# A SUITE OF HOMES REPRESENTING THE U.S. HOUSING STOCK

A. Persily, D. Leber

National Institute of Standards and Technology
Gaithersburg, MD 20899 USA

## ABSTRACT

In order to facilitate nationwide analysis of ventilation and indoor air quality issues in residential buildings, a set of homes has been defined to represent the housing stock of the United States. This so-called "suite of homes" is based on two residential housing surveys, the U.S. Department of Energy Residential Energy Consumptions Survey (RECS) and the U.S. Census Bureau American Housing Survey (AHS). The RECS dataset includes about 6□00 U.S. residences and the AHS covers about 60□00, and are both intended to periodically characterize the U.S. housing stock. Based on these datasets, about 175 buildings were defined that represent approximately 75 % of the U.S. housing stock, and just over 200 to represent 80 %. These buildings are grouped into four categories: detached, attached, manufactured homes and apartment buildings. This paper describes the RECS and AHS datasets and how they were used to define this suite of homes. Among the key characteristics addressed in defining these homes are age, floor area, number of floors, foundation type and presence of a garage. As an extension of this effort, these homes will be set up in the multizone airflow model CONTAMW and made available for analyzes of residential ventilation, energy and indoor air quality issues.

**KEYWORDS:** database, modeling, residential, ventilation

## INTRODUCTION

Concerns about residential indoor air quality have led to the proposal and evaluation of a number of interventions to improve indoor environmental conditions, including mechanical ventilation, air cleaning and moisture control strategies (Emmerich and Persily 1996). Research studies and demonstration projects have provided much valuable data on the potential impacts of such interventions in specific buildings; however, it is important to assess their potential impact on a larger scale, such as in a specific climate zone or even nationwide. Determining these impacts through field testing would require an extensive and costly effort. Alternatively, modeling could be used to estimate the impact of these interventions, thereby enabling more sound policy decisions. In order to obtain more reliable impact estimates, such modeling analysis needs to be performed on a set of buildings that is representative of the residential building stock. NIST has recently initiated an effort to define a representative collection of residential buildings based on a statistical analysis of the United States (U.S.) housing stock. This paper describes the process by which these buildings were defined. The next step in this effort will be to enter these buildings into the indoor air quality analysis program CONTAM.

## DATA SOURCES

In developing this collection of residential buildings, statistical analyses were performed on two residential building databases, the U.S. Census Bureau's American Housing Survey's (AHS) and the United States (U.S.) Department of Energy's (DOE) Residential Energy Consumption Survey (RECS). Every other year the U.S. Bureau of the Census collects data via surveys and interviews to develop a housing inventory of the United States for the U.S. Department of Housing and Urban Development (HUD). Named the American Housing Survey, this inventory is based on a representative sample of approximately 56 000 homes selected using a sampling method based on classifying all the counties in the United States (HUD 1999). The AHS is used to measure specific changes in the housing inventory and assess progress towards the goal of providing sustainable living conditions to all Americans. After collection of the survey data, the Census Bureau compiles all the data into a publicly available database on the American Housing Survey website. The U.S. Department of Energy (DOE) Residential Energy Consumption Survey (RECS) is a collection of statistical information covering the characteristics of the housing units and occupants in the United States, with emphasis on the consumption of and expenditures for energy in these housing units (DOE 1999). The RECS survey has been conducted by DOE roughly every three or four years over the past few decades; the 1997 survey was used in this effort and incorporates data from approximately 5 900 housing units. A primary purpose for the RECS is to provide inputs to DOE's National Energy Modeling System, but the data are also used by other government agencies and researchers.

Given that the RECS database is more easily accessible in electronic format, it was preferable for use in the statistical analysis to define the representative suite of homes. However, in order to justify using the DOE RECS data, the two surveys were compared. The results of that comparison are shown in Table 1. Note that the two surveys are different in how they summarize the survey results for selected variables. For example the floor area values in the AHS database do not include apartments or single, attached homes. Therefore, to better compare the two datasets, some of the variables in Table 1 do not include all four housing types as noted in the table. Note that for some of the variables, the total percentages do not add up to 100 % due to missing data.

