Sentinel Indicators of Unhealthy Homes

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ABSTRACT

Objective: Home observation reveals factors that are highly relevant to children's health and development, but no standardized tool currently exists that is both brief enough for widespread application and detailed enough to capture a broad spectrum of environmental concerns. The purpose of this study was to begin developing a brief, easily administered home observation tool that could identify sentinel indicators of unhealthy homes with minimum burden to study participants.

Methods: Investigators developed a new dwelling unit observation (DUO) tool based on review of existing home assessment tools and subjective selection of items that were easy to administer, highly informative, and possibly indicative of more extensive environmental concerns. The new DUO was pilot tested in a sample of 18 homes that varied widely in value and location within a Texas county.

Results: The most outstanding sentinel observations indicating potentially unhealthy conditions, all of which occurred with a frequency of one in 18 dwellings, included a roach infestation, structural disrepair, extremely unclean indoor surfaces, poor access to services (18 miles from the nearest grocery store), and close proximity to an agricultural field. Sentinel air quality measurements obtained with 15-minute readings on handheld sensors included elevated carbon monoxide (CO) and carbon dioxide (CO2) in a home with poor ventilation and elevated particulates (PM 2.5) in a home with indoor tobacco smoking.

Conclusions: Using the DUO, data collectors without any specialized training were able to record the most important environmental factors related to health and simple air quality measurements in a matter of minutes. Sentinel indicators of unhealthy conditions can trigger more detailed evaluations, limiting such evaluations to homes that are most likely to have a problem.

BACKGROUND

The home, or dwelling unit, has a significant impact on health and well-being.[1] Characteristics contributing to good health include adequate space for the number of occupants, good ventilation, good repair, and control of pests. Older homes are more likely than newer homes to have hazardous materials such as asbestos, lead-based paint, or residues from pesticides that are now banned. Indoor air pollution can irritate the airways, increase the risk of cardiovascular disease, and contribute to general malaise.[2] The quality of indoor air is particularly important in places like Texas, where people spend more time indoors than average during the summer due to excessive heat and outdoor pests.[3]

Because many commonly used home assessment tools require hours to administer and generate large amounts of data,[4] a simpler tool focused on sentinel indicators offers many practical advantages. The purpose of this study was to develop a brief, easily administered home observation tool that could identify sentinel indicators of unhealthy homes with minimum burden to study participants, primarily in the context of the National Children's Study (NCS). The first home assessments in the NCS took days to complete using an intricate environmental sampling protocol and highly trained technicians. Since NCS cannot possibly measure every contaminant in every participant's home, a screening tool to select homes for extensive environmental sampling would limit more intricate sampling to homes with sentinel indicators on initial screening.

A "sentinel indicator" in epidemiological studies is an early sign, usually an illness or injury, that reflects a potential health hazard for the exposed population. For instance, a canary's illness after entering a coal mine has been used as a sentinel indicator of toxic gas. In this study, a sentinel indicator refers to a housing condition picked up on screening that may indicate more widespread concerns about the home. In terms of screening homes for sentinel indicators, the goal was to develop a tool that could be completed in 30 minutes or less by data collectors with no specialized training. The tool relies on observations rather than asking questions of participants, which reduces participant burden. The homes with sentinel indicators are candidates for more intense data collection, while those homes without any such indicators can be characterized only by the screening tool.

This study was a pilot project conducted in a rural Texas area for the NCS, a prospective cohort study of a diverse, nationally representative group of children from before birth through age 21 years.[5] Although the dwelling unit observation (DUO) tool was developed for NCS, it could be used as a screening tool in other longitudinal health studies, with or without children in the home.

Population and Methods

A. Development of the Dwelling Unit Observation (DUO) Tool

The DUO was based on a review of several existing tools, including NCS legacy tools;[6,7] the Canadian Healthy Infant Longitudinal Development (CHILD) Study environmental assessment tools;[8] other home assessment tools from Housing and Urban Development (HUD),[9] the Environmental Protection Agency (EPA),[10] the Centers for Disease Control and Prevention (CDC),[11] the Agency for Toxic Substances and Disease Registry (ATSDR),[12] the Home Observation for Measurement of the Environment (HOME) tool, which has been widely used in children's health research for 40 years,[13] National Environmental Education Foundation (NEEF)'s pediatric environmental history questionnaire,[14] the 2011 Enterprise Green Communities Checklist,[15] and housing related publications from National Institute of Environmental Health Sciences (NIEHS) funded Centers for Children's Environmental Health and Disease Prevention, Research.[16-20] Initially, over 100 items from the NCS legacy tools (Structural Visual Observations or SVO and Dwelling Unit Visual Observations or DUVO) and Canadian tool (CHILD Environmental Assessment) were listed by row on an Excel spreadsheet in the following categories: neighborhood contaminant sources, structural visual observations, indoor ventilation, sources of combustion, pets and pests, safety, cleanliness and clutter, and social observations. The items were included on the DUO only if both informative value and ease of collection were subjectively ranked as "high" by the investigators. The initial list was reduced from over 100 to 43 items. Examples of items that were deleted at this stage were observations about humidifiers, air cleaners, and door seals. As investigators reviewed additional home assessment instruments, the strategy switched to selecting items of interest rather listing every item and eliminating those with low informative value or ease of collection. Extant data, social observations, and digital photographs were not included in the NCS legacy or Canadian instruments but were added to the DUO for their high

