Residential Population Generator (RPGen) Technical Manual

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Introduction

The Residential Population Generator (RPGen) module generates a simulated population of individuals along with their corresponding individual and household characteristics. The individuals and their characteristics are intended to be representative of the general U.S. population. RPGen takes large, nationally administered databases representing U.S. demographic, household, and housing patterns as input. The purpose of this manual is to provide the logic, rationale, and methods implemented in RPGen, in addition to providing additional guidance in how to run and use RPGen. This guide serves as a supplement to the description of RPGen presented in East et al. 2020.

Description of Code

RPGen randomly samples demographic data from the U.S. Census Bureau’s American Community Survey’s 5-Year Public Use Microdata Sample (PUMS), housing data from the American Housing Survey (AHS), and residential characteristics from the Residential Energy Consumption Survey (RECS). The generated dataset links demographic characteristics of each recorded individual to characteristics of their home, including location (as defined by region of the country), household income, house type, and household composition. Thus, RPGen produces a synthetic sample population of individuals that are 1) associated with a suite of internally consistent personal and residential characteristics, and 2) reflective of underlying demographic associations in real-world US populations. This output can be used in the modeling of interindividual variation in external and internal doses of chemicals from exposure sources. Although RPGen was initially created as a modular component of EPA’s Combined Human Exposure Model (CHEM) framework, it’s outputs can be readily adapted to other exposure modeling platforms requiring synthetic sample populations. The RPGen code and input files are freely available at <https://github.com/HumanExposure/RPGen>.

Required Packages

RPGen is programmed in the open source language R and uses R packages available in the Comprehensive R Archive Network (CRAN). The following packages are installed automatically if not already installed by the user.

* bit64
* data.table
* downloader
* dplyr
* dtplyr
* ggplot2
* httk
* msm
* plyr
* stringr
* tidyverse
* truncnorm
* survey

Inputs to RPGen

RPGen takes national surveys of individual, household, and housing characteristics and links them using key characteristics. In RPGen, three national databases are linked: The 5 Year Public Use Microdata Sample (PUMS), the American Housing Survey (AHS), and the Residential Energy Consumption Survey (RECS). Currently, RPGen uses 2015 RECS data, 2017 AHS data, and 2014-2018 PUMS data. The R package *httk* (1.9.2) is used to generate physiological data using National Health and Nutrition Survey (NHANES) data. As of September 2020, the versions of data sources in RPGen included the following numbers of observations: PUMS (including both personal and housing information): approximately 15. 9 million observations; RECS: 5,659 observations; AHS: 66,752. Table 1 contains further information on data sources.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Data Source | Year | Update Period | Update Delay | File Size | Source |
| [American Housing Survey (AHS)](https://www.census.gov/programs-surveys/ahs/data.html) | 2017 | Every two years | 2017 file released August 2018 | 3.3MB | U.S. Census Bureau |
| [Residential Energy Consumption Survey (RECS)](https://www.eia.gov/consumption/residential/data/2015/index.php?view=microdata) | 2015 | Every 4-6 years | 2015 file released April 2017 | 3MB | U.S. Energy Information Bureau |
| [5-Year Public Use Microdata Survey (PUMS): Housing Data](https://www2.census.gov/programs-surveys/acs/data/pums/2018/5-Year/) | 2014-2018 | Annually | 2018 version released January 30, 2020 | 880MB | U.S. American Community Survey |
| [5-Year Public Use Microdata Survey (PUMS): Person Data](https://www2.census.gov/programs-surveys/acs/data/pums/2018/5-Year/) | 2014-2018 | Manually | 2018 version released January 30, 2020 | 2.1GB | U.S. American Community Survey |

Table 1: Data sources used in RPGen

Implementation

1. Variable Selection

A number of factors, including household composition, housing characteristics, and locational factors influence the products that individuals in households use, and therefore the exposure to chemicals from those products. RPGen uses bins of several categorical factors to capture these influences. The RECS, AHS, and PUMS datasets all share some common variables that are combined into a shared *pool* variable. This indexing variable allows for the explicit linking of observations across datasets, thus allowing for the plausible assemblage of individuals with internally consistent household characteristics. The *pool* variable ranges in value from 1-288, with levels representing the unique factorial combinations possible of 5 categorical variables, including region (levels=4), setting (levels=2), house type (levels=3), family type (levels=4), and income category (levels=3). In the “Appending Datasets” section below, we describe each of the 5 component categorical variables and how their levels are determined.

When all input source are combined, RPGen outputs populations of individuals described by 125 variables, including the pool variable. See Appendix A for a list and description of all output variables. Note that although the suite of housing characteristics output by RPGen includes air rate exchange variables, air exchange rates are not calculated. As RPGen was originally designed as a module in the Combined Human Exposure Model (CHEM) framework, another module (Source to Dose) currently calculates air exchange rate for each household. For more information on this module, please see documentation listed at the following URL: <https://github.com/HumanExposure/source2dose>.

1. Design Considerations

Because the PUMS dataset is relatively large (> 15,000,000 observations), input files are split by region before being read into RPGen. If region(s) are specified by the user, only the corresponding files are loaded, resulting in a faster runtime.

Because the observations in RECS, AHS, and PUMS are samples representative of the larger population, each input file has a weight, representing the degree to which each residence or person represent the U.S. population (U.S. Census Bureau, 2014). These weights are utilized by RPGen to create a sample population that is similarly representative of the U.S.

1. Appending Source Datasets

Assembling the pool variable

The pool variable was assembled from the factorial combinations of 5 categorical variables described below. See Appendix B for a list and description of each level of pool.

*Region*

PUMS data are provided with Public Use Microdata Areas (PUMAs), geographically contiguous areas built on census tracts and counties. Containing at least 100,000 people, these areas add geographic resolution to the PUMS dataset. However, RECS and AHS do not contain resolution to the PUMA level. AHS provides a state variable, while RECS only contains household data by region. Thus, households in each dataset are matched and associated with a regional designation. Users can specify particular states using Federal Information Processing Standard (FIPS) codes in Appendix C.

