.10051	0.119643	-0.34757	-0.17845	-0.17321	-0.00567	-0.37276
EnvIllness		1	0.692882	0.13399	0.04447	0.340635	-0.23934	0.211934	0.124381	0.266374	0.423275	0.062699	-0.04647	0.018837	0.013799	0.347218	0.083063	0.265189	-0.252	0.03079	0.125336	0.034612	-0.34196	-0.17589	-0.14327	0.073493	-0.16553	-0.00542	0.142849	-0.05327	-0.01256	-0.0617	-0.24267	0.023458	0.362418
Mold			1	0.101976	-0.03592	0.495653	-0.19437	0.135234	0.067083	0.384198	0.351241	-0.05728	0.135502	-0.02105	0.217426	0.352078	0.113869	0.25683	-0.11721	0.082801	0.229286	-0.04924	-0.31178	-0.27587	-0.35582	-0.05422	-0.10755	-0.14582	0.074464	-0.15182	-0.08688	-0.2935	-0.47105	-0.28028	0.133134
Maint				1	0.144484	0.30155	0.102747	0.060184	0.282626	0.432909	0.384149	0.187123	-0.00812	0.218981	-0.13694	0.01074	0.166309	0.095892	-0.07174	0.09912	0.276827	0.334914	-0.50313	0.068933	0.063768	0.189726	0.022423	-0.16719	0.045648	-0.22907	0.081224	0.009877	0.020127	0.15644	0.244741
Filth					1	0.20119	0.179947	0.259008	0.183585	0.127896	0.030373	0.37279	0.025968	0.304131	-0.02351	-0.04393	0.094406	0.063259	0.220997	0.030461	0.144602	0.143095	-0.15351	0.087489	0.28574	0.277907	0.183332	0.093966	0.112281	0.031349	0.253554	0.166476	0.421723	0.006173	0.087577
Struct						1	0.054006	0.234942	0.336815	0.625811	0.41989	0.037247	0.246936	0.040074	0.167266	0.21127	0.375895	0.330451	0.109413	0.087397	0.340403	0.015088	-0.23615	-0.06888	-0.26888	0.058607	-0.1353	-0.20695	0.086412	-0.06753	-0.01873	-0.20045	-0.29071	-0.27138	0.037463
PoorQualMatl							1	-0.12439	0.147937	0.050417	-0.00635	0.218097	0.101106	0.094248	0.07834	-0.18147	0.021126	-0.08	0.262492	0.167688	0.204913	-0.09457	-0.14115	0.102636	0.19454	-0.00955	0.260999	-0.0067	0.238359	0.172287	0.0709	0.121982	0.332518	-0.04213	0.062644
DilapOutdate								1	0.249122	0.160924	0.270295	0.344789	-0.15093	0.055077	-0.12417	0.292411	0.263072	0.319386	0.089957	0.067179	-0.08739	0.009915	-0.09913	-0.21316	-0.09155	0.448103	0.019289	0.3134	0.197786	-0.05584	-0.02048	0.242411	0.033588	0.055135	0.283257
WeatherDamage									1	0.347156	0.344164	0.024418	0.080491	0.229533	0.055067	0.169252	0.165374	0.209921	0.078039	0.247951	0.037748	0.068217	-0.24295	0.050294	0.009254	0.1783	0.199267	0.179312	0.071488	-0.07547	0.045234	-0.13435	-0.05838	-0.21693	0.033912
Plumb&Leaks										1	0.459774	-0.02375	0.086997	0.155705	-0.03838	0.0967	0.091906	0.139919	0.092866	0.017132	0.199087	0.12911	-0.41764	-0.06678	-0.22314	0.057136	-0.08005	-0.15836	0.085142	-0.16117	-0.01134	-0.19114	-0.20433	-0.20803	-0.00418
ClimCntrl											1	0.208459	0.083	0.116975	0.104604	0.246179	0.177613	0.287987	-0.17019	0.17747	0.01844	-0.04267	-0.27254	-0.17183	-0.36804	0.109043	-0.29052	0.155932	0.276149	-0.21137	-0.15987	0.045355	-0.26571	0.257147	0.331226
ApplReplace												1	-0.13654	-0.0112	0.114706	0.176053	0.265134	0.294984	0.176687	0.205729	0.024569	0.343195	-0.0736	-0.16312	-0.03849	0.218896	0.141231	0.169807	0.123961	0.067747	0.279612	0.326664	0.263975	0.430825	0.481065
FaultyWiring													1	0.121672	0.045375	0.055276	0.015384	0.015808	0.151097	0.060301	0.021134	-0.27931	-0.20399	-0.13756	-0.22194	-0.27004	0.173405	-0.21123	0.029938	0.107561	-0.04443	-0.03453	-0.08505	-0.00614	-0.14065
Lead														1	0.031129	0.105183	-0.01844	0.073095	0.052971	-0.00996	0.330169	0.055648	-0.27318	0.153975	-0.06333	-0.00814	0.138586	0.052746	0.076033	-0.04543	0.180451	-0.16209	-0.17143	-0.18184	0.125493