informative value and ease of collection. Extant data include items such as air quality index, weather, proximity to pollutant sources, access to services, and real estate appraisal value.[21]

B. Selection of Sensors for Air Quality Measurements

The indoor air measurements in the initial NCS protocol required large, expensive air pumps that were left running in the participant's home over a number of hours. The DUO protocol was much simpler, involving 15-minute readings with hand-held devices. The sensors used for this pilot study were selected for convenience, as they were purchased for other studies and available to investigators at no additional cost. The sound meter (Quest Technologies Model 2900) was used to monitor sound levels inside and outside the home. The TSI Q-Trak measures temperature, humidity, carbon monoxide (CO), and carbon dioxide (CO2) using a small hand-held device with a probe attached and costs less than $1,000. All monitors were calibrated before use. Average CO levels in homes without gas stoves vary from 0.5 to 5 parts per million (ppm),[22] and no health effects are expected in adults unless CO exceeds 25 ppm for more than an hour;[23] nonetheless, small elevations of CO may reflect poorly ventilated combustion by-products and trigger additional tests. CO2 is generally not considered a health hazard, but increasing levels are associated with stuffiness indoors due to lack of fresh, outdoor air.[24] A probe for total volatile organic carbons (VOCs) is available with the Q-Trak but was not used for this pilot study. The TSI SidePak is "a miniature battery operated laser photometer that measures air borne particle mass concentration in units of milligram per cubic meter," according to the product brochure, and weighs 16 ounces. It also costs less than $1,000. These sensors require about thirty minutes of training to use properly. Recalibration between homes takes a few minutes and can be done on the road. The hand-held sensors are not meant to replace more extensive air monitoring but rather to identify homes with initial elevations of CO2, CO, or particulates for more extensive air monitoring in follow up evaluations.

C. Complete DUO Tool

The final DUO tool has five sections: extant data, outdoor observations, indoor observations, real-time air and sound measurements, and Global Positioning System (GPS) coordinates. A few area observations, or abbreviated systematic social observations, such as presence of abandoned buildings and litter are also included.[25] See Table 1 for a summary of items included on the DUO field tool. The complete tool can be obtained from the authors.

D. Enrollment of Participants

The study team invited 27 families with young children living in a predominantly rural area of Texas to participate in the study by letter and phone. The study team knew all the invited families from participation in other studies. About 65%, or 18/27, of those who received invitation letters actually participated in the study. No one refused to participate, but some potential participants could not be reached. This was a non-random, convenience sample for the purpose of field-testing a new home observation tool. Despite the potential selection bias of this approach, the sample contained a broad range of homes in terms of appraisal value, state of repair, and location within the county (see Table 2, Extant Data).

E. Field Testing the DUO Tool

The field-testing phase started with training the data collection team, which included two investigators, two research nurses, and two data collectors. Investigators developed an illustrated training manual detailing how to interpret each answer choice on the DUO. Training consisted of four hours of reviewing the manual item by item, followed by implementing the DUO for practice at the homes of two volunteers. Recruitment and data collection procedures were approved by Battelle Memorial Institute institutional review board (IRB) for human subjects' protection. Data collection was completed over a one-week period in late July 2012. An average of four team members (two field staff and two investigators) evaluated each

Table 1: Observations included on the dwelling unit observation (DUO) field tool

Summary of Items Included on the DUO Field Tool	
	Number of Items Recorded
I. Outside the Dwelling	
A. Geographic Coordinates	1
B. Photos	3
C. Sources of Contaminants	6
D. Structural Visual Observations	5
E. Abbreviated Systematic Social Observations	6
Subtotal / Outside the Dwelling	*21*
II. Inside the Dwelling	
A. General Information	7
B. Ventilation Assessment	9
C. Combustion Sources	6
D. Flooring	3
E. Pets, Pests, and Mold	7
Subtotal / Inside the Dwelling	*32*
III. Both Outside and Inside the Dwelling	
F. Noise	2
G. Air Measurements	6
Subtotal / Both Outside and Inside the Dwelling	*8*
Total Number of Items	***61***

