A Case for Action: Moving Towards a New Era in Housing

By Carl Grimes

Executive Summary
Military housing is at a critical juncture. The historically developed housing technology didn't consider the needs or health of occupants much beyond basic survival. While much current technology is focused on reducing or removing harm to the occupants, it is inconsistently applied. A path forward to a new era of military housing, one that is focused on supporting occupant health, and ultimately improving essential measures of readiness and cognitive function, is possible. But this critical shift can only occur when a fundamental change in how we think about homes and their relation to people is integrated into otherwise incremental construction practices.

It is wrong to assume that homes are inert physical structures and thus don't impact occupants. In fact, occupants are biologically dynamic organisms within a physical structure that is both biologically and chemically active. The complexity of the resulting interrelationships is beyond the conceptual capabilities of current methods. But they do appear to fit comfortably within the formalism of Systems Theory guiding Systems Engineering.

There are two conceptual changes required to make this shift in thinking. First, accepting houses as systems requires more than an acknowledgement of what those systems are. It means taking the next step to identify and describe how those systems influence each other. Second, accepting people as biological organisms rather than unaffected occupants requires more than a quick nod that, of course, we are alive. It means taking the next step to understand that houses affect us and we likewise affect our houses. In other words, the relationships among and between the systems of a house includes people.

Current practices and policies have failed to develop houses that support human health, because fundamentally they exclude consideration of biology, particularly the interrelationships between people and the multitude of elements that influence the indoor environment. Ample scientific research supports a deepening understanding of the health consequences of those relationships and provides a robust framework, grounded in systems theory, to move forward and improve outcomes.

Bold leadership can drive change. Acknowledging the connection between houses and people leads to a shift in the actions that get taken to build, repair, maintain, and live in homes. When those actions shift in concert with each other and occupant heath is an objective rather than an afterthought a new era of housing is possible.

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Introduction

The fundamentals of housing structures and internal control systems have not significantly improved over the past 150 years. Four walls, a roof, and basic systems to supply water and power, remove sewage, and control temperature are the basics of every home. While today's homes may be cosmetically improved with enhanced materials and Wi-Fi controlled appliances, they continue to be built in much the same way with the same limited purpose of protecting people from the burden of the outdoor environment.

The cosmetic and aesthetic improvements have been accomplished with technologies and methods that have inadvertently altered conditions of the indoor environment, thereby creating a new set of risks. People now need to be protected from the indoor environment itself. Although the basics of protection from the indoor environment are generally known, their infrequent use is mostly limited to preventing exposure to previously determined hazards, not of health in general.

The infrequent attempts to actively *enhance* health have mostly failed because data and guidance is limited to single-event measurements of a limited set of factors then interpreted by the broad practices for general public health; excluding the needs of individuals. A brief history will reveal how this occurred and what needs to be included. Then, the development of a general framework is outlined for a new era in housing – which is the ultimate purpose of this paper.

Housing Conditions Affect People

It is now generally accepted that poor physical conditions of houses can affect the health and well-being of occupants.[1,2,3,4,5,6,7,8,9,10,11,12,13,14] Hazards such as asbestos[15] are known to cause physical harm and lead-based paint[16] can also cause cognitive harm, which is why they are regulated with enforcement provisions. Severity of reactions[17] from other contaminants, including pests, mold, moisture, and dust, can range from nuisance "hay fever" symptoms, to interfering with normal functioning, chronically disabling, or life-threatening asthma attacks and allergic anaphylactic shock. Confusion of neurological and immune issues with "routine allergy" also account for a number of health effects.[18]

The extremes of otherwise acceptable boundaries of too hot, too cold, too damp, too dry, too drafty, too stale, too smelly, too dirty, and too noisy can create undue stress as the physiological and neurological balancing mechanisms of the human body struggle to regain equilibrium (homeostasis).[19,20] Failure to adapt to the extremes for a prolonged time can result in long term health effects or even death. Long term exposure to low levels can also result in serious health consequences. Not all individuals will always be affected the same; there is a distribution Bell curve for exposure levels, individual susceptibility to harm, and severity of impact from those exposures.[21]

Less well known and not as broadly accepted is the impact of complex occurrences and characteristics considered "normal." Such as, it is normal for crawlspaces to be wet, smelly, and infested with spiders and rodents. It is normal for air conditioning in humid climates to condense water on the ducting and drip through ceilings. It is normal for cleaning products to have a strong fragrance, sometimes irritating eyes and trigger asthma. It is normal for the roof or windows of houses to occasionally leak. It is normal for pesticides to trigger headaches or neurological symptoms. Such "normal" events are almost never included in either public health criteria or the International Statistical Classification of Diseases and Related Health Problems (ICD) – owned and maintained by the World Health Organization (WHO).[22] Therefore, they are typically dismissed as not requiring action because they are "normal" occurrences. They don't rise to the level of requiring a medical diagnosis despite the otherwise observable functioning of the person.[23]

Mostly unknown, and typically dismissed for consideration, are complaints which arise from only single families, or individuals. These small groups, or statistical "groups-of-one," are rarely included in public health[24] or the ICD. The individuality and increased complexity are therefore outside the current knowledge and systems. Therefore, complaints and demands for change beyond currently accepted capabilities cannot be true. They are routinely dismissed as troublemakers, a drain on society, and not worthy of consideration. Those who persist risk being labeled "psychogenic" or hallucinatory.[25]

Thought patterns for both medicine and construction struggled to include excess moisture in buildings and how that impacts occupants.

If the premise is accepted that a group is only as strong as its weakest link, then Military readiness must also consider individuals rather than only the group as a whole. The range of effects by military housing conditions must then include individual effects. Not only of the active duty person, but of their family support system.