*Urban or Rural*

Because habits and product use vary widely between urban and rural users, observations were associated with a rural/urban designation. Urban and rural designations are provided in AHS and RECS, but not PUMS. Both the AHS and the RECS surveys use Micropolitan and Metropolitan statistical areas, issued by the Office of Management and Budget (OMB) in 2010, and are coded as *OMB13CBSA* and *METROMICRO* respectively. Metropolitan areas have at least one urbanized area containing 50,000 or more individuals and Micropolitan contains a cluster of at least 10,000 but less than 50,000 individuals and exist adjacent to a metropolitan statistical area. All metropolitan statistical areas are coded as urban, and all other areas are considered rural.

In PUMS, the urban/rural designation is made based on population density of each PUMA and is reflected in the file *puma\_density.csv* provided. Population density of PUMAs were calculated using the U.S. Census Topologically Integrated Geographic Encoding and Referencing (TIGER) dataset. RPGen classifies an individual’s location of residence as urban if the population density is >129.8 people/km2, and rural for a lower population density. This threshold was equivalent to the population density of Chapel Hill, N.C. in 2016, a relatively small city (approximately 70,000 people) largely surrounded by agricultural and forested landcover. The variable *compid* is presented in RPGen output, which is the state ID followed by the PUMA.

Note that the combination of census region and the urban/rural status results in eight possible location-states to be associated with records in the three inputs datasets and the resulting RPGen output.

*House Type*

A variety of housing types are identified in the AHS and RECS datasets. Within RPGen, housing types have been simplified and condensed as: single-unit (stand-alone, either detached or attached) structures, multi-unit structures (such as apartments or condominiums), and other (mobile homes, boats, etc.). It is believed that the largest influence of house type on exposure will be in the determination of air exchange rates which influence indoor air concentrations (Breen et al., 2014). Additional impacts of housing type on product use relate to the presence or absence of required yard or outdoor maintenance, which are typically not required when one does not live in an owned, stand-alone unit.

Although the PUMS database also includes persons living in group quarters, such as military bases, prisons, and shelters, it was determined that it was inappropriate to match these records with household records in AHS and RECS, which do not. In addition, living arrangements (such as cooking and cleaning, and general product use) and housing characteristics are quite different in these situations from those assumed in AHS and RECS. RPGen therefore excludes such persons.

*Family Category*

Household composition, specifically whether a household includes adults with or without children, has significant implications for products use and exposure implications of product use. To reflect this, households are grouped into 4 bins based on household composition, which is determined by the number of adults and children in each household. RECS, AHS, and PUMS, each contain the number of adults and children per household.

*Income Category*

Household income is used as an indicator of wealth, which may inform product use and policy implications given analyses of exposure and risk. However, because living costs and purchasing power vary across the U.S., income categories are first sorted by region and urban or rural status, and then assigned to bins corresponding to the households with the top, middle, and bottom third of income within that region and urban or rural designation. This is applied separately to all three databases, before being linked via pool. For PUMS, the data are spread over 5 years, and an annual inflation adjustment is included in the data. The number and size of bins related to purchasing power were chosen arbitrarily in the absence of data indicating how consumer product use varies with income.

Table 2: All categorical variables and levels considered in calculating the pool variable

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Setting | Region | House Type | Family Type | Income Category |
| Urban | Northeast | Stand Alone | 1 Adult, 0 Children | 1 |
| Rural | Midwest | Multi Structure | 2+ Adults, 0 Children | 2 |
|  | South | Other | 1 Adult, 1+ Children | 3 |
|  | West |  | 2+ Adults, 1+ Children |  |

*Generation of Physiological Characteristics*

For each generated individual in RPGen, physiological variables are calculated using the R package *httk* (version 1.9.2). Outputs are varied slightly within RPGen to account for natural physiological variation within the population. These modifications include adding limits of 225cm and 160kg to the generated population. Although persons beyond these limits exist, the regression equations used in *httk* to generate physiological variables must be extrapolated beyond the range of the empirical data, and often return impossible results. Physiological information returned for each individual include height, weight, skin area, organ masses, and blood flows to each organ, which can be used as parameters in models of in-vivo toxicokinetics of chemicals (e.g., physiologically-based pharmacokinetic (PBPK) models).

1. Assembling the population

*Weighting Process*

The PUMS dataset consists of greater than 15 million randomly sampled census records, and thus serves as the basis of the assembly process. Everyone in the PUMS dataset is assigned a statistical sampling weight, *pwgtp*, which reflects the estimated number of similar individuals (based on a suite of demographic characteristics) that live in the US according to the census data. To utilize these sampling weights for sampling individuals from PUMS, RPGen uses a two-step process. First, a vector of random numbers between 0-1 (*rand*) is generated for the desired number of samples. Next, the statistical sampling weights in the PUMS dataset are assembled into a cumulatively summed vector that is divided by the maximum value of that vector (*cumsumnorm*). This vector ranges from 0-1, with interval sizes between values reflecting the relative statistical sampling weights of each person in the PUMS dataset. Lastly, the values of rand are paired with the intervals in which they fall in *cumsumnorm*. The matched intervals of *cumsumnorm* are then selected to become members of RPGen. Because individuals with larger statistical weights result in proportionately larger intervals than smaller weights, as it is more likely that a value from *rand* will fall into them. Thus, individuals’ probability to be included in RPGen are determined by their weights(*pwgtp)*. Housing characteristics are sequentially matched to each person based on their pool value using a similar process. First, all the values in AHS or RECS that have matching pool values to an individual are identified. Then, using statistical sampling weights specific to both RECS and AHS, the same two-step sampling process described above is employed. The complete output is a synthetic population with individuals from PUMS and housing variables from AHS and RECS. Finally, *httk* physiological variables are calculated based on the age, race, and gender with *get.randoms().*

Randomization

Many random seeds are generated to facilitate sensitivity analysis in RPGen and to ensure reproducibility of sampled populations. However, dangers exist if the same generator is used to produce seeds, as there is a possibility of generating correlated streams of values. Therefore, two different random generator functions used, a 32-bit generator for the list of seed values (*get.seeds*) and a 64-bit generator for the values assigned to the variables (*get.randoms*). The function *get.seeds()* is a prime modulus multiplicative generator which returns integers from 1 to 231 - 2 with equal probability. Two of these values are pasted together to form 64-bit seeds needed by the Marsiglia-Multicarry generator used in *get.randoms()*. The chance that two modeling variables will have correlated values is effectively zero. All randomness in RPGen is produced in calls to *get.seeds()* and *get.randoms()* which are both dependent only on the seed from the control file and are reproducible while not producing correlated outputs. In addition, *get.randoms*() provides functionality to control the seeds set for individual randomly selected variables, more easily allowing for sensitivity and uncertainty analyses.