## SAMPLE SELECTION

The representative collection of homes was determined using a sampling scheme in which, for each of the four building types, a number of relevant building characteristics, or factors, in Table 1 were considered for a discrete number of "levels". The factors and individual factor levels considered for each building type are listed in Table 2. For each building type, each considered factor level was crossed with all other factor levels resulting in a factorial type layout of cells defining the "population" for each housing type. The number of cells in the population by building type consist of: Single, Detached - 432; Single, Attached - 432; Apartment Units - 400; and, Manufactured Homes - 16. The RECS database assigns a "weight" for each housing unit or cell that defines how many units it represents nationwide. These weights were aggregated across building characteristics to represent each housing unit, or cell, in the considered population. The first step in the sampling process was, for each building type (single family, etc.), to sort the cells in descending order based on the cell's weight. Figure 1 shows the percentage of homes covered for each of the four housing types as a function of the number of cells included. Note that the percent coverage increases very quickly for the manufactured homes due to the smaller amount of variation among these

buildings. For all four housing types, the addition of additional cells in the sample reaches a point of "diminishing returns" where increasing the sample size does not lead to a significant increase in coverage.

The next step in the process was to select the cells, again for each of the four housing types, which encompass 75 % and 80 % of the total number of units for that type based on the cell weights. This approach led to unequal numbers of homes of each type, but comparable percentages of national coverage. Table 3 shows the number of homes and the percent of the total represented for 75 % and 80 % representation.

TABLE 1
Summary of data from AHS and RECS

| | | Percentage | |
|---|---|---|---|
| **Variable** | **Variable Ranges** | **AHS** | **RECS** |
| **Unit Type** | Single, detached | 72.4 | 62.9 |
| | Single, attached | 5.8 | 9.8 |
| | Apartment | 16.1 | 21.1 |
| | Manufactured home | 5.7 | 6.2 |
| **Region** | Northeast | 16.6 | 19.4 |
| | Midwest | 26.0 | 23.7 |
| | South | 34.2 | 35.4 |
| | West | 23.0 | 21.5 |
| **Forced-air distribution** | Yes | 63.2 | 53.4 |
| | No | 36.8 | 46.6 |
| **Floor area *** | < 1000 $ft^2$ (93 $m^2$) | 14.0 | 29.0 |
| | 1000-1999 $ft^2$ (93-186 $m^2$) | 46.1 | 45.1 |
| | 2000-2999 $ft^2$ (186-279 $m^2$) | 21.7 | 13.0 |
| | > 3000 $ft^2$ (279 $m^2$) | 10.7 | 4.0 |
| **Occupants per household** | 1 | 24.3 | 25.2 |
| | 2 | 33.9 | 32.5 |
| | 3-4 | 31.6 | 32.2 |
| | 5-6 | 8.9 | 10.1 (≥ 5) |
| | 7-10 | 1.2 | -- |
| | >10 | 0.1 | -- |
| **Central air conditioning** | Yes | 52.0 | 42.1 |
| | No | 48.0 | 57.9 |
| **Year built** | <1940 | 17.3 | 19.9 |
| | 1940-1949 | 7.4 | 9.3 |
| | 1950-1959 | 13.1 | 13.1 |
| | 1960-1969 | 14.4 | 14.9 |
| | 1970-1979 | 19.8 | 13.2 |
| | 1980-1989 | 6.4 | 6.2 |
| | >1990 | 21.6 | 23.4 |
| **Garage or carport **** | Yes | 56.4 | 53.7 |
| | No | 43.5 | 25.2 |
| **Foundations type ***** | Basement | 44.6 | 32.7 |
| | Crawl space | 25.8 | 22.2 |
| | Slab | 28.7 | 22.6 |
| **Number of stories ***** | 1 | 35.1 | 55.8 |
| | 2 | 35.1 | 39.8 |
| | ≥ 3 | 29.6 | 3.1 |

* Does not include apartment units or single, attached units
** Does not include apartment units.
*** RECS does not include apartment units, and both do not include manufactured homes.