Housing Conditions Change Over Time

The interior conditions affecting people can change for a variety of reasons; introduction of new building materials, evolution of construction practices, even alteration of the outdoor environment. When the effects of housing conditions on people change, then management methods must identify and account for the changing conditions. Ideally, we could predict impact and prevent negative consequences before they happen. Unfortunately, the history of housing is filled with examples of the opposite being true.

Houses built shortly after the end of WWII were built differently than those before the war. The rapid influx of returning military and the sudden increase in families placed a large demand for consideration of simple construction, faster, at affordable prices.[26] Optimization of structure and the effects on occupants took an understandable back seat to the immediate needs of basic shelter. Plus, the preference of available building materials included asbestos and asbestos-containing materials, plus lead-based paint. Energy was cheap so there was little pressure to build energy efficient houses. The result was health impacts from lead and asbestos exposures and homes that were poorly built.

By the mid-1970s, however, the oil embargo[27] made energy efficiency a necessity, so houses were built with increased air-tightness. Unfortunately, reducing air loss through the structure also reduced the amount of moisture and indoor pollutants that could escape outside. Occupant complaints began to increase. The complaints did not fit current patterns of disease and treatment.[28] Thought patterns for both medicine and construction struggled to include excess moisture in buildings and how that impacts occupants, so resolution of problems was slow if they occurred at all.

About the same time the evidence was increasing for severe health impacts from exposure to asbestos and lead-based paint. Although legislation regulated both as hazards in the 1970s, there is still a significant inventory of military houses built since the late 1940s and the 1950s. Even occupants of more recently built or remodeled houses are at risk of asbestos exposure because of the lack of controls over imported building materials.[29,30] And occupants, especially children under the age of 6, continue to be at risk for lead exposure even in homes where the lead has been remediated, if maintenance is deferred, or proper precautions aren't taken during repairs or routine upgrade activities that disturb building materials.

After the 2005 hurricane season in the Gulf states the demand for sheet rock exceeded the domestic supply. To meet demand, sheet rock was imported from China.[31] Subsequently, there was a noticeable increase in occupant complaints of unpleasant or off-odors and among those reports of illness. Because reports came from individuals rather than entire families or larger groups and there are no diagnostic codes or public health criteria guiding diagnosis and treatment from this specific exposure, health concerns were mostly dismissed. Eventually, structural damage, including serious corrosion of metal wiring, became visible and often necessitated complete removal and replacement of all electrical wiring and components. This finally prompted investigation into the source of the problem - excess levels of Sulphur in the sheet rock from China. But the initial alerts that a problem existed were from people, occupants who complained of an unwanted odor. Investigation into the source is what identified the damage to materials. Once the damaged materials were removed the occupant complaints resolved.

The same series of devastating hurricanes identified another issue in housing that required attention. Temporary housing with manufactured trailers used near New Orleans was provided by the Federal Emergency Management Agency (FEMA). Rather quickly occupant complaints about health reactions in those housing units rose beyond individuals and small groups to a large percentage of all FEMA trailers.[32] Eventually, it was discovered that heat and humidity forced high levels of formaldehyde into the indoor living space. This added to the emerging awareness of the impact of chemicals in building materials on occupant health and resulted in a broader focus on formaldehyde in all homes (at it was common in many types of manufactured flooring), not just FEMA trailers. Again, the initial alert to the issue came from occupant observation of conditions.

More recently, concerns have been raised that sheet rock is frequently contaminated with *Stachybotrys chartarum* mold (S. chartarum),[33] otherwise known as "toxic black mold" with expressed concerns about health effects. The suspicion is that the gypsum used in the manufacturing process of sheet rock is stored outside in large piles.[34] If left long enough there is the possibility that S. chartarum and other molds could have already begun amplifying prior to being used in sheet rock. If true, then the mold "garden" may have already been planted, ready to "bloom" inside the house with the introduction of moisture from leaks, condensation, or high relative humidity. This is an unresolved issue but it raises awareness about possible causes when families or individuals notify authorities of a concern.

In addition to discrete problems caused by specific building materials, it is also important to note that all building materials deteriorate naturally over time. They lose their initial characteristics (i.e., get softer, develop cracks or other damage) which can result in failure to maintain the separation between indoors and outdoors. The most common result is water intrusion. The deterioration is also a microbial process involving mold and bacteria. The combination of the two, even with reasonable maintenance, can quickly cascade to cause conditions with potentially negative effects on people. The older the house the greater the possibility of unhealthy conditions.

But perhaps the greatest change in housing conditions has just begun. Rather than individual materials or components, climate change can alter the characteristics of the entire structure.[35,36,37] As the climate warms the need for air conditioning increases and indoor moisture levels rise. As the climate becomes more unstable and less predictable houses will need to be designed, constructed, and maintained according to the demands of worst conditions rather than average conditions. Failure to do so could result in more rapid failure of the building envelope against rain, snow, and wind. Materials with previously acceptably low levels of VOCs and toxic chemicals could become toxic, much like the FEMA trailers in the heat and humidity of the Gulf Coast. Mandatory energy efficiency as part of the attempt to reduce carbon footprint must rebalance moisture dynamics, much like the oil embargo 45 years ago. As we've learned from past experience, monitoring occupant experience inside these newly vulnerable buildings can provide early warning for a need to make changes.

The changes in housing noted above, and the corrective responses, highlight two key points:

1. All changes were analyzed and responded to individually rather than as one component among many in the whole system.
2. None directly addressed the biological dynamics of the structure and the people.