WaterQual															1	0.027591	0.032266	0.066363	0.146396	0.364967	0.00027	-0.00981	0.272793	-0.03847	0.028919	0.014805	-0.03242	0.046605	0.036791	-0.05907	-0.0373	-0.11959	0.01827	0.051502	0.079073
PestInsects																1	0.313228	0.8031	-0.03861	0.039059	0.097574	0.034654	-0.11272	-0.12183	-0.22609	-0.02303	-0.14142	-0.0524	0.233048	-0.02089	-0.04968	-0.01854	-0.248	-0.05299	0.24293
PestRodents																	1	0.806063	0.072492	0.125701	0.162199	0.208614	-0.05835	0.162585	-0.24065	0.310753	-0.04144	0.009553	0.102107	-0.02254	0.060237	0.080822	-0.12974	-0.04679	0.15732
PestTotal																		1	0.047482	0.08505	0.073394	0.174381	-0.13883	0.012086	-0.26073	0.160051	-0.10265	-0.01675	0.163861	-0.02531	0.043589	0.107532	-0.22164	-0.04018	0.223968
Landscap																			1	0.226736	0.021128	0.110749	-0.10495	0.244857	0.101809	0.076246	0.086177	0.107239	0.052659	0.290333	0.374436	-0.0198	0.188455	-0.01154	0.106394
UnsafePlaygrnd																				1	0.183348	0.341173	0.100125	0.079986	0.002713	0.307215	-0.03679	0.136116	0.275068	0.033629	0.210083	-0.02361	0.011013	0.217953	0.552504
FireHaz																					1	0.098473	-0.16427	0.118948	0.094837	0.057451	-0.03435	-0.14873	0.181835	0.061562	0.090844	-0.36536	-0.02755	-0.12446	0.189693
Management																						1	-0.0578	0.070244	0.139594	0.203145	0.104043	0.021926	-0.01537	-0.0228	0.394997	0.23193	0.051216	0.083977	0.464448
Praise																							1	-0.07463	-0.13156	0.089541	-0.05416	0.112932	-0.1143	-0.02101	-0.25982	-0.11794	-0.12971	-0.04801	-0.19446
LongWaitlist																								1	0.228093	0.140993	-0.10807	0.040909	0.192801	0.245091	0.131116	-0.03669	0.235437	0.012484	-0.12122
MoveOutIssues																									1	0.112897	0.20564	0.140272	-0.14315	0.173765	0.267594	0.010395	0.752013	0.106349	0.016223
TooSmall																										1	0.118124	0.350956	0.029559	0.044479	0.129624	0.286132	0.158391	0.175721	0.370237
DisrespectMgt																											1	-0.04985	-0.03514	0.186839	0.261125	0.119224	0.23066	-0.10507	0.015376
RankIssues																												1	0.282906	-0.01457	0.130843	0.364511	0.233562	0.202509	0.166984
Security																													1	0.009326	0.084296	0.076676	-0.00086	0.220908	0.203145
RulesNotEnforced																														1	0.418623	-0.04584	0.230549	-0.03533	-0.03879
LiedtobyMgt																															1	0.149791	0.261431	0.074017	0.32407
BasAllowHous																																1	0.275653	0.285389	0.252366
FeeDisputes																																	1	0.369208	0.059124
UtilFeeIssues																																		1	0.245261
PaidOutofPock																																			1

Cross Correlations	Overall Grade	EnvIllness	Mold	Maint	Filth	Struct	PoorQualI	DilapOutd	WeatherD	Plumb&Le	ClimCntrl	ApplRepla	FaultyWir	Lead	WaterQua	PestInsec	PestRode
Overall Grade	1	-0.3248	-0.23245	-0.55697	-0.15623	-0.17848	-0.07136	-0.06642	-0.24915	-0.34338	-0.20488	-0.18268	-0.06752	-0.15344	0.278286	-0.17093	-0.16039
EnvIllness		1	0.692882	0.13399	0.04447	0.340635	-0.23934	0.211934	0.124381	0.266374	0.423275	0.062699	-0.04647	0.018837	0.013799	0.347218	0.083063
Mold			1	0.101976	-0.03592	0.495653	-0.19437	0.135234	0.067063	0.384198	0.351241	-0.05728	0.135502	-0.02105	0.217426	0.352078	0.113869
Maint				1	0.144484	0.30155	0.102747	0.060184	0.282626	0.432909	0.384149	0.187123	-0.00812	0.218981	-0.13694	0.01074	0.166309