Table 2: Extant data descriptive values

Variable	n	Mean	Range
Walk Score (http://www.walkscore.com/)	18	33	0-66
Miles to Grocery Store (maps.google.com , search for grocery stores near residence)	18	2.9	0-18
Population Density of Census Block	18	3706	9-20,652
Outdoor Temperature at Time of Data Collection (airnow.gov)	18	96 ◦ F	82-102 ◦ F
Air Quality Index* (http://www.airnow.gov/index.cfm?action=airnow.maps)	18	Green	16 Green, 2 Yellow
Appraisal Value of Single Family Units (http://lamarcad.org/)	8	$50,622	$14,930 - $162,760

*Obtained from modeling. According to the Texas Commission on Environmental Quality, the closest air monitoring station is located 50 miles from the study area

home. One team (investigator + field staff) started inside, and the other started outside the home, then they switched. The purpose of having multiple observers at each dwelling unit was to evaluate the consistency of responses, or reliability, of the tool.

RESULTS

A. Reliability of Observations

Each team of two observers consisted of one investigator and one data collector, yielding four observations for each item on the DUO. Inter-observer reliability for each item on the DUO was variable. See Table 3 for kappa values reflecting the reliability of representative items. The consistency of responses (reliability) between pairs, including the two investigators, the two data collectors, within team investigator and data collector, and across team investigator and data collector was equivalent. In other words, the two investigators disagreed with each other about as frequently as they disagreed with the data collectors. The data collectors disagreed with each other about as frequently as they disagreed with the investigators. Agreement was generally best on extremes. For instance, all four raters agreed on identifying a severe roach infestation as a pest problem. Reliability was not as good on more subtle items such as whether a couple of dead crickets indicated a pest problem. Since disagreement on subtle items is insignificant for this screening tool, reliability could be enhanced by reducing answer choices on some items such as presence of pests to two choices: none to few pests (applies to 95% of homes) or unusually severe infestation (seen to this degree in only about 5% of homes).

B. Feasibility, Acceptability, and Cost of DUO Overall

The DUO took about 30 minutes to complete, which is much less than the several hours required for the initial NCS home assessment with environmental sampling or the HUD Healthy Home assessment. Since the DUO protocol required 15 minutes of air monitoring both inside and outside the home, it could not be completed in less than 30 minutes. The observations generally took less time than the air measurements. The size of the home was less important than the home's condition in terms of the time required to make observations. For instance, if the indoor environment had chipping paint and a crack in the ceiling, the observers took several minutes to rate the severity of indoor disrepair. In some instances, no one was home at the scheduled time, or the team had the wrong address. One participant asked us not to look in her bedroom. Overall, study participants were pleasant and cooperative and seemed to enjoy interacting with the study team.

While the development cost of the DUO was high, the marginal cost of implementing the DUO within the NCS infrastructure that existed at the time of the pilot study was relatively low. This included scheduling participants (average of three calls to 27 prospective participants over several weeks), scheduling data collectors (who were already trained and cleared for human subjects research), and conducting the training for the DUO. The implementation cost within the NCS infrastructure, not including development, supplies, or indirect cost, was about $8,000 for labor for 18 home assessments (four people working full time on this project for two weeks at an average salary of $1,000 per week) for the pilot study. The labor cost for two data collectors to conduct the DUO would be about $4,000 for 18 homes, or about $222 per home, including travel time between homes.

C. Section 1: Extant Data

Extant environmental and assessment data from Texas Department of Transportation (TxDOT), Tiger Roads, United States Department of Agriculture (USDA) Cropland layers, ToxMap, Google Earth, Google Maps, WalkScore, weather from the National Weather Service, census data for population density, and county tax appraisals provided some general information about each home (see Table 2). The most prominent potential health risk identified with extant data included extreme outdoor heat (average high temperature = 102 degrees F during the week of data collection), which impacted all the homes in the study. The extant sentinel indicators of a potentially unhealthy environment included remote location, low value, and proximity to an agricultural field. A rural home (population density = 9 in census block, walk score = 0) had poor access to services such as grocery stores (nearest grocery store = 18 miles). One home had a tax appraisal value < $15,000 due to disrepair and posed a safety hazard to residents. Finally, one home was next to an alfalfa field identified with USDA cropland layers, which could be a risk factor for agricultural pesticides or run-off.