Sources Pointing to New Ideas

Housing contracts based on information and ideas ten and twenty years ago are now out of date. Many problems resulting from old housing stock, previous materials, maintenance schedules, and other routines cannot be corrected with the same procedures that caused or allowed them. New ideas require not only the enhancement of current ideas, but also the leaving behind of some of the previously tried-and-true favorites. Without significant changes to fundamentals, any new era of housing will continue to remain stubbornly resistant to change.

Despite the obstacles, there has been significant movement on two fronts. One is the continued research into damp buildings with the resulting biological amplification. The other is the background applications of the principles and methods of systems theory (originating with neural networks) as applied to biology. Though there is still much to learn, this direction has shown promise at those points where conventional methods are stymied.

The following list of selected resources contribute in their own way to what is known about components of the systems of the indoor environment and their impact on occupants. The variety of credible and cognizant sources have developed an expanding preponderance of evidence that the indoor environment both as a whole and its individual parts is neither static nor benign. Any failure to meet current requirements for causation according to the legal criteria of contracts is more a measure of a gap between housing and the law, than between housing and people. The requirements of the Bradford-Hill criteria are more applicable and useful because people don't live in the courtroom.[38] There is sufficient evidence to act immediately and forcefully without the need to delay while waiting for further details. More research won't alter the fact that reactions to buildings are happening, prevention is needed, and that significant action can be executed now.

The modern chronology starts in the early 1970s with a national policy on Integrated Pest Management, which was an early move to protect people from exposures that could damage health. Moisture and mold focus began in the 1990s, though the basics were documented as far back as Leviticus 14.[39] The progression accelerates consistently and broadly since the beginning of this century, but we've limited our review to landmark documents and breakthrough studies as there are too many individual studies to recount. For example, the 2nd Edition of *Recognition, Evaluation, and Control of Indoor Mold (2020)* references 147 studies in Chapter 1 alone.

<u>1972 Integrated Pest Management (IPM)</u>[40]
IPM is based on management of pestilence "by the most economical means with the least possible hazard to people, property, and the environment" instead of killing by chemicals as a first and only response It was integrated into national policy by President Richard Nixon in 1972. In 1979 President Jimmy Carter "established and interagency IP Coordinating Committee to ensue development and implementation of IPM practices."

<u>1993 The New York City Department of Health Mold Guidelines</u>[41]
NYC published the first mold document, which identified *Stachybotrys* as a health concern. This position was updated six years later to include all mold growth.

<u>1996 Field Guide for the Determination of Biological Contaminants in Environmental Samples, AIHA</u>[42]
The first expert review of how to evaluate samples of biological contaminants was critical in setting industry standards.

<u>1999 *Bioaerosols: Assessment and Control*, American Conference of Governmental Industrial Hygiene</u> [43]
This publication identified the science-based procedures necessary to shift from industrial procedures to the non-industrial indoor environment with an emphasis on moisture generated microorganisms. Of special note was their position in Section 15.5 for what constituted a successful remediation: "The ultimate criterion for the adequacy of abatement efforts for treating biological contamination is the ability of people to occupy or re-occupy the space without health complaints or physical discomfort."

1999 Publication of the peer reviewed and statistically validated Environment Exposure Sensitivity Inventory[44,45]

The first, and still only, peer reviewed, statistically validated basis for the Quick Environmental Exposure Sensitivity Inventory (QEESI) screening tool to identify individuals with chemical intolerance (also referred to as MCS or Multiple Chemical Sensitivity). This was an outgrowth from the 1987 book by Ashford and Miller, *Chemical Exposure: Low Levels and High Stakes*.

1999 *IICRC S500 Standard and Reference Guide for Professional Water Damage Restoration*, Institute of Inspection, Cleaning and Restoration Certification[46]

The first industry consensus standard for professional water damage restoration. It identified a range of categories of water contamination plus procedures for restoration. It was revised and American National Standards Institute (ANSI) accredited in 2006 and again in 2015. It is also the fundamental basis for preventing mold growth in buildings. If the water damage is sufficiently addressed in a timely manner then mold is unable to grow and there will be no need to invoke ANSI-IICRC S520 Standard and Reference Guide for Professional Mold Remediation. This established that visible mold growth is proof that water damage was not mitigated and restored properly.

2000 *Clearing the Air: Asthma and Indoor Air Exposures*, Institute of Medicine[47]

The first clear statement about the role in asthma of airborne contaminants both biological and chemical. One distinction was between the development of the disease of asthma and the exacerbation of existing asthma. Another was the shift from binary declaration of causation (caused or not caused) to the more realistic and useable categories of causation:

- Sufficient evidence of a causal relationship
- Sufficient evidence of an association
- Limited or suggestive evidence of an association
- Inadequate or insufficient evidence to determine
- Limited or suggestive evidence of no association

2004 *Damp Indoor Spaces and Health*, Institute of Medicine[48]

The original title was "Mold and Health," but the committee quickly realized that limiting their report to just mold was too limiting. They changed the title and scope to "damp indoor spaces" because when there is sufficient moisture for mold growth, there is also sufficient moisture for bacterial growth, especially gram-negative bacteria. Also, with a longer time frame the damp spaces became attractive environments for the presence and amplification of insect and rodent populations. Water damaged material could also release their chemicals into the air, further increasing the components of exposure.

2006 *ANSI-IICRC S520 Standard and Reference Guide for Professional Mold Remediation*, Institute of Inspection, Cleaning and Restoration Certification[49]

The original S520, released in 2003 was the first industry consensus mold remediation standard. It advanced the previous concept of mold growth as simply present or not present, to three descriptive categories each with slightly different procedures for remediation: active fungal growth, settled spores and fragments from fungal growth, and the normal fungal ecology. In 2006, S520 was successfully ANSI Accredited. Together S500 and S520 constitute the industry standard for water damage and mold remediation.