Filth					1	0.20119	0.179947	0.259008	0.183585	0.127896	0.030373	0.37279	0.025968	0.304131	-0.02351	-0.04393	0.094406
Struct						1	0.054006	0.234942	0.336815	0.625811	0.41989	0.037247	0.246936	0.040074	0.167266	0.21127	0.375895
PoorQualMatl							1	-0.12439	0.147937	0.050417	-0.00635	0.218097	0.101106	0.094248	0.07834	-0.18147	0.021126
DilapOutdate								1	0.249122	0.160924	0.270295	0.344789	-0.15093	0.055077	-0.12417	0.292411	0.263072
WeatherDamage									1	0.347156	0.344164	0.024418	0.080491	0.229533	0.055067	0.169252	0.165374
Plumb&Leaks										1	0.459774	-0.02375	0.086997	0.155705	-0.03838	0.0967	0.091906
ClimCntrl											1	0.208459	0.083	0.116975	0.104604	0.246179	0.177613
ApplReplace												1	-0.13654	-0.0112	0.114706	0.176053	0.265134
FaultyWiring													1	0.121672	0.045375	0.055276	0.015384
Lead														1	0.031129	0.105183	-0.01844
WaterQual															1	0.027591	0.032266
PestInsects																1	0.313228
PestRodents																	1

Table 4a First half of cross correlation matrix.

Cross Correlations	PestTotal	Landscap	UnsafePla	FireHaz	Managem	Praise	LongWaitl	MoveOutI	TooSmall	Disrespec	RankIssue	Security	RulesNotE	LiedtobyM	BasAllowH	Fee	Disput	UtilFee	Iss	PaidOutof
Overall Grade	-0.19281	-0.01134	0.004289	-0.14533	-0.30131	0.797409	-0.03295	-0.15576	-0.00034	-0.17427	0.081722	-0.10051	0.119643	-0.34757	-0.17845	-0.17321	-0.00567	-0.37276		
EnvIllness	0.265189	-0.252	0.03079	0.125336	0.034612	-0.34196	-0.17589	-0.14327	0.073493	-0.16553	-0.00542	0.142849	-0.05327	-0.01256	-0.0617	-0.24267	0.023458	0.362418		
Mold	0.25683	-0.11721	0.082801	0.229296	-0.04924	-0.31178	-0.27587	-0.35582	-0.05422	-0.10755	-0.14582	0.074464	-0.15182	-0.08688	-0.2935	-0.47105	-0.28028	0.133134		
Maint	0.095892	-0.07174	0.09912	0.276827	0.334914	-0.50313	0.068933	0.063768	0.189726	0.022423	-0.16719	0.045648	-0.22907	0.081224	0.009877	0.020127	0.15644	0.244741		
Filth	0.063259	0.220997	0.030461	0.144602	0.143095	-0.15351	0.087489	0.28574	0.277907	0.183332	0.093966	0.112281	0.031349	0.253554	0.166476	0.421723	0.006173	0.087577		
Struct	0.330451	0.109413	0.087937	0.340403	0.015068	-0.23615	-0.06888	-0.26888	0.058607	-0.1353	-0.20695	0.086412	-0.06753	-0.01873	-0.20045	-0.29071	-0.27138	0.037463		
PoorQualMatl	-0.08	0.262492	0.167688	0.204913	-0.09457	-0.14115	0.102636	0.19454	-0.00955	0.260999	-0.0067	0.238359	0.172287	0.0709	0.121982	0.332518	-0.04213	0.062644		
DilapOutdate	0.319386	0.089957	0.067179	-0.08739	0.009915	-0.09913	-0.21316	-0.09155	0.448103	0.019289	0.3134	0.197786	-0.05584	-0.02048	0.242411	0.033588	0.055135	0.283257		
WeatherDamage	0.209921	0.078039	0.247951	0.037748	0.068217	-0.24295	0.050294	0.009254	0.1783	0.199267	0.179312	0.071488	-0.07547	0.045234	-0.13435	-0.05838	-0.21693	0.033912		
Plumb&Leaks	0.139919	0.092866	0.017132	0.199087	0.12911	-0.41764	-0.06678	-0.22314	0.057136	-0.08005	-0.15836	0.085142	-0.16117	-0.01134	-0.19114	-0.20433	-0.20603	-0.00418		
ClimCntrl	0.287987	-0.17019	0.17747	0.01844	-0.04267	-0.27254	-0.17183	-0.36804	0.109043	-0.29052	0.155932	0.276149	-0.21137	-0.15987	0.045355	-0.26571	0.257147	0.331226		
ApplReplace	0.294984	0.176687	0.205729	0.024569	0.343195	-0.0736	-0.16312	-0.03849	0.218896	0.141231	0.169807	0.123961	0.067747	0.279612	0.326664	0.263975	0.430825	0.481065		
FaultyWiring	0.015808	0.151097	0.060301	0.021134	-0.27931	-0.20399	-0.13756	-0.22194	-0.27004	0.173405	-0.21123	0.029938	0.107561	-0.04443	-0.03453	-0.08505	-0.00614	-0.14065		