Pool representation

Some possible levels of pool are rare (e.g., high-income rural apartments) and thus would be unlikely to be sampled. Thus, not all levels of pool are necessarily represented in the datasets. When RPGen selects a pool that does not exist, it resolves this by shifting the pool value up by 1 and if needed, 2 in scenarios where pools do not exist. Currently, PUMS does not have any missing pools and complete, exportable reports of possible pools are available in RStudio’s *Global Environment* when RPGen is run.

Organization of RPGen Code and Files

The following files and folders are required for RPGen. Shown below is the default file structure when cloning from GitHub. Note that no files, with the exception of the *Control.R* file, should be edited.

Structure within the RPGen Folder:

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• . . ./RPGen/data/ Location of required input .rda and .txt files

• . . ./RPGen/input/ Location of user .txt files to be called in RPGen

• . . ./RPGen/output/ Location where output files are written

• . . ./RPGen/R/ Contains 6 .R files which construct RPGen.

• . . ./RPGen/tests/ Contains tests for RPGen data loading and running

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Contents of /data/: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

• RPGen AHS.rda

A condensed version of the AHS database. Do not modify.

• RPGen RECS.rda

A condensed version of the RECS database. Do not modify.

• RPGen PUMS .rda files

Condensed versions of the PUMS database, split by region. Do not modify.

• RPGen PUMA Density.rda

Disseminates PUMS data. Do not modify.

• RPGen States.txt

Index of states and state FIPS codes. Do not modify.

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Contents of /R/: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

• AHS Downloader.R

An R script that, provided a hyperlink to AHS, will populate the input folder with a condensed input file.

• RECS Downloader.R

An R script that, provided a hyperlink to RECS, will populate the input folder with a condensed input file.

• PUMS Downloader.R

An R script that, provided hyperlinks to PUMS 5 year housing and population data, will populate the input folder with four condensed input files, split by region.

• Control. R

An R script that calls *PopGen.R*, *Housing.R*, and *Packages.R* to create RPGen’s output

• PopGen.R

An R script population generator that merges the condensed versions of the PUMS input and httk functions to randomly generate and describe a population.

• Housing.R

An R script that loads RECS and AHS before matching them to the population created in PopGen

• Packages.R

An R script that downloads packages required for RPGen if not already downloaded and loads all packages from the library.

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Contents of /tests/: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

• contents.R

Tests if the contents of a column within a dataframe are within a queried range. Will report if values are outside of the range, if values are missing, or both.

• pool test.R

Converts a pool number to a readable character string (See Appendix B).

• report card.R

Applies contents test.R to urban, region, location, housetyp, famcat, inccat, and pool variables within RPGen and calls pool.reader on missing pools.

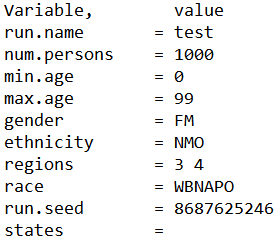
\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Users may create .txt input files to be called in RPGen. Identically named folders will be overwritten in /output/ will be overwritten, so it is recommended to manually move output after completion of RPGen.

Running RPGen

Users should ensure that the file structure described above is in place. Users will then ‘source’ the R/Control.R script and call the *RPGen.run* function. The *RPGen.run* function uses either a .txt runfile supplied by the user in the input folder (e.g. RPGen.run(‘run1.txt’) ), or arguments can be interactively entered into the function following an open function call (i.e., RPGen.run()). The file ‘run1.txt’ file is provided as an example run file; its contents shown below in Figure 1.

*Figure 1. Example RPGen runfile*



Options for parameters are detailed below.

When the run is complete, users will be able to access the named output folders in the output folder.

Input Options

As shown in Figure 1, multiple options are available to the user within the control file. These options include:

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• run.name

The run.name can be specified to any unique name the user desires. This variable is assigned as the folder name containing the output files. If no name is specified, the output files will load directly into RPGen/output without creating a subfolder.

• num.persons

User may specify any number of individuals to simulate; must be an integer value

• min.age

Minimum age of individuals in the simulated population; must be an integer ≥ 0

• max.age

Maximum age of individuals in the simulated population; must be an integer ≤ 99

• gender

M = male, F = female

• ethnicity

N = non-Hispanic, M = Mexican-American, O = other-Hispanic

• regions

If this parameter and ‘states’ are left blank, all regions will be included in the model run. Alternatively, the user can define geographic by listing values with single spaces. There are four regions: 1 = West, 2 = Mid-West, 3 = South, 4 = North-East. Region codes are found in Appendix C. For increased geographic specify, the user may also opt to use states input.

• race

W = White, B = African American, N = Native American, A = Asian American, P = Pacific Islander, O = Other/mixed

• run.seed

Random number seed used to initiate run. Users may replicate previous runs by using the exact input parameters, including the run.seed. Value must be an integer from 1 to 2147483646.

• states

If this parameter and ‘regions’ are left blank, all states will be included in the model run. Alternatively, the user can specify state FIPS codes to run the model for a specific geographic area. FIPS codes should be entered as two-digit codes separated by a single space. FIPS codes are provided in Appendix C.

The gender, ethnicity, and race parameters may take on multiple letter codes (see Figure 1.) Each of these non-numeric inputs are entered without spaces. However, inputs for multiple states must be entered with spaces.

Variables may also be entered directly into the console by calling RPGen.run() without a runfile, as shown in figure 2 below. A name for the run is required, as it will name the folder containing RPGen’s output.