In some instances, the GPS measurement at the door was more accurate than the coordinates obtained by entering the street address into Google Earth. Differences such as those illustrated in Figure 1 could be quite important for measuring proximity to pollutant sources. In these homes, the Google Earth coordinates placed the homes within 300 meters of a major highway, which is a risk factor for cardiovascular effects from air pollution. The actual coordinates, taken with a Trimble Juno SB Handheld, placed the homes outside the radius of expected health effects from living near the highway.

D. Section 2: Outdoor Observations

The data collection team observed the area around the home, potential pollutant sources, type of structure, and state of repair from outside the home, including taking three high resolution digital photos of the dwelling unit and the homes down the street. The type of structure included eleven single family dwelling units and seven multi-family dwelling units, some of which were subsidized. All 18 dwellings were single level (no basements or stairs). Most had attached garages and brick exteriors. The homes reflected a wide range of dwelling unit types, from small apartments to spacious new brick homes with in-ground swimming pools. The exteriors varied widely from immaculate to severe disrepair. The subsidized dwellings appeared to be structurally sound and actively maintained. The only sentinel indicator identified from outdoor observation was severe disrepair in the privately owned home valued at <$15,000 by tax appraisal data.

E. Section 3: Indoor Observations

Interior observations included cleanliness, occupant density, ventilation, combustion sources, floor type, furry pets, pests, and signs of mold.26 Judging from observation alone, the homes had no more than two occupants per bedroom, indicating that over-crowded living conditions did not occur in this sample. Most homes were tightly sealed to conserve energy, and occupants were staying indoors with the air conditioning running due to the excessive heat of the Texas summer. The HVAC systems did not bring in any outdoor air, and exhaust fans in the kitchens and bathrooms were of variable quality. A small amount of mold was occasionally visible, typically around the shower base, but no patches exceeding one inch in diameter. Gas appliances were common. As anticipated, most homes in this study (16/18) had central, ducted, forced air cooling systems, and some (2/18) had only window units for cooling. Most homes had carpet and furry pets indoors.

Sentinel indicators of a potentially unhealthy indoor environment included a pest infestation and unclean surfaces. One of 18 dwellings had a strong pungent odor upon entry and multiple roach sightings during the home visit, indicating a severe roach infestation. A different home, only one of the 18 visited, had a build-up of grime on all surfaces and was universally classified as "unclean" by all observers.

F. Section 4: Real Time Air and Sound Measurements

The sensors detected several sentinel indicators of poor indoor air quality. One dwelling unit had higher levels of both CO (4.2 ppm) and CO2 (2300 ppm) than the others (see Table 3.). The American Society of Heating, Refrigeration & Air Conditioning Engineers (ASHRAE) CO2 level of concern for CO2 is 1000 ppm, reflecting poor ventilation, and five of twelve homes tested exceeded this level. One of the 18 dwellings had much higher PM2.5 than the others (see Table 4). This was a rural home with obvious indicators of tobacco smoking indoors such as ashtrays with cigarette butts. In addition, this home did not have a central HVAC system.

There was no significant difference in outdoor PM 2.5 between any of the 18 dwellings, regardless of proximity to highways. The sound level measurements were in a similar range both inside and outside for all dwellings.

DISCUSSION

As a screening instrument to identify sentinel indicators of unhealthy homes, the DUO was successful in identifying the most salient health risks in the home environment and triggers for additional testing. Furthermore, the DUO field evaluation was acceptable to participants, feasible to administer with minimum training, and cost effective, using widely available hand held instruments for air measurements. The most outstanding sentinel indicators from extant data and observations included a low density area, associated with lack of services;[27] a low value home, associated with disrepair; proximity to an agricultural field, associated with run-off; grimy surfaces indoors, associated with incidental ingestion of toxic substances and a disorderly home;[28] and a roach infestation, associated with increased risk of allergies and asthma.[29] Easily obtained air quality measurements that could trigger additional testing included elevated CO and CO2 in a poorly ventilated home and elevated particulates in a home with indoor tobacco smoking.

Table 3: Inter-Rater Reliability on Key Items

Key Term	Fleiss' Kappa
Dwelling Unit Type (five choices)	0.67
Clutter Indoors (three categories)	0.48
Pests (yes or no)	0.48
Close to Major Highway (yes or no)	0.44
Forced Air, Central HVAC (yes or no)	0.35
Cleanliness Indoors (yes or no)	0.31
Outside Disrepair (three categories)	0.26
Mold (yes or no)	0.11
Indoor Disrepair (three categories)	0.10

Interpretation: Kappa of "1" indicates perfect agreement. Kappa below 0.3 indicates that agreement on the item was inadequate, and the wording of the item and/or training in collecting the data needs improvement.