2008 *Recognition, Evaluation, and Control of Indoor Mold*, American Industrial Hygiene Association [50]

This publication detailed concepts and procedures for recognizing indoor mold, how to evaluate it, and control procedures. Primary conclusions included:

- Indoor exposures are a complex mixture of molds, bacteria, fragments of both types of organisms; their multiple toxic products; and biologically derived small particles, gases and other air pollutants. Effects, depending on the susceptibility of the exposed occupants and their degree of exposure, can be combinations of allergic response, inflammation and its consequences, and other toxic responses. This complex exposure and effect picture is not addressed by risk assessment focused on spores or individual toxins. This statement further broadened the bioaerosols scope and the evaluation scope to more than just the limited identifiers of mold growth, and that single testing methods were insufficient.
- The implications of this research are that prevention of unwanted moisture, and removal of filth caused by moisture, is necessary to prevent disease. This statement expanded the awareness and need beyond the single contaminant framework of industrial hygiene to the multiplicity of contaminants of filth. Filth is a public health concept, which takes responsibility away from just regulatory compliance.

In addition, the report concluded that formal intervention studies present sufficient evidence to support three statements:

- Moisture is the primary environmental condition associated with disease.
- Intervention is possible to resolve moisture problems and subsequent biological contamination.
- Intervention can resolve disease but requires careful manipulation of the environment.

2009 *WHO guidelines for indoor air quality: dampness and mould*, World Health Organization[51]

This document reinforces previous findings about dampness in buildings, biological growth, and the scientific evidence about health problems – on a global basis. Not just respiratory symptoms, allergy, asthma, but also *"perturbation of the immunological system."* It also states that the guidelines are meant for "protecting public health," therefore not limited to regulatory compliance.

2005-2010 Collection of Medical Practice Parameters which included home assessments, American Academy of Allergy, Asthma, and Immunology and American College of Allergy, Asthma, and Immunology[52]

Medical Practice Parameters establish the standard of care for physicians. These parameters included furry animals, rodents, cockroach, and dust mites as potential sources for reaction. Mold was added later in the peer reviewed Journal of Allergy and Clinical Immunology. One key feature was for the first-time environmental assessment was integrated with clinical diagnosis. A two-part evaluation was included for initial diagnostic screening and when to recommend and on-site evaluation.

2012 Sloan Foundation Research Program of the Microbiome of the Built Environment[53]

A five year $50M research program analyzing the microbial presence and dynamics of the indoor built environment. A key finding is that the indoor microbiology is a massive, dynamic ecosystem. Influences in one aspect, or even one genus of mold or bacteria, can affect the overall characteristics of the ecology. Some organisms that are pathogens in one set of conditions may be neutral in another, and even necessary for life in yet another. It is somewhat analogous to IPM with the results depending on environment, opportunity, and inter-relationships of the factors.

2012 ASHRAE Position Document on Limiting Indoor Mold and Dampness in Buildings[54]

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) writes ANSI Accredited standards so they can be accepted into code enforcement. This is a first document with that intention by officially stating that:

> *ASHRAE takes the position that all policymakers, regulatory authorities, building professionals, and building occupants should be aware that indoor dampness, mold, and microbial growth are warnings of potential problems. All concerned should make decisions and take actions that help buildings, their contents, and their systems stay as dry as possible, given their functions. This position document provides help in understanding some of the complex interactions and decisions that lead to indoor dampness.*

2012 Housing and Urban Development (HUD) Healthy Homes Program Guidance Manual[55]

Published as the *7 Principles of a Healthy Home*, it was later incorporated into the National Center for Healthy Housing training for the Health Home Specialists certification accredited by the National Environmental Health Association (NEHA). The seven principles set a general baseline for what constitutes a healthy home:

- Keep it Dry
- Keep it Clean
- Keep it Safe
- Keep it Ventilated
- Keep it Pest-Free
- Keep it Contaminant-Free
- Keep it Maintained

2013 *Moisture Control Guidance for Building Design*, Construction and Maintenance, U.S. EPA[56]

EPA cites previous work plus additional research from Lawrence Berkeley Lab and the BASE study (1994-1998) to set forth the following important conclusions:

- Moisture control is fundamental to the proper functioning of any building.
- Controlling moisture is important to protect occupants from adverse health effects.
- In addition to causing health problems moisture can damage building materials and components.
- 85 percent of the buildings had been damaged by water at some time and 45 percent had leaks at the time the data were collected.
- Building dampness and mold raise the risk of a variety of respiratory and asthma-related health effects by 30 to 50 percent.

2015 Harvard T.H. Chan School of Public Health's Center for Health and the Global Environment[57]

A series of double-blind studies concluded that cognitive function scores were better in green building conditions compared to the conventional building conditions across nine functional domains, including crisis response, strategy, and focused activity level.

On average, cognitive scores were:

- 61 percent higher in green building conditions
- 101 percent higher in enhanced green building conditions

Of the nine cognitive functions measured, three stood out:

- Crises response (97% higher scores in green conditions and 131% higher in green+)
- Strategy (183% and 299% higher)
- Information usage (272% and 299% higher)

2018 Sloan Foundation Indoor Chemistry Research Program[58]

A five year $50M research project analyzing the chemistry of indoor environments as influenced by adverse conditions and ordinary activities. Focused on advancing understanding of indoor chemical sources, characterize the chemical and physical transformations taking place indoors, and determine how indoor chemistry is shaped by building attributes and occupancy.