*Figure 2. Example Run Input for RPGen*

Text, letter

Description automatically generated

Outputs

Output from RPGen is a file named “pophouse.csv”, that will be saved into subfolder named with the run name in the output folder. The file “pophouse.csv” contains housing, residential, demographic, and physiological data.

Appendices

Appendix A: Data Dictionary for RPGen Output Variables

| **Variable Name** | **Description** |
| --- | --- |
| **Population Variables from PUMS** | |
| gender | gender of selected person (primary individual); Male or Female |
| reth | ethnic group (httkpop categories) |
| compid | 7-digit code; first two digits = state FIPS, last 5 digits = 2010 PUMA |
| recno | PUMS record number |
| race | W=White, B=Black, N=Native American, A=Asian, P=Pacific Islander, O=Other |
| ethnicity | M=Mexican hispanic, O=other hispanic, N=not hispanic |
| age | age in full years, rounded down (range= 0 to 96) |
| pwgtp | statistical sampling weight |
| pool | combination of database matching variables family type, house type, income, census region, and urban/rural (range 1-288) |
| ages | 40-character string, each pair is age of one household member (range 00-96) |
| genders | 20-character string, each is M or F |
| state | 2-digit FIPS code for one of the 50 states or DC (range 01=Alabama to 56=Wyoming) |
| commute | one-way commute-to-work time in minutes (if a worker) |
| vehicles | number of vehicles available to household (excluding trucks) |
| **Housing Variables from AHS** | |
| baths | number of full bathrooms; 0-10 (capped at ten), -6=NA |
| bedrms | number of bedrooms; 0-10 (capped at ten), -6=NA |
| built | year house was built; each year for 1990+, rounded down to 5x for 1970-1989, rounded down to 10x for 1920-1969, earlier=1919 |
| cellar | type of basement; 1=full basement, 2=partial basement, 3=crawl space, 4=slab, 5=other, -6=NA |
| hequip | main heating equipment; 1=forced air furnace, 2=steam radiators, 3=heat pump, 4=electric baseboard, 5-14=others |
| lot | square footage of lot; range is 200 - 999,997 square feet (almost 22 acres) |
| pwt | statistical weight within AHS; used for random selection |
| rooms | number of rooms; 1-21 (capped at 21) |
| sewdis | type of sewage disposal; 1=septic tank, 2=chemical toilet, 3=outhouse, 4=other, 5=none, -6=municipal system |
| unitsf | square footage of house (excl. garage, unfinished areas); 99-99998 (minimum allowed=99, capped at 99,998) |
| water | source of water (for washing and bathing); 1=water system, 2=well, 3=spring, 4=cistern, 5=stream or lake, 6=bottled, 7=other |
| control | record number from full 2013 AHS database |
| region | census region |
| urban | rural or urban |
| housetyp | housing type |
| famcat | family type |
| inccat | income category |
| family | integer variable equal number of adults (max = 2) times 10, plus number of children (max = 1) |
| **Housing Variables from RECS** | |
| doeid | record number from 2009 RECS database |
| nweight | sampling weight |
| hdd30yr | average annual heating degree days; range 0 – 13346 |
| cdd30yr | average annual cooling degree days; range 0 – 5357 |
| kownrent | own or rent house; 1=owned, 2=rented, 3 = stay without rent |
| stories | number of stories in single-family home; 10=one, 20=two, 31=three, 32=4+, 40=split-level, 50=other, -2=not a single family home |
| stove | number of cooktops (not combined with ovens); range 1-10 |
| stovefuel | fuel used for cooktop; 1=gas, 2=propane, 5=electric, 21=other |
| oven | number of ovens (not combined with cooktops); range 0-10 |
| ovenfuel | fuel used for oven; 1=gas, 2=propane, 5=electric, 21=other |
| ovenuse | frequency of oven use; 0=not used, 1=3+ per day, 2=twice per day, 3=once per day, 4 = few times per week, 5=1/week, 6=less |
| outgrill | outdoor grill used; 0=no, 1=yes |
| dishwash | dishwasher used in home; 0=no, 1=yes |
| cwasher | clothes washer used in home; 0=no, 1=yes |
| washload | frequency clothes washer used; 1=1/week or less, 2=2-4 per week, 3=5-9 per week, 4=10-15 per week, 5= 16+ per week |
| dryer | clothes dryer used in home; 0=no, 1=yes |
| dryruse | frequency clothes dryer used; 1=every time clothes washed, 2=sometimes when clothes washed, 3=rarely, -2=NA |
| tvcolor | number of televisions used in home; range 0-15 |
| elperiph | number of electronic peripherals used at home (e.g., printers, scanners, fax machine copiers); range 0-9, -2=NA |
| moisture | humidifier used at home; 0=no, 1=yes |
| prkgplc1 | have an attached garage; 0=no, 1=yes |
| cooltype | type of air conditioning system; 1=central, 2=window/wall, 3=both, -2=none |
| tempniteac | temperature setting at night (in warm weather); range 45-96, -2=no AC |
| numberac | number of window/wall AC units; range 1-15, -2=NA |
| numcfan | number of ceiling fans used; range 0-15 |
| notmoist | dehumidifier used at home; 0=no, 1=yes |
| highceil | high ceilings in home; 0=no, 1=yes |
| windows | number of windows in heated areas of home; 0=none, 10=1-2, 20=3-5, 30=6-9, 41=10-15, 42=16-19, 50=20-29, 60=30+ |
| adqinsul | level of insulation; 1=well insulated, 2=adequate, 3=poor, 4=none |
| drafty | home drafty in winter; 1=always, 2=mostly, 3=sometimes, 4=never |
| swim | swimming pool or hot tub; 0=none, 1=hot tub only, 2=pool only, 3=both |
| **Physiological variables from httk** | |
| mean\_logh | mean of log(height) for this age-gender group |
| mean\_logbw | mean of log(body weight) for this age-gender group |
| weight | body weight in kilograms; calculated from mean\_logbw and logbw\_resid |
| height | height in centimeters; calculated from mean\_logh and logh\_resid |
| blood\_mass | mass of blood (kg) |
| brain\_mass | mass of brain (kg) |
| gonads\_mass | mass of gonads (kg) |
| heart\_mass | mass of heart (kg) |
| kidneys\_mass | mass of kidneys (kg) |
| large\_intestine\_mass | mass of large intestines (kg) |
| liver\_mass | mass of liver (kg) |
| lung\_mass | mass of lungs (kg) |
| muscle\_mass | mass of muscular tissue (kg) |
| pancreas\_mass | mass of pancreas (kg) |
| skeleton\_mass | bone mass (kg) |
| skin\_mass | mass of skin tissue (kg) |
| small\_intestine\_mass | mass of small intestines (kg) |
| spleen\_mass | mass of spleen (kg) |
| stomach\_mass | mass of stomach (kg) |
| adipose\_flow | blood flow to adipose tissue [-] |
| brain\_flow | blood flow to brain [-] |
| CO | cardiac output (L/h) |
| gonads\_flow | blood flow to gonads [-] |
| heart\_flow | blood flow to heart muscle (not into heart) [-] |
| kidneys\_flow | blood flow to kidneys [-] |
| large\_intestine\_flow | blood flow to large intestines [-] |
| liver\_flow | blood flow to liver [-] |
| lung\_flow | blood flow to lung tissue [-] |
| muscle\_flow | blood flow to muscles [-] |
| pancreas\_flow | blood flow to pancreas [-] |
| skeleton\_flow | blood flow to bone tissue [-] |
| skin\_flow | blood flow to skin tissue [-] |
| small\_intestine\_flow | blood flow to small intestines [-] |
| spleen\_flow | blood flow to spleen [-] |
| stomach\_flow | blood flow to stomach [-] |
| other\_mass | mass of other tissues (kg) |
| adipose\_mass | mass of adipose tissue (kg) |
| org\_flow\_check | relevant to httkpop r package |
| weight\_adj | adjusted body weight (sum of organ masses) (kg) |
| BSA\_adj | adjusted body surface area (cm2) |
| million.cells.per.gliver | hepatocellularity, million cells/g liver |
| hematocrit | percent volume of red blood cells in the blood |
| serum\_creat | serum creatinine, mg/dL |
| gfr\_est | estimated glomerular filtration rate, mL/min/1.73m2 BSA |
| bmi\_adj | adjusted body mass index |
| bmi | body mass index |
| BSA | body surface area (cm2) |
| age\_months | age in months (randomly sampled, consistent with age in years) |