Table 4: Air Quality Measurements from Sensors

Variable	n	Range	Median	Mean	Outlier
Carbon Monoxide - Outdoor	18	0.5-1.0	0.7	0.8	none
Carbon Monoxide – Indoor*	18	0.2-4.1	0.7	0.7	4.1**
Carbon Dioxide – Outdoor	18	400-440	420	420	none
Carbon Dioxide – Indoor*	18	600-2200	700	1009	2200**
PM 2.5 – Outdoor*	18	5-12	7	11	none
PM 2.5 – Indoor***	18	10-70	12	9	70

*American Society of Heating, Refrigeration & Air Conditioning Engineers (ASHRAE), carbon monoxide Level of concern indoors = 9 ppm; ASHRAE carbon dioxide level of concern = 1000 ppm (not for the carbon dioxide itself but as a surrogate for other bioeffluents or odors); Environmental Protection Agency's National Ambient Air Quality
Standards list 15 $\mu g/m^3$ as the annual limit and 65 $\mu g/m^3$ as the 24-hour limit for $PM_{2.5}$ in outdoor air.
**The highest carbon monoxide and highest carbon dioxide occurred in the same home.
*** Actual measurements divided by 3 to correct for tobacco smoke particle size, as determined by calibration experiments comparing the SidePak to pump-and-filter gravimetric methods[30]

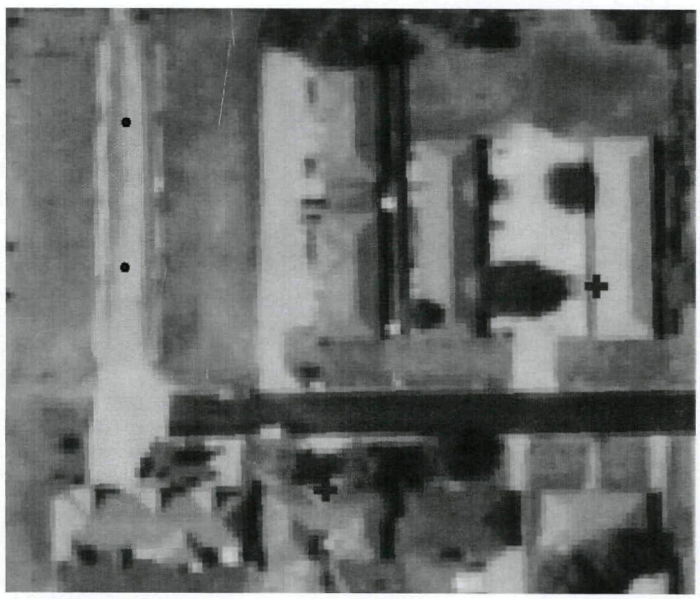

Figure 1: Geographical coordinates of residence by entering address into Google Earth vs. taking an actual measurement at the home. The crosses reflect the actual address as measured with a Trimble Juno SB Handheld device, while the dots reflect the geographical coordinates obtained by entering the address into Google Earth. The dots (false location) are close enough to a major highway to be a health concern, while the crosses (real location) are not.

The air measurements are good examples of how sentinel indicators can serve as "dwelling canaries." The elevated CO alludes to potentially higher values when gas appliances are in use. This measurement came from a public housing unit that had natural gas appliances and recent tightening of the building envelope to conserve energy, which contributed to both the CO and CO2 elevations. If resources were available, sentinel indicators such as these could trigger more detailed dwelling inspections such as gas appliance performance, combustion gas generation, and venting before the problem becomes a health risk to the occupants. Elevated PM 2.5 in another home could trigger a follow-up study of particulate air pollution over a longer period of time with documentation of occupant activities to help identify the extent and source of exposure.

The DUO tool is still in the development phase and not ready for use in other studies. Additional studies of content, validity, reliability, and seasonality could strengthen the DUO field tool. Comparison to longer assessments (HUD or EPA) might identify items for inclusion or deletion from the DUO. Funding was not available to conduct the longer assessments in the field alongside the DUO. Long-term air quality measurements, as well as professional inspections for mold, pests, and disrepair in a sample of DUO assessed homes, would also help establish the DUO's validity compared to professional measurements. A few items on the DUO, such as degree of mold and indoor disrepair, had poor inter-observer reliability and need refinement in phrasing along with additional training. Finally, the DUO should be repeated in the winter when use of gas furnaces is prevalent, and the risk of combustion byproducts such as CO in indoor air increases.

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