# The Residential Population Generator (RPGen) - parametrization of residential, demographic, and physiological data to model intraindividual exposure, dose, and risk.

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***Abstract:*** The Residential Population Generator (RPGen) creates a population for use in intraindividual probabilistic models of exposure and dose by appending datasets. To do this, two requirements should be considered: the set of inputs used for an individual must be internally consistent (reflect data that could come from a single individual); and the variation in the data sets across individuals should be representative of variation among individuals in the modeled population. RPGen meets these requirements by creating synthetic populations with demographic, residential, and physiological characteristics. A database of modeled individuals is created by linking data from US census and US housing surveys with physiological characteristics from the National Health and Nutrition Examination Survey data. The final modeled population data parameters include characteristics of the individual's community residence demographics, and physiology. RPGen output can be used to support user-developed chemical exposure models that estimate intraindividual exposure in a desired population. By creating profiles and characteristics that determine exposure, RPGen allows modelers to generate data-driven populations and identify those potentially vulnerable to chemical exposures.

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## Background

EPA's Office of Research and Development is developing the Combined Human Exposure Model (CHEM) to characterize chemicals exposures that occur as a result of the use of consumer products and support lifecycle impact assessments (Csiszar et al., 2016). In CHEM, individual exposure is characterized by the residence, activities, and concentration of chemicals in products. These three elements are handled in the Residential Population Generator (RPGen), Product Use Scheduler (PUS) and Source-to-Dose (S2D) respectively. As the first module, RPGen creates internally consistent records with demographic, housing, residential, and physiological data. In total, RPGen contains 126 characteristics, with records varying by age, gender, income and region, which reflect interindividual variability in exposure-related parameters. In CHEM, these parameters inform patterns of use in the Product Use Scheduler, but RPGen is transferrable to other models, tools, and dashboards. RPGen output informs the exposome, providing physiological variables and residential characteristics that characterize activities undertaken. By creating a consistent, granular population, RPGen creates an informative component for models of exposure, dose, and risk.

## Methods

No single survey contains all parameters required for characterizing individuals in RPGen. Therefore, three surveys are linked using similar variables: the Residential Energy Consumption Survey (RECS), the American Housing Survey (AHS), and the Public Use Microdata Survey (PUMS). Additionally, the R Package *httk* (Pearce et al. 2017; Ring et al., 2017) is called, which generates physiological traits based on age and ethnicity inputs from PUMS. Data is updated manually as needed in the RPGen GitHub repository. Each input in Table 1 provides a different component to the population: RECS describes the residence, parameters in AHS describe the household, PUMS variables contain demographics, and NHANES data informs the physiological variables. Examples of variables from RPGen records are visible in Tables 3-6.

**Table 1. Data sets used in this version of the RPGen. Note: NHANES data derived from EPA's *httk*.**

| Survey | Source | Date of Data Collection | Number of Records |
|---|---|---|---|
| Residential Energy Consumption Survey (RECS) | US Energy Information Association: https://www.eia.gov/consumption/residential/data/2015/ | 2015 | 5,686 |
| American Housing Survey (AHS) | US Census Bureau: https://www.census.gov/programs-surveys/ahs/data.html | 2017 | 57,972 |
| Public Use Microdata Survey (PUMS) | US Census Bureau: https://www.census.gov/programs-surveys/acs/data/pums.html | 2014-2018 | 15,094,428 |
| National Health and Nutrition Examination Survey (NHANES) | US CDC: https://wwwn.cdc.gov/nchs/nhanes/Default.aspx | 2007-2008, 2009-2010, 2011-2012 | 24,546 |

Records are linked using similar parameters in each dataset. For this reason, both the 'person' and 'housing' versions of PUMS are imported into RPGen. A *pool* variable is created, with 288 possibilities, matching households from RECS and AHS with individuals in PUMS (Table 2).