TABLE 2
Cells for each housing type

| VARIABLE | VARIABLE RANGE OR LEVEL |
|---|---|
| **SINGLE FAMILY (attached and detached)** | |
| **Forced-air distribution** | Yes |
| | No |
| **Floor area *** | < 1600 $ft^2$ (149 $m^2$) |
| | 1600-2399 $ft^2$ (149-223 $m^2$) |
| | >2400 $ft^2$ (223 $m^2$) |
| **Year built** | <1940 |
| | 1940-1969 |
| | 1970-1989 |
| | >1990 |
| **Garage or carport **** | Yes |
| | No |
| **Foundations type ***** | Basement |
| | Crawl space |
| | Slab |
| **Number of stories ***** | 1 |
| | 2 |
| | ≥ 3 |
| **APARTMENTS** | |
| **# of units in building** | 2-4 |
| | 5-9 |
| | 10-19 |
| | 20-39 |
| | >40 |
| **Floor area** | < 1000 $ft^2$ (< 93 $m^2$) |
| | > 1000 $ft^2$ (> 93 $m^2$) |
| **Year built** | <1940 |
| | 1940-1969 |
| | 1970-1989 |
| | >1990 |
| **Central heating system** | Yes |
| | No |
| **MANUFACTURED HOMES** | |
| **Floor area** | < 1600 $ft^2$ (< 149 $m^2$) |
| | > 1600 $ft^2$ (> 149 $m^2$) |
| **Year built** | <1940 |
| | 1940-1969 |
| | 1970-1989 |
| | >1990 |
| **Central heating system** | Yes |
| | No |