Appendix B: Pool Value Index

|  |  |
| --- | --- |
| ***Pool* Value** | **Residence Description** |
| 1 | Rural North East Stand Alone One Adult Low Income |
| 2 | Rural North East Stand Alone One Adult Middle Income |
| 3 | Rural North East Stand Alone One Adult High Income |
| 4 | Rural North East Stand Alone One Adult with Kids Low Income |
| 5 | Rural North East Stand Alone One Adult with Kids Middle Income |
| 6 | Rural North East Stand Alone One Adult with Kids High Income |
| 7 | Rural North East Stand Alone Adults Low Income |
| 8 | Rural North East Stand Alone Adults Middle Income |
| 9 | Rural North East Stand Alone Adults High Income |
| 10 | Rural North East Stand Alone Adults with Kids Low Income |
| 11 | Rural North East Stand Alone Adults with Kids Middle Income |
| 12 | Rural North East Stand Alone Adults with Kids High Income |
| 13 | Rural North East Multi Unit Structure One Adult Low Income |
| 14 | Rural North East Multi Unit Structure One Adult Middle Income |
| 15 | Rural North East Multi Unit Structure One Adult High Income |
| 16 | Rural North East Multi Unit Structure One Adult with Kids Low Income |
| 17 | Rural North East Multi Unit Structure One Adult with Kids Middle Income |
| 18 | Rural North East Multi Unit Structure One Adult with Kids High Income |
| 19 | Rural North East Multi Unit Structure Adults Low Income |
| 20 | Rural North East Multi Unit Structure Adults Middle Income |
| 21 | Rural North East Multi Unit Structure Adults High Income |
| 22 | Rural North East Multi Unit Structure Adults with Kids Low Income |
| 23 | Rural North East Multi Unit Structure Adults with Kids Middle Income |
| 24 | Rural North East Multi Unit Structure Adults with Kids High Income |
| 25 | Rural North East Other House type One Adult Low Income |
| 26 | Rural North East Other House type One Adult Middle Income |
| 27 | Rural North East Other House type One Adult High Income |
| 28 | Rural North East Other House type One Adult with Kids Low Income |
| 29 | Rural North East Other House type One Adult with Kids Middle Income |
| 30 | Rural North East Other House type One Adult with Kids High Income |
| 31 | Rural North East Other House type Adults Low Income |
| 32 | Rural North East Other House type Adults Middle Income |
| 33 | Rural North East Other House type Adults High Income |
| 34 | Rural North East Other House type Adults with Kids Low Income |
| 35 | Rural North East Other House type Adults with Kids Middle Income |
| 36 | Rural North East Other House type Adults with Kids High Income |
| 37 | Urban North East Stand Alone One Adult Low Income |
| 38 | Urban North East Stand Alone One Adult Middle Income |
| 39 | Urban North East Stand Alone One Adult High Income |
| 40 | Urban North East Stand Alone One Adult with Kids Low Income |
| 41 | Urban North East Stand Alone One Adult with Kids Middle Income |
| 42 | Urban North East Stand Alone One Adult with Kids High Income |
| 43 | Urban North East Stand Alone Adults Low Income |
| 44 | Urban North East Stand Alone Adults Middle Income |
| 45 | Urban North East Stand Alone Adults High Income |
| 46 | Urban North East Stand Alone Adults with Kids Low Income |
| 47 | Urban North East Stand Alone Adults with Kids Middle Income |
| 48 | Urban North East Stand Alone Adults with Kids High Income |
| 49 | Urban North East Multi Unit Structure One Adult Low Income |
| 50 | Urban North East Multi Unit Structure One Adult Middle Income |
| 51 | Urban North East Multi Unit Structure One Adult High Income |
| 52 | Urban North East Multi Unit Structure One Adult with Kids Low Income |
| 53 | Urban North East Multi Unit Structure One Adult with Kids Middle Income |
| 54 | Urban North East Multi Unit Structure One Adult with Kids High Income |
| 55 | Urban North East Multi Unit Structure Adults Low Income |
| 56 | Urban North East Multi Unit Structure Adults Middle Income |
| 57 | Urban North East Multi Unit Structure Adults High Income |
| 58 | Urban North East Multi Unit Structure Adults with Kids Low Income |
| 59 | Urban North East Multi Unit Structure Adults with Kids Middle Income |
| 60 | Urban North East Multi Unit Structure Adults with Kids High Income |
| 61 | Urban North East Other House type One Adult Low Income |
| 62 | Urban North East Other House type One Adult Middle Income |
| 63 | Urban North East Other House type One Adult High Income |
| 64 | Urban North East Other House type One Adult with Kids Low Income |
| 65 | Urban North East Other House type One Adult with Kids Middle Income |
| 66 | Urban North East Other House type One Adult with Kids High Income |
| 67 | Urban North East Other House type Adults Low Income |
| 68 | Urban North East Other House type Adults Middle Income |
| 69 | Urban North East Other House type Adults High Income |
| 70 | Urban North East Other House type Adults with Kids Low Income |
| 71 | Urban North East Other House type Adults with Kids Middle Income |
| 72 | Urban North East Other House type Adults with Kids High Income |
| 73 | Rural Midwest Stand Alone One Adult Low Income |
| 74 | Rural Midwest Stand Alone One Adult Middle Income |
| 75 | Rural Midwest Stand Alone One Adult High Income |
| 76 | Rural Midwest Stand Alone One Adult with Kids Low Income |
| 77 | Rural Midwest Stand Alone One Adult with Kids Middle Income |
| 78 | Rural Midwest Stand Alone One Adult with Kids High Income |
| 79 | Rural Midwest Stand Alone Adults Low Income |
| 80 | Rural Midwest Stand Alone Adults Middle Income |
| 81 | Rural Midwest Stand Alone Adults High Income |
| 82 | Rural Midwest Stand Alone Adults with Kids Low Income |
| 83 | Rural Midwest Stand Alone Adults with Kids Middle Income |
| 84 | Rural Midwest Stand Alone Adults with Kids High Income |
| 85 | Rural Midwest Multi Unit Structure One Adult Low Income |
| 86 | Rural Midwest Multi Unit Structure One Adult Middle Income |
| 87 | Rural Midwest Multi Unit Structure One Adult High Income |
| 88 | Rural Midwest Multi Unit Structure One Adult with Kids Low Income |
| 89 | Rural Midwest Multi Unit Structure One Adult with Kids Middle Income |
| 90 | Rural Midwest Multi Unit Structure One Adult with Kids High Income |
| 91 | Rural Midwest Multi Unit Structure Adults Low Income |
| 92 | Rural Midwest Multi Unit Structure Adults Middle Income |