2020 *Recognition, Evaluation and Control of Indoor Mold*, 2nd ed, American Industrial Hygiene Association[60]

This update to the 2008 publication includes, among other updates, health-based evidence from the American Academy of Allergy, Asthma, and Immunology and latest information on remediation.

2020 *Damp Buildings, Human Health and HVAC Design*, ASHRAE[61]
The original document was published for draft in 2016, updated and officially published as an ASHRAE Special Publication in 2020. The publication is significant for the following conclusions:

- A damp building can be defined using three subjective markers and four objective measurements.
- People will be affected by damp buildings often before the structure is impacted.
- Meta-Analysis of epidemiological evidence of dampness and asthma identify odds ratios ranging from 1.2 to an extraordinary 40.

Awareness of New Issues

Not everything needs to change or be excluded. Much of what is already known and implemented individually actually functions as intended, but in isolation from other components of the total system of a house and without the connection to biology. The challenge is identifying what works and what doesn't both for stopping health issues, recovering from current one, and enhancing improved functioning. What is needed is putting them altogether as a system that is interactive with the dynamics of biological organisms – people, pets, the microbiome and indoor chemistry of the built environment, and the macrobiome of small life forms. To begin that process there are five key changes that need to be understood and integrated into the movement forward.

Humans in the US have become a species of the indoor environment.

We are now an indoor species.

Humans evolved over millennia in the outdoors because "indoors" didn't yet exist. Eventually, shelter and protections were limited to what existed, what was available, and the awareness of how to utilize what was needed.

THE CORSI CODE

Average Life Expectancy	**79 years**
Indoors	**69 years**
At Home	**54 years**
In Bed	**26 years**
In Vehicles	**4.3 years**
Outside	**6 years**

total time spent over life expectancy

Fraction of time indoors, at home, in transit and outside based on Klepeis et al., J Exp Anal Env Epid 2001, 11, 231

Over the centuries the structures of societies and economies developed. Time saving machines were invented and needed protection from the elements as work moved indoors. House structures evolved to meet demands ranging from urban density to consumer desires. Slowly we removed ourselves from the outdoors, In fact, noted indoor air quality expert Professor Richard Corsi, determined we spend 69 out of 79 years indoors, with only about 6 years outdoors.[62] And that outdoor time is mostly in transit from one indoor structure to another. Humans in the US have become a species of the indoor environment.

Environmental impact on health and well-being is now, therefore, primarily from the indoors.

When we lived outdoors the quality of the air was determined by the presence of the natural flora and fauna. Humans adapted to the local environment and changes in both occurred slowly enough to generally keep pace with each other. The shift to indoors occurred in decades rather than over multiple generations, too fast for our genome to keep pace. The changes from naturally occurring materials to man-made structures are dramatic. Instead of natural flora and fauna we have artificial scents from stores like Bed, Bath, and Beyond. Our indoor environment sources of exposure are now determined by structural materials, furnishings, cooking, cleaning, aesthetics, fragrances, and chemical additives in materials and food. Not only will the eventual effects on our genetics be novel, but so will what makes us ill and what can make us healthy.

The indoor environment is not inert. It is biologically active.

The built indoor environment[63] has never been totally inert. There has always been the naturally occurring small life forms[64] including fungi and bacteria.[65,66] The difference is that we now are beginning to understand the nature of the interactions that are happening and how they impact health.

"Indoors" is a biological ecosystem thriving with people, the microbiome, plus the plethora of macro "critters". This multiplicity of life forms is not only actively engaged with each other but with the structure of the houses themselves. All living organisms extract nutrients from the surfaces in their environment, metabolize them, and leave waste behind (solid, liquid, and gas). These alterations are of the environmental conditions, the organisms, and the structural components themselves. These are physical and chemical processes which are available to interact and synthesize with the outgassing of volatile organic compounds (VOCs), semi-VOCs from structural materials and contents, along with the VOCs generated by the bacteria, mold, pets, and people.

A house and its occupants are a dynamically relational system.

The training programs by the National Center for Healthy Housing (NCHH)[67] is based on the fundamental principle that houses are systems. They are not discrete, isolated units or pieces like a collection of Lego parts. Rather, houses are composed of multiple systems which interact dynamically with themselves and with other dynamic systems. Some of these systems are mechanical while others, including the occupants of the house and the microbiome, are biological and chemical. The reality is that of complex of dynamic interrelationships between material reality and the biological/chemical reality of all occupants[68] – micro, macro, and human.

While the relationships among and between the various systems have not been fully explored and delineated, even on the level of statistical linearity, the acceptance that there are complex dynamic interrelationships at work is an important step towards development of a strategy to implement the concepts and procedures that would address the exposures that now confront us as an "indoor species."

Building codes are insufficient to protect health.

While the International Building Code (IBC)[69] mentions both health and safety, in reality it only applies to the minimum structural requirements necessary to prevent physical safety issues such as structural collapse and fire. These are fundamentally insufficient for health protection. Although there is a schedule for periodic review and updates, it is not uncommon for changes to take as long as twenty years to be officially adopted. It can therefore be difficult for building codes to be reflective of the most current knowledge from either building or medical science. In addition, local building departments can modify and alter requirements to meet local conditions. While this can be useful and important, it also leads to inconsistencies across states and even between adjacent jurisdictions.

However, building maintenance codes do have some value, though still limited. The International Property Maintenance Code (IPMC)[70] addresses maintenance of existing structures based on how buildings are used, rather than how they are initially built. For example, IPMC has provisions for:

- Prevention and extermination of pests and other infestation
- Sanitation of both the interior and exterior
- Ventilation and exhaust fans
- Prevention of moisture intrusion
- Elimination of certain hazards
- The general condition of habitable spaces
- Proper functioning of forced air duct system
- Responsibilities of occupants and owners

It is important to note that while these provisions are more directly associated with the health of occupants, they are not connected to a definition of what constitutes health, so they don't provide explicit guidelines. In addition, adherence to IPMC is not mandatory.