Lead	0.073095	0.052971	-0.00996	0.330169	0.055648	-0.27318	0.153975	-0.06333	-0.00814	0.138586	0.052746	0.076033	-0.04543	0.180451	-0.16209	-0.17143	-0.18184	0.125493		
WaterQual	0.066363	0.146396	0.364967	0.00027	-0.00981	0.272793	-0.03847	0.028919	0.014805	-0.03242	0.046605	0.036791	-0.05907	-0.0373	-0.11959	0.01827	0.051502	0.079073		
PestInsects	0.8031	-0.03861	0.039059	0.097574	0.034654	-0.11272	-0.12183	-0.22609	-0.02303	-0.14142	-0.0524	0.233048	-0.02089	-0.04968	-0.01854	-0.248	-0.05299	0.24293		
PestRodents	0.806063	0.072492	0.125701	0.162199	0.208614	-0.05835	0.162585	-0.24065	0.310753	-0.04144	0.009553	0.102107	-0.02254	0.060237	0.080822	-0.12974	-0.04679	0.15732		
PestTotal	1	0.047482	0.08505	0.073394	0.174381	-0.13883	0.012086	-0.26073	0.160051	-0.10265	-0.01675	0.163861	-0.02531	0.043589	0.107532	-0.22164	-0.04018	0.223968		
Landscap		1	0.226736	0.021128	0.110749	-0.10495	0.244857	0.101809	0.076246	0.086177	0.107239	0.052659	0.290333	0.374436	-0.0198	0.188455	-0.01154	0.106394		
UnsafePlaygrnd			1	0.183348	0.341173	0.100125	0.079986	0.002713	0.307215	-0.03679	0.136116	0.275068	0.033629	0.210083	-0.02361	0.011013	0.217953	0.552504		
FireHaz				1	0.098473	-0.16427	0.118948	0.094837	0.057451	-0.03435	-0.14873	0.181835	0.061562	0.090844	-0.36536	-0.02755	-0.12446	0.189693		
Management					1	-0.0578	0.070244	0.139594	0.203145	0.104043	0.021926	-0.01537	-0.0228	0.394997	0.23193	0.051216	0.083977	0.464448		
Praise						1	-0.07463	-0.13156	0.039541	-0.05416	0.112932	-0.1143	-0.02101	-0.25982	-0.11794	-0.12971	-0.04801	-0.19446		
LongWaitlist							1	0.228093	0.140993	-0.10807	0.040909	0.192801	0.245091	0.131116	-0.03669	0.235437	0.012484	-0.12122		
MoveOutIssues								1	0.112897	0.20564	0.140272	-0.14315	0.173765	0.267594	0.010395	0.752013	0.106349	0.016223		
TooSmall									1	0.118124	0.350956	0.029559	0.044479	0.129624	0.286132	0.158391	0.175721	0.370237		
DisrespectMgt										1	-0.04985	-0.03514	0.186839	0.261125	0.119224	0.23066	-0.10507	0.015376		
RankIssues											1	0.282906	-0.01457	0.130343	0.364511	0.233562	0.202509	0.166984		
Security												1	0.009326	0.084296	0.076676	-0.00086	0.220908	0.203145		
RulesNotEnforced													1	0.418623	-0.04584	0.230549	-0.03533	-0.03879		
LiedtobyMgt														1	0.149791	0.261431	0.074017	0.32407		
BasAllowHous															1	0.275653	0.285389	0.252366		
FeeDisputes																1	0.369208	0.059124		
UtilFeeIssues																	1	0.245261		
PaidOutofPock																		1		

Table 4b Second half of the cross correlation matrix

References

(1) Preliminary Research Report: Living Conditions of Families in Privatized Military Housing, Military Families Association Network (MFAN) report to US Senate Comm on Armed Services Joint Subcommittee on Personnel, Readiness, and Management Support, February 13, 2019
(2) Final Report: Living Conditions of Families In Privatized Military Housing; Final Report, Military Families Association Network (MFAN), May 2019
(3) Final Research Report: Living Conditions of Families in Privatized Military Housing Executive Summary, Military Families Association Network (MFAN), May 2019
(4) H. S. Brightman, D. K. Milton, D. Wypij, H. A. Burge, J. D. Spengler, "Evaluating Building-Related Symptoms Using the US EPA BASE Study Results", Indoor Air 2008; 18: 335–345
(5) Florence Nightingale, Notes on Nursing, 1859.