| 93 | Rural Midwest Multi Unit Structure Adults High Income |
| 94 | Rural Midwest Multi Unit Structure Adults with Kids Low Income |
| 95 | Rural Midwest Multi Unit Structure Adults with Kids Middle Income |
| 96 | Rural Midwest Multi Unit Structure Adults with Kids High Income |
| 97 | Rural Midwest Other House type One Adult Low Income |
| 98 | Rural Midwest Other House type One Adult Middle Income |
| 99 | Rural Midwest Other House type One Adult High Income |
| 100 | Rural Midwest Other House type One Adult with Kids Low Income |
| 101 | Rural Midwest Other House type One Adult with Kids Middle Income |
| 102 | Rural Midwest Other House type One Adult with Kids High Income |
| 103 | Rural Midwest Other House type Adults Low Income |
| 104 | Rural Midwest Other House type Adults Middle Income |
| 105 | Rural Midwest Other House type Adults High Income |
| 106 | Rural Midwest Other House type Adults with Kids Low Income |
| 107 | Rural Midwest Other House type Adults with Kids Middle Income |
| 108 | Rural Midwest Other House type Adults with Kids High Income |
| 109 | Urban Midwest Stand Alone One Adult Low Income |
| 110 | Urban Midwest Stand Alone One Adult Middle Income |
| 111 | Urban Midwest Stand Alone One Adult High Income |
| 112 | Urban Midwest Stand Alone One Adult with Kids Low Income |
| 113 | Urban Midwest Stand Alone One Adult with Kids Middle Income |
| 114 | Urban Midwest Stand Alone One Adult with Kids High Income |
| 115 | Urban Midwest Stand Alone Adults Low Income |
| 116 | Urban Midwest Stand Alone Adults Middle Income |
| 117 | Urban Midwest Stand Alone Adults High Income |
| 118 | Urban Midwest Stand Alone Adults with Kids Low Income |
| 119 | Urban Midwest Stand Alone Adults with Kids Middle Income |
| 120 | Urban Midwest Stand Alone Adults with Kids High Income |
| 121 | Urban Midwest Multi Unit Structure One Adult Low Income |
| 122 | Urban Midwest Multi Unit Structure One Adult Middle Income |
| 123 | Urban Midwest Multi Unit Structure One Adult High Income |
| 124 | Urban Midwest Multi Unit Structure One Adult with Kids Low Income |
| 125 | Urban Midwest Multi Unit Structure One Adult with Kids Middle Income |
| 126 | Urban Midwest Multi Unit Structure One Adult with Kids High Income |
| 127 | Urban Midwest Multi Unit Structure Adults Low Income |
| 128 | Urban Midwest Multi Unit Structure Adults Middle Income |
| 129 | Urban Midwest Multi Unit Structure Adults High Income |
| 130 | Urban Midwest Multi Unit Structure Adults with Kids Low Income |
| 131 | Urban Midwest Multi Unit Structure Adults with Kids Middle Income |
| 132 | Urban Midwest Multi Unit Structure Adults with Kids High Income |
| 133 | Urban Midwest Other House type One Adult Low Income |
| 134 | Urban Midwest Other House type One Adult Middle Income |
| 135 | Urban Midwest Other House type One Adult High Income |
| 136 | Urban Midwest Other House type One Adult with Kids Low Income |
| 137 | Urban Midwest Other House type One Adult with Kids Middle Income |
| 138 | Urban Midwest Other House type One Adult with Kids High Income |
| 139 | Urban Midwest Other House type Adults Low Income |
| 140 | Urban Midwest Other House type Adults Middle Income |
| 141 | Urban Midwest Other House type Adults High Income |
| 142 | Urban Midwest Other House type Adults with Kids Low Income |
| 143 | Urban Midwest Other House type Adults with Kids Middle Income |
| 144 | Urban Midwest Other House type Adults with Kids High Income |
| 145 | Rural South Stand Alone One Adult Low Income |
| 146 | Rural South Stand Alone One Adult Middle Income |
| 147 | Rural South Stand Alone One Adult High Income |
| 148 | Rural South Stand Alone One Adult with Kids Low Income |
| 149 | Rural South Stand Alone One Adult with Kids Middle Income |
| 150 | Rural South Stand Alone One Adult with Kids High Income |
| 151 | Rural South Stand Alone Adults Low Income |
| 152 | Rural South Stand Alone Adults Middle Income |
| 153 | Rural South Stand Alone Adults High Income |
| 154 | Rural South Stand Alone Adults with Kids Low Income |
| 155 | Rural South Stand Alone Adults with Kids Middle Income |
| 156 | Rural South Stand Alone Adults with Kids High Income |
| 157 | Rural South Multi Unit Structure One Adult Low Income |
| 158 | Rural South Multi Unit Structure One Adult Middle Income |
| 159 | Rural South Multi Unit Structure One Adult High Income |
| 160 | Rural South Multi Unit Structure One Adult with Kids Low Income |
| 161 | Rural South Multi Unit Structure One Adult with Kids Middle Income |
| 162 | Rural South Multi Unit Structure One Adult with Kids High Income |
| 163 | Rural South Multi Unit Structure Adults Low Income |
| 164 | Rural South Multi Unit Structure Adults Middle Income |
| 165 | Rural South Multi Unit Structure Adults High Income |
| 166 | Rural South Multi Unit Structure Adults with Kids Low Income |
| 167 | Rural South Multi Unit Structure Adults with Kids Middle Income |
| 168 | Rural South Multi Unit Structure Adults with Kids High Income |
| 169 | Rural South Other House type One Adult Low Income |
| 170 | Rural South Other House type One Adult Middle Income |
| 171 | Rural South Other House type One Adult High Income |
| 172 | Rural South Other House type One Adult with Kids Low Income |
| 173 | Rural South Other House type One Adult with Kids Middle Income |
| 174 | Rural South Other House type One Adult with Kids High Income |
| 175 | Rural South Other House type Adults Low Income |
| 176 | Rural South Other House type Adults Middle Income |
| 177 | Rural South Other House type Adults High Income |
| 178 | Rural South Other House type Adults with Kids Low Income |
| 179 | Rural South Other House type Adults with Kids Middle Income |
| 180 | Rural South Other House type Adults with Kids High Income |
| 181 | Urban South Stand Alone One Adult Low Income |
| 182 | Urban South Stand Alone One Adult Middle Income |
| 183 | Urban South Stand Alone One Adult High Income |
| 184 | Urban South Stand Alone One Adult with Kids Low Income |
| 185 | Urban South Stand Alone One Adult with Kids Middle Income |
| 186 | Urban South Stand Alone One Adult with Kids High Income |
| 187 | Urban South Stand Alone Adults Low Income |
| 188 | Urban South Stand Alone Adults Middle Income |
| 189 | Urban South Stand Alone Adults High Income |
| 190 | Urban South Stand Alone Adults with Kids Low Income |