An Unintended Consequence of Science: Removing Personal Experience

While the connection between homes and health has been the subject of an ever-growing body of research in the 21st century, the reality is that the subjective awareness of the connection actually predates science. The earliest recorded reference to respiratory distress, "noisy breathing," dates back to China in 2600 BC. Hippocrates was the first to use the word "asthma" around 400 BC.[71] Vetruvius wrote about mold damage in buildings in 27 BC.[72] Leviticus 14 has detailed instruction on how to eradicate mold in houses.[73] Sir John Floyer wrote *A Treatise on the Asthma* in which he flatly stated, "damp houses cause asthma" in 1698.[74] One of the first books entirely dedicated to a discussion of homes and health, *Our Homes and How to Make Them Healthy*, was published in 1883.[75] Then not much occurred directly with health and housing for the next hundred years.

The gap can be predominantly explained by the intense focus from the late 1800s to the late 1900s on objectivity through "science" and its verification of findings by experiment. The resulting "illumination" of life was critical to provide greater protection of public health from disease. However, the move to exclude belief driven by superstition, the occult, and evil forces (as they were), unintentionally removed nearly all belief and confidence in the validity of personal experience. The limitation was quickly declared to be inconsequential by "scientists." The result was meteoric advances in science that came at the expense of critical understanding of individual health in general and its relation to housing specifically.

Medical Blindness

A major shift started in the late 1880's when Robert Koch introduced Koch's Postulates.[76] Simply put, Koch's Postulates moved medicine away from folk beliefs and the vagaries of disease caused by prevalent fears of "miasma"[77,78] or "rising damp"[79] toward a repeatable objective procedure to prove that a "germ" was not only a probable cause of disease as the result of infection, but that the specific "germ" could be isolated and identified. Therefore, avoidance and treatment became possibilities. Objectivity took center stage.

As science continued to develop, the goal of objectivity grew stronger and the removal of subjectivity increased.[80,81,82,83,84] The move towards reductionism, a model based on identifying the largest group of a phenomenon and reducing its parts and pieces to the smallest possible, allowed observations and measurements of the smallest reduced pieces under different conditions identified properties and predicted behavior with the goal of the discovery of universal laws. Reductionism necessarily excluded all hints of subjectivity as being outside of the boundaries of the category being investigated.

Thus, the movement to laboratory testing, MRIs, EEGs, and other instruments which remove the subjectivity of the patient from the process regardless of what the person reports or experiences. Instead, subjectivity is at most a clue for further investigation by the objective methods of science to reveal the real truth.

But not every disease was infectious, and not every infection could be proven by Koch's Postulates. And some illnesses were not "disease" at all. These gaps of medicine remained highly subjective and open to popular myths, beliefs, and fears. This phenomenon continues to this day in the areas where medicine has yet to successfully diagnose and treat. This is especially true for illnesses claimed by individuals from sources assumed to be benign or inert, like houses.

Psychological Blindness

Psychology was intended to address the subjectivity of people. So, it was only natural that unsupported victims sought help here and why physicians referred them. But eventually, similar pressures to limit subjectivity, the basis for psychological diagnosis and treatment, led to the creation of psychiatry.

Psychiatry requires a medical degree, which means diagnosis and treatment must be objective in order to be scientific. One of the tenets of psychiatry is that physical possibilities of the illness must be excluded before a psychological diagnosis can be rendered. Anyone who has experienced the inability of medicine to diagnose their concern and continued the pursuit anyway, may well have been referred to a psychiatrist – who, invariably judges all remaining concerns as evidence of a psychological problem.

Deliberate Exclusion

The culmination of the efforts for scientific objectivity by framing all activities into the model of reductionism was the publication of *Medical Education in the United States and Canada*[85] in 1910 by Andrew Flexner of the Carnegie Foundation.

The Flexner Report[86,87] was an influential commentary that was critical of the state of medical education in Canada and the US. It recommended following the reductionist methods of German medical schools, removing subjectivity from medical diagnosis, leaving only what could be objectively determined by scientific testing. The Flexner Report codified reductionism in medicine, including psychiatry. Usually leaving the person out of the process except for initial clues and for payment of the science-based services.

What neither the Flexner Report nor the objectivity of reductive science has been able to successfully account for, however, is the undeniable existence of biological life. Both medicine and psychiatry work with whole, biological beings, but are limited to procedures which can account only for a portion of the whole.

The appearance of the justification for the exclusion of biology from science and policy is understandable. But only in the context of how mankind learns about his world. We couldn't begin 500 years ago by understanding the complexity that is known today – like how reductionism requires. We begin with the extremely simple, slowly evolve to some complexity, and eventually to the more sophisticated.[88,89] We can't discover calculus before we know arithmetic. We can't read Shakespeare before we know the ABCs. Recognizing and addressing complexity comes after simplicity, not the other way around. But the small parts of the simplicity do not govern or entail the overarching complexity. Rather, the complex governs the simple.

Not recognizing this can lead to misunderstanding the place of biology in the entire scheme of the world. The power and authority of science – as opposed to superstition and fear – was reductionism.[90,91] Essentially, finding the biggest example of a topic, breaking it down into its constituent parts to analyze it. The claim is that biology cannot be that largest set of existence because of its rarity. The only known existence of life is the planet Earth, and even it is overwhelmed. Therefore, according to this argument, there is nothing of value to leaned from living biology that can't be learned from the material objects.