**Table 2. Assembly of 288 Possible Household Bins (*pool*).**

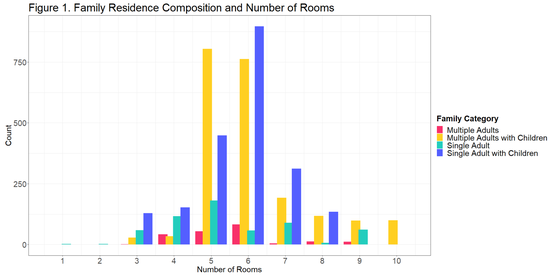
| Setting | Region | House Type | Family Category | Income Category |
|---|---|---|---|---|
| Urban | Northeast | Stand Alone | 1 Adult, 0 Children | 1 |
| Rural | Midwest | Multi Structure | 2+ Adults, 0 Children | 2 |
| | South | Other | 1 Adult, 1+ Children | 3 |
| | West | | 2+ Adults, 1+ Children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

*Location* is determined by crossing an either *rural* or *urban* setting with one of four US regions. Houses are grouped as stand-alone, multi-structure (e.g. apartments and condominiums), or other (e.g. mobile homes). Family category depends on the number of adults and children in the household, as co-inhabitants inform interindividual exposure. Income category rank is calculated for each of the eight *location* outcomes, as purchasing power varies between *setting* and *region*. When running RPGen, the user selects the number of individuals, demographics, age ranges, states, and a seed value for replicability.

## RPGen Results for 5,000 Individuals

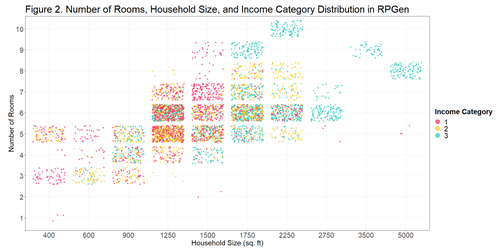
A nationwide sample run with all genders, ethnicities, and ages with 5,000 individuals was performed to illustrate the population generated by RPGen. Creation of a household is imperative in modeling interindividual exposure, or exposure between individuals. Therefore, family category serves as an input to *pool* as well as a descriptor of residences. As visualized in Figure 1, distributions of family category vary across the number of rooms.

Figure 1. Family Residence Composition and Number of Rooms



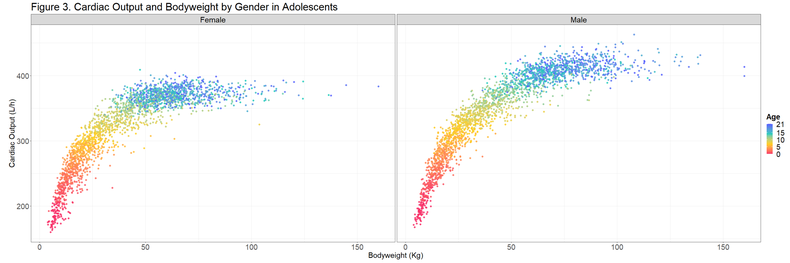

The largest households, with the greatest number of rooms, are occupied by those in the highest income category (Figure 2). Points in Figure 2 are jittered to show the density of each household size and number of room outcome, representing the likelihood of each occurrence. More 6 room 1250 square foot residences were generated than any other pairing.

Figure 2. Number of Rooms, Household Size, and Income Category Distribution in RPGen




As children have been identified as a particularly vulnerable subgroup (Egeghy et al., 2011), another sample run of 5,000 individuals was performed with ages restricted between 0 and 21. The distributions of bodyweight against cardiac output are different between males and females, and this is captured in RPGen (Figure 3). A random element is applied to physiological variables from *httk* to create the variation in Figure 3.

Figure 3. Cardiac Output and Bodyweight by Gender in Adolescents




## RPGen Output for Four Individuals

Tables 3-6 present selected parameters from RPGen records for four example individuals of different ages and genders living in different types of homes, in different portions of the country, with different family categories. Data are color coded to reflect the survey that provides the data. PUMS–red, httk–yellow, AHS–teal, and RECS–purple.