| 191 | Urban South Stand Alone Adults with Kids Middle Income |
| 192 | Urban South Stand Alone Adults with Kids High Income |
| 193 | Urban South Multi Unit Structure One Adult Low Income |
| 194 | Urban South Multi Unit Structure One Adult Middle Income |
| 195 | Urban South Multi Unit Structure One Adult High Income |
| 196 | Urban South Multi Unit Structure One Adult with Kids Low Income |
| 197 | Urban South Multi Unit Structure One Adult with Kids Middle Income |
| 198 | Urban South Multi Unit Structure One Adult with Kids High Income |
| 199 | Urban South Multi Unit Structure Adults Low Income |
| 200 | Urban South Multi Unit Structure Adults Middle Income |
| 201 | Urban South Multi Unit Structure Adults High Income |
| 202 | Urban South Multi Unit Structure Adults with Kids Low Income |
| 203 | Urban South Multi Unit Structure Adults with Kids Middle Income |
| 204 | Urban South Multi Unit Structure Adults with Kids High Income |
| 205 | Urban South Other House type One Adult Low Income |
| 206 | Urban South Other House type One Adult Middle Income |
| 207 | Urban South Other House type One Adult High Income |
| 208 | Urban South Other House type One Adult with Kids Low Income |
| 209 | Urban South Other House type One Adult with Kids Middle Income |
| 210 | Urban South Other House type One Adult with Kids High Income |
| 211 | Urban South Other House type Adults Low Income |
| 212 | Urban South Other House type Adults Middle Income |
| 213 | Urban South Other House type Adults High Income |
| 214 | Urban South Other House type Adults with Kids Low Income |
| 215 | Urban South Other House type Adults with Kids Middle Income |
| 216 | Urban South Other House type Adults with Kids High Income |
| 217 | Rural West Stand Alone One Adult Low Income |
| 218 | Rural West Stand Alone One Adult Middle Income |
| 219 | Rural West Stand Alone One Adult High Income |
| 220 | Rural West Stand Alone One Adult with Kids Low Income |
| 221 | Rural West Stand Alone One Adult with Kids Middle Income |
| 222 | Rural West Stand Alone One Adult with Kids High Income |
| 223 | Rural West Stand Alone Adults Low Income |
| 224 | Rural West Stand Alone Adults Middle Income |
| 225 | Rural West Stand Alone Adults High Income |
| 226 | Rural West Stand Alone Adults with Kids Low Income |
| 227 | Rural West Stand Alone Adults with Kids Middle Income |
| 228 | Rural West Stand Alone Adults with Kids High Income |
| 229 | Rural West Multi Unit Structure One Adult Low Income |
| 230 | Rural West Multi Unit Structure One Adult Middle Income |
| 231 | Rural West Multi Unit Structure One Adult High Income |
| 232 | Rural West Multi Unit Structure One Adult with Kids Low Income |
| 233 | Rural West Multi Unit Structure One Adult with Kids Middle Income |
| 234 | Rural West Multi Unit Structure One Adult with Kids High Income |
| 235 | Rural West Multi Unit Structure Adults Low Income |
| 236 | Rural West Multi Unit Structure Adults Middle Income |
| 237 | Rural West Multi Unit Structure Adults High Income |
| 238 | Rural West Multi Unit Structure Adults with Kids Low Income |
| 239 | Rural West Multi Unit Structure Adults with Kids Middle Income |
| 240 | Rural West Multi Unit Structure Adults with Kids High Income |
| 241 | Rural West Other House type One Adult Low Income |
| 242 | Rural West Other House type One Adult Middle Income |
| 243 | Rural West Other House type One Adult High Income |
| 244 | Rural West Other House type One Adult with Kids Low Income |
| 245 | Rural West Other House type One Adult with Kids Middle Income |
| 246 | Rural West Other House type One Adult with Kids High Income |
| 247 | Rural West Other House type Adults Low Income |
| 248 | Rural West Other House type Adults Middle Income |
| 249 | Rural West Other House type Adults High Income |
| 250 | Rural West Other House type Adults with Kids Low Income |
| 251 | Rural West Other House type Adults with Kids Middle Income |
| 252 | Rural West Other House type Adults with Kids High Income |
| 253 | Urban West Stand Alone One Adult Low Income |
| 254 | Urban West Stand Alone One Adult Middle Income |
| 255 | Urban West Stand Alone One Adult High Income |
| 256 | Urban West Stand Alone One Adult with Kids Low Income |
| 257 | Urban West Stand Alone One Adult with Kids Middle Income |
| 258 | Urban West Stand Alone One Adult with Kids High Income |
| 259 | Urban West Stand Alone Adults Low Income |
| 260 | Urban West Stand Alone Adults Middle Income |
| 261 | Urban West Stand Alone Adults High Income |
| 262 | Urban West Stand Alone Adults with Kids Low Income |
| 263 | Urban West Stand Alone Adults with Kids Middle Income |
| 264 | Urban West Stand Alone Adults with Kids High Income |
| 265 | Urban West Multi Unit Structure One Adult Low Income |
| 266 | Urban West Multi Unit Structure One Adult Middle Income |
| 267 | Urban West Multi Unit Structure One Adult High Income |
| 268 | Urban West Multi Unit Structure One Adult with Kids Low Income |
| 269 | Urban West Multi Unit Structure One Adult with Kids Middle Income |
| 270 | Urban West Multi Unit Structure One Adult with Kids High Income |
| 271 | Urban West Multi Unit Structure Adults Low Income |
| 272 | Urban West Multi Unit Structure Adults Middle Income |
| 273 | Urban West Multi Unit Structure Adults High Income |
| 274 | Urban West Multi Unit Structure Adults with Kids Low Income |
| 275 | Urban West Multi Unit Structure Adults with Kids Middle Income |
| 276 | Urban West Multi Unit Structure Adults with Kids High Income |
| 277 | Urban West Other House type One Adult Low Income |
| 278 | Urban West Other House type One Adult Middle Income |
| 279 | Urban West Other House type One Adult High Income |
| 280 | Urban West Other House type One Adult with Kids Low Income |
| 281 | Urban West Other House type One Adult with Kids Middle Income |
| 282 | Urban West Other House type One Adult with Kids High Income |
| 283 | Urban West Other House type Adults Low Income |
| 284 | Urban West Other House type Adults Middle Income |
| 285 | Urban West Other House type Adults High Income |
| 286 | Urban West Other House type Adults with Kids Low Income |
| 287 | Urban West Other House type Adults with Kids Middle Income |
| 288 | Urban West Other House type Adults with Kids High Income |