This attitude is not from 2500 BC or the 1800s, but as recently as 1971. Jacques Monod, a leading voice in science, wrote in Chance and Necessity:[92]

> *Biology is marginal because – the living world constituting but a tiny and very "special" part of the universe – it does not seem likely that the study of living things will ever uncover general laws applicable outside the biosphere.*

Given this history, the belief, authority, and policy that people in houses have no relevance, no importance, and are at most an unnecessary vexation devoid of any intellectual or practical consequence isn't surprising. It is the combination of:

- The rejection of biology as a source of valuable information.
- The rejection of the subjective in medicine by the Flexner Report.
- The absolute requirements of reductionism that there can be no reference outside of the objective structure.

Except…Life exists and must be taken into account.

Systems Theory and Houses

This was the dilemma that physicist Erwin Schrödinger confronted in the 1940s as a result of his work in quantum mechanics. He was a strict reductionist, but when he attempted to apply the laws and procedures of physics, which was believed to be the basis for everything in the universe, to biology, he was stymied. Phenomena like growth rather than deterioration violated the Second Law of Thermodynamics. Only one could be true, yet both existed. Atoms and molecules, the bases of physics and chemistry, could combine to form new substances, but neither could reproduce in its own image as biology does. Physics and chemistry can take apart materials and put them back together again. When biology takes apart an organism, the first consequence is that life – the very thing being studied – is gone and can never return. Study the life of a sparrow by dissecting it and the first step kills it. Study the sparrow without killing it and you only have subjective observations, not objective science through validated experimentation. His eventual conclusion, in *What is Life*?[93] was that the tools of the mechanistic metaphor of physics and chemistry were insufficient for the study of life, and a "new physics" was needed.

- Ultimately, it was systems theory, conceptually developed in the 1960s and then mathematically formalized by Robert Rosen with the publication of his book, *Life Itself*, in 1991[94] that enabled what Schrödinger called a "new physics" and began to provide a structure to integrate the objective and the subjective. Systems theory is about developing broadly applicable concepts and principles, as opposed to concepts and principles specific to one domain of knowledge. The latest applications include mechanical controls with biological-type feedback and signaling by Edward Rietman[95] et al in 2011, and to medicine by Richard Berlin[96] in 2017.

A parallel development by Benjamin Blanchard was systems engineering[97] in 2004, with continued development as recently as 2016. Its roots reach back to 1998[98] as a formalization of industry practices from the mid-1970s. Prior to those, military standards, beginning with MIL-STD-499 in 1969[99] had a profound impact on the early development of Systems Engineering and standardization of its processes. Simply stated, modern systems engineering is an interdisciplinary field which concentrates on the design and application of the whole as distinct from the parts, looking at a problem in its entirety, taking account of all the facets and all the variables.[100]

Philomena Bluyssen used Blanchard's work in her seminal books of 2009[101] and 2014[102] which represent the best contemporary and comprehensive investigations and developmental structures of people in buildings. Together they effectively illustrate the way the various factors interact with each other and how they affect the human body, while pointing out ways in which the quality of the indoor environment can be anchored as a goal in planning processes. Professor Bluyssen expanded her academic knowledge into the SenseLab, a laboratory for testing and experiencing single and combinations of indoor environmental conditions.[103]

The Path Forward

Simply put, the reality and complexity of biology cannot be ignored. It affects the material world and the material world affects it. Consider the lowly fungi. It is alive and when it "eats" it extracts nutrients from the material where it is living. That process alters the non-living material. As the fungi metabolizes the nutrients it also leaves behind waste, substances it cannot use. The liquid waste further alters the material where it is growing and the volatile emissions alter the air breathed by the occupants of the house. With sufficient time, that lowly biological life form can rot the internal structure of a house and damage the health of occupants. In parallel, the water source that is feeding the fungi might also be feeding pests, which get sprayed with pesticides which increase occupant exposure to toxins, or changing the relative indoor humidity, which causes the air conditioning to run longer and runs up the electric bill. The "butterfly effect" in action.

The resolution of the gap between where houses are and where they need to be to support health is routinely assumed too complex, costly, and unmanageable to be addressed because the current conceptual framework isn't sufficient. There can be no advancement toward improving health through housing by persisting with what has proven not to achieve the desired benefits, so the time has come to change the framework and adopt an approach grounded in a theory which at least acknowledges biology.

Once the framework has shifted to systems theory, the principles of a healthy home are relatively simple and often incremental, though close attention to detail is often required for successful execution:

- Continuous, balanced, mechanical ventilation
- Properly sealed and insulated
- Less-toxic materials and products
- Cleanable surfaces
- Healthy home habits

The central tenets of this approach include:

- Occupant health as a stated objective, not an afterthought.
- Methodologies and practices that include biology and acknowledge the dynamic interrelationship between people and the multitude of systems and conditions in a house.
- Shared coordinated responsibility among the universe of people who are involved with a house – from the owner to the builder, to the maintenance and repair technicians, to the occupants, to inspectors and the assessors of the inspection findings. Everyone has a role to play and that role includes awareness and consideration of related conditions. No more tasks strictly limited to just one, and only one, purpose. Events are rarely unconnected to all else.