**Table 3. Sample of variables describing demographics (PUMS)**

| Individual | Age (Years) | Age (Months) | State | Race | Gender | Household Income | Genders, Ages of co-inhabitants |
|---|---|---|---|---|---|---|---|
| Infant | 0 | 7 | Florida | White | Female | N/A | Male, 2, Female, 47, Male, 53 |
| Teen | 16 | 65 | Mass. | Black | Female | N/A | Male, 15 Female, 45, Male, 45 |
| Adult | 47 | 564 | Arkansas | White | Male | $ 75,000 | Male 70, Female, 41 |
| Older Adult | 78 | 909 | Illinois | Asian | Male | $ 2,000 | Female, 70 |

**Table 4. Sample of generated physiological variables (*httk*)**

| Individual | Bodyweight (kg) | Height (cm) | Body Surface Area (cm²) | Cardiac Output (L/h) | Liver Blood Flow (L/h) | Serum Creatinine (mg/dL) |
|---|---|---|---|---|---|---|
| Infant | 3.97 | 65 | 2670 | 121 | 2.09 | N/A |
| Teen | 74.5 | 168 | 18800 | 248 | 54.1 | 0.64 |
| Adult | 78.1 | 178 | 19600 | 268 | 51.2 | 1.24 |
| Older Adult | 64.3 | 173 | 17600 | 227 | 48.8 | 1.14 |

**Table 5. Sample of variables describing appliances (RECS)**

| Individual | Dish Washer | Washing Machine | Dryer | Loads washed per week | Outdoor Grill | Ceiling Fans | Televisions |
|---|---|---|---|---|---|---|---|
| Infant | Yes | Yes | Yes | 4 | Yes | 3 | 3 |
| Teen | No | Yes | Yes | 6 | Yes | 0 | 2 |
| Adult | Yes | Yes | Yes | 7 | Yes | 2 | 3 |
| Older Adult | No | No | No | 0 | No | 3 | 2 |

**Table 6. Sample of variables describing residence (AHS, RECS, PUMS)**

| Individual | Size of Unit (ft²) | Number of Rooms | Garage | Cellar | Stories | Windows | Cars |
|---|---|---|---|---|---|---|---|
| Infant | 1250 | 7 | N/A | N/A | N/A | 3 to 5 | 1 |
| Teen | 1250 | 6 | 0 | 0 | 2 | 10 to 15 | 2 |
| Adult | 2750 | 7 | 1 | 1 | 1 | 10 to 15 | 3 |
| Older Adult | 600 | 5 | N/A | N/A | N/A | 6 to 9 | 2 |

## Discussion

RPGen output can be combined with a wide range of user-developed chemical exposure scenarios to estimate intraindividual exposure in a desired population. However, as RPGen was designed as a module in CHEM, a model for consumer products, only breathing rates (inhalation) and skin surface area (dermal) are included. Therefore, parameters that describe the ingestion of liquids and diet constructions are not included in RPGen. Furthermore, households are matched in eight possible location bins across the contiguous US. Therefore, households lack the geographic resolution that are afforded to individuals, as each PUMS record has as assigned Public Use Microdata Area (PUMA). Nevertheless, the pooled RPGen profiles offer increased granularity when compared with point estimates of exposure factors or distributions of exposure factors. This is due to RPGen's ability to define the exposome for each unique individual as opposed to assuming a collection of probabilistic exposure outcomes. The benefits are twofold: first, chemical exposure predictions to are informed by the correlated physiological, demographic, and housing variables within RPGen. Grouping of these variables into profiles improve the exposure estimates of individuals. Secondary benefit comes from the same variables: age, ethnicity, income, and location allow for comparison with dose outcomes to determine high risk subpopulations and communities.

## References

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