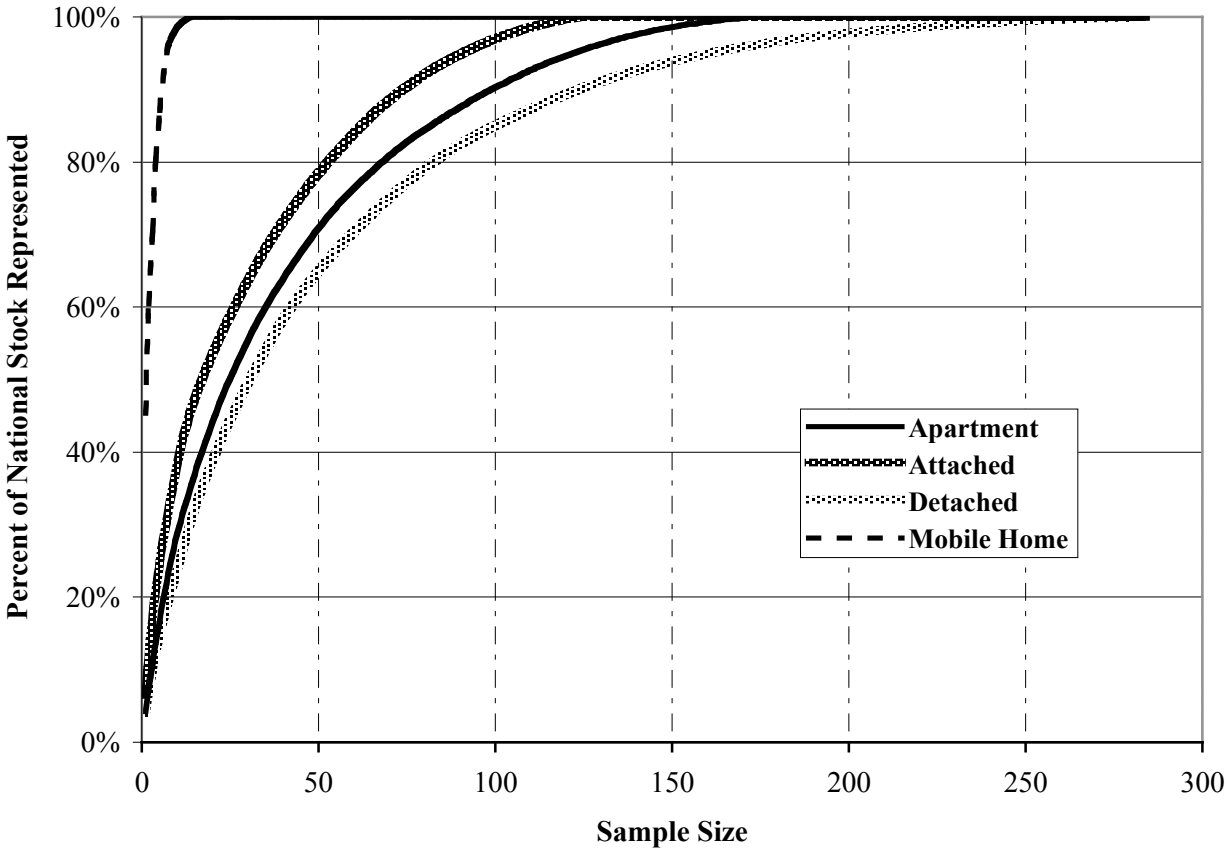


Figure 1: Percentage coverage as a function of sample size

TABLE 3
Summary of data from AHS and RECS

| | 75% Representation | | 80% Representation | |
|---|---|---|---|---|
| **Type of Housing** | **Sample Size** | **% Represented** | **Sample Size** | **% Represented** |
| Single, detached | 70 | 75.1 | 83 | 80.2 |
| Single, attached | 45 | 75.3 | 53 | 80.2 |
| Apartments | 58 | 75.4 | 69 | 80.4 |
| Manufactured homes | 3 | 70.6 | 4 | 80.4 |
| Total | 176 | 74.8 | 209 | 80.2 |

## ADDITIONAL WORK

Once the specific number of residences to be included in the representative sample is defined, two additional steps are planned. The first will be a "counting" effort in which each of the residences in the sample will be examined with respect to a number of variables. Specifically, using other data from the RECS and AHS datasets, the distribution of each house with respect to the number of occupants, number of bedrooms and bathrooms, cooking fuel, geographic region of the country and other variables will be established. For example, for a specific manufactured house defined by each variable in Table 2, these residences will be further divided by the number of occupants, geographic location and other variables of interest. In addition, each of the units defined will be entered into the CONTAMW airflow and indoor air quality model (Dols and Walton, 2002). In this effort, the age of the unit will be used as a surrogate for envelope airtightness based on existing data relating building age

to envelope airtightness (Sherman and Dickeroff 1998). Many of the inputs required by the CONTAMW models of these residences will be based on judgment, but the existence of these models will allow analyses of many ventilation and indoor air quality issues with a level of confidence in their representativeness that was not previously possible.

## ACKNOWLEDGEMENTS

This work was sponsored by the U.S Department of Housing and Urban Development, Office of Healthy Homes and Lead Hazards Control.

## REFERENCES

DOE. 1999. A Look at Residential Energy Consumption in 1997. DOE/EIA-0632 (97), U.S. Department of Energy.

Dols, WS and Walton, GN. 2002. CONTAMW 2.0 User Manual. National Institute of Standards and Technology, NISTIR 6921.

HUD. 1999. American Housing Survey for the United States. H150/99. U.S. Department of Housing and Urban Development, U.S. Department of Commerce.

Sherman, M. and Dickeroff, D. 1998. Air-Tightness of U.S. Dwellings. ASHRAE Transactions 104 (2): 1359-1367.