Changing the framework allows new processes to happen. For example, focus of responsibility and sequence for a reported issue after occupancy is the person in the house:

- Issues of comfort and health starts with people, not a cabinet, bathroom sink, or an exterior wall manufactured with the latest materials. Houses don't call for help, select a housing situation, or choose what is most comfortable and healthy for themselves. The person(s) in the house is the one who determines a need and communicates it. The process begins with them.
    - It is not the person's responsibility to investigate and determine the cause, just to identify a need.
- It is then the responsibility of the service provider, designer, builder, or manager of the house to identify the cause of the reported need. Not to determine if that person's need is legitimate or not. Rather, they inspect, document, report the conditions of the house, and develop a plan for alterations or corrections.
    - An appropriate contractor then complies with the scope of work, verified by the assessor
- The work is deemed complete upon verification that all tasks have been completed in a manner that returns the house to its original condition before the complaints.
    - This requires integration with the occupant as an integral component of the entire system of the house.

Summary

Application of a single tenet, principle or step will not solve the complex, deeply rooted problems with housing, much like the application of a single band-aid will not fix a broken arm. But with bold leadership and decisive action guided by a framework centered around people, there is an opportunity to permanently change housing so it is less likely to harm people, more likely to be supportive, with an intent to allow rest, healing, and enhancement of ability to function.

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Supplemental: A Note on Cognition

The importance of actively managing the relationship between people and their indoor environment can be clearly seen by focusing on cognition.

In 2015, Harvard's T.H. Chan School of Public Health published a major study showing several adverse effects of exposure to carbon dioxide (CO2) especially on higher cognitive function.[1] The study concluded that:

> "People who work in well-ventilated offices with below-average levels of pollutants and carbon dioxide (CO2), have significantly higher cognitive functioning scores – in crucial areas such as responding to a crisis or developing strategy – than those who work in offices with typical levels… these results suggest that even modest improvements to indoor environmental quality may have a profound impact on performance of workers."[2]

The researchers looked at people's experiences in "green" vs. "non-green" buildings in a double-blind study. The findings suggest that the indoor environments in which many people work daily could be adversely affecting cognitive function—and that, conversely, improved air quality could greatly increase the cognitive function. On average, cognitive scores were 61% higher on the "green" building day and 101% higher on the two green+ building days than on the "non-green" (conventional) building day.[3] Low emitting materials and ventilation were keys attributed to "green" building design and construction.

Of the nine cognitive functions measured, three stood out[4]:

- Crises response (97% higher scores in "green" buildings and 131% higher in "green+" buildings)
- Strategy (183% and 299% higher)
- Information usage (272% and 299% higher)

In addition, the study found the quality of sleep of the workers in green offices, measured using special watches with sensors, was 6% higher[5], indicating persistent effects from indoor exposures.

Furthering the Harvard study, the EPA and Schmidt[6,7] noted the findings that the largest exposure to outdoor pollutants is indoors because of the times spent indoors. Also, that the indoor sources of pollutants are now being detected outdoors at levels higher than previously seen and that one half of VOCs now come from chemicals in pesticides, coatings, printing inks, adhesives, cleaning agents, and personal care products.[8] The actual rates and levels depends on the multivariant characteristics of the building structure, systems, and occupant use such as window opening.

Expanding to the home, where people spend the majority of their time, it isn't a big leap to conclude that if homes were upgraded with the goal of reducing indoor exposures, we could expect to see significant improvements in cognition and performance of the occupants.

Footnotes : A Note on Cognition

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Supplemental: Sleep Component of Health (and Homes)

In discussing the impact of the indoor environment on health and well-being sleep is a particularly important area to examine as it is fundamental to our ability to maintain both health and cognition. While not intended to illustrate consequences, Professor Richard Corsi's "Corsi Code" makes an impactful point of time we spend in bed – 26 years of our lives (that is slightly less than 50% of the total time we spend at home.)[1] That time is critically important, as sleep affects almost every type of tissue and system in the body – from the brain, heart, and lungs to metabolism, immune function, mood, and disease resistance.[2]

Research shows that a chronic lack of sleep, or getting poor quality sleep, increases the risk of disorders including high blood pressure, cardiovascular disease, diabetes, depression, and obesity. In addition, sleep is important to a number of brain functions, including how nerve cells (neurons) communicate with each other. In fact, your brain and body stay remarkably active while you sleep. Recent findings suggest that sleep plays a housekeeping role that removes toxins in your brain that build up while you are awake.[3]

Spending 8 hours a night breathing in everything from mold, pollen, dust, or a perfume collection to elevated levels of CO2, chemicals off-gassing from mattresses, carpet, and building materials or even the fragrance of scented candles is not supportive of the recovery processes that need to happen during sleep. Doing it night after night, year after year, can actually be damaging to health.[4,5]

Any number of wearable devices now enable sleep tracking to help people understand the amount of sleep they are getting and give some insight into sleep quality. However, measurement of only some of the factors gives only a partial answer and no solution. What need to be examined is the multitudes of conditions present in the home and their relational combinations in the indoor environment in order to take actions that resolve issues and improve sleep.

Footnotes: Sleep Component of Health (and Homes)

[1] *Fraction of time indoors, at home, in transit and outside*. Richard Corsi based on Klepeis et al.J Exp Anal Env Epid 2001, 321

[2] *Understanding Sleep: Brain Basics.* National Institutes of Health. https://catalog.ninds.nih.gov/pubstatic//17-NS-3440-C/17-NS-3440-C.pdf

[3] "Sleep Drives Metabolite Clearance from the Adult Brain". Lulu Xie and others. Science 18 Oct 2013:Vol. 342, Issue 6156, pp. 373-377 DOI: 10.1126/science.1241224

[4] "Light exposure during sleep may increase insulin resistance: Chronic overnight light exposure could have long-term effects on metabolic function." American Academy of Sleep Medicine. ScienceDaily 4 June 2018.

[5] *How Sleep Clears the Brain*. National Institutes of Health. https://www.nih.gov/news-events/nih-research-matters/how-sleep-clears-brain