(6) DK Milton, PM Glencross, and MD Walters; "Risk of Sick Leave with Outdoor Air Supply Rates, Humidification, and Occupants Complaints"; Indoor Air; Vol 10, pp212-221; 2000
(7) S.N. Rudnick, D.K. Milton, "Risk of indoor airborne infection transmission estimated from carbon dioxide concentration", Indoor Air, Vol 13, pp237-245, 2003
(8) R. Maddalena, M. J. Mendell, K. Eliseeva, W. R. Chan, D. P. Sullivan, M. Russell, U. Satish, W. J. Fisk, "Effects of ventilation rate per person and per floor area on perceived air quality, sick building syndrome symptoms, and decision-making", Indoor Air, Vol 25, pp362-370, 2015
(9) Joseph G. Allen, Piers MacNaughton, Usha Satish, Suresh Santanam, Jose Vallarino, and John D. Spengler; "Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures in Office Workers: A Controlled Exposure Study of Green and Conventional Office Environments";Env Health Perspectives; Oct 2015
(10) Piers MacNaughton, James Pegues, Usha Satish, Suresh Santanam, John Spengler, and Joseph Allen; "Economic, Environmental and Health Implications of Enhanced Ventilation in Office Buildings"; Int. J. Environ. Res. Public Health 2015, 12, 14709-14722
(11) P. Strøm-Tejsen, D. Zukowska, P. Wargocki, D. P. Wyon; "The effects of bedroom air quality on sleep and next-day performance", Indoor Air; doi:10.1111/ina.12254; 2015
(12) WHO Guidelines for Indoor Air Quality : Dampness and Mould, World Health Organization report, ISBN 978 92 890 4168 3, editors, E. Heseltine, J. Rosen, 2009
(13) M Davies, M Ucci, M McCarthy, T Oreszczyn, I Ridley, D Mumovic, J Singh and S Pretlove, "A Review of Evidence Linking Ventilation Rates in Dwellings and Respiratory Health: A Focus on House Dust Mites and Mould", International Journal of Ventilation 3(2) · September 2004
(14) Meryl D. Colton, Jose Guillermo Cedeno Laurent, Piers MacNaughton, John Kane, Mae Bennett-Fripp, John Spengler, Gary Adamkiewicz, "Health Benefits of Green Public Housing: Associations With Asthma Morbidity and Building-Related Symptoms", Neighborhood and Health; American Journal of Public Health, Vol 105, No. 12, Dec 2015
(15) I. Walker, M Sherman, B Less, "Houses are Dumb Without Smart Ventilation", LBNL-6747E, March 2014
(16) Gaëlle Guyot, Max H. Sherman, Iain S. Walker, Jordan D. Clark, "Residential smart ventilation: a review", LBNL report 2001056, Sept 2017
(17) Gaëlle Guyot, Max H. Sherman, Iain S. Walker, "Smart ventilation energy and indoor air quality performance in residential buildings: a review", DOI : 10.1016/j.enbuild.2017.12.05, Dec 2017
(18) Ken Eklund, Rick Kunkle, Adria Banks, and David Hales, Pacific Northwest Residential Ventilation Effectiveness Study, Washington State University Energy Program, REPORT #E15-015, Sept 2015