Appendix C: FIPS and Region Codes for RPGen Input

|  |  |  |
| --- | --- | --- |
| **State name** | **FIPS code** | **Region code** |
| Alabama | 01 | 3 |
| Alaska | 02 | 4 |
| Arizona | 04 | 4 |
| Arkansas | 05 | 3 |
| California | 06 | 4 |
| Colorado | 08 | 4 |
| Connecticut | 09 | 1 |
| Delaware | 10 | 3 |
| District of Columbia | 11 | 3 |
| Florida | 12 | 3 |
| Georgia | 13 | 3 |
| Hawaii | 15 | 4 |
| Idaho | 16 | 4 |
| Illinois | 17 | 2 |
| Indiana | 18 | 2 |
| Iowa | 19 | 2 |
| Kansas | 20 | 2 |
| Kentucky | 21 | 3 |
| Louisiana | 22 | 3 |
| Maine | 23 | 1 |
| Maryland | 24 | 3 |
| Massachusetts | 25 | 1 |
| Michigan | 26 | 2 |
| Minnesota | 27 | 2 |
| Mississippi | 28 | 3 |
| Missouri | 29 | 2 |
| Montana | 30 | 4 |
| Nebraska | 31 | 2 |
| Nevada | 32 | 4 |
| New Hampshire | 33 | 1 |
| New Jersey | 34 | 1 |
| New Mexico | 35 | 4 |
| New York | 36 | 1 |
| North Carolina | 37 | 3 |
| North Dakota | 38 | 2 |
| Ohio | 39 | 2 |
| Oklahoma | 40 | 3 |
| Oregon | 41 | 4 |
| Pennsylvania | 42 | 1 |
| Rhode Island | 44 | 1 |
| South Carolina | 45 | 3 |
| South Dakota | 46 | 2 |
| Tennessee | 47 | 3 |
| Texas | 48 | 3 |
| Utah | 49 | 4 |
| Vermont | 50 | 1 |
| Virginia | 51 | 3 |
| Washington | 53 | 4 |
| West Virginia | 54 | 3 |
| Wisconsin | 55 | 2 |
| Wyoming | 56 | 4 |

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