README: GHHP – Final Energy Demand Calculator

Overview

GHHP – Final-Energy-Demand Calculator is an `R`-based tool that extends the German Heating and Housing Panel (GHHP) by providing building-level estimates of energy performance. Using GHHP data on key building characteristics – such as construction period, past retrofits, and installed heating and hot-water systems – the application estimates, for each panel observation, the final energy demand (kWh/m^{2}a) and the corresponding reference annual heating costs (€/year). Final energy demand represents the amount of energy required to heat a dwelling and supply hot water under standardized conditions, making it a central indicator of a building's energy efficiency.

The estimation procedure follows the established *Kurzverfahren Energieprofil* developed by Loga et al. (2005). Default parameter tables – such as envelope U-values, window G-values, climate coefficients, system loss and credit factors, and energy-carrier prices – are included but can be modified by users to test alternative assumptions or price scenarios. By linking an engineering model with representative survey data, *GHHP – Final-Energy-Demand Calculator* enables a consistent assessment of energy efficiency both at the household level and across the German residential building stock. In doing so, it provides valuable evidence for designing policies to decarbonize the building sector.

Data Requirements and Sources

Input data from the German Heating and Housing Panel (GHHP) are available under a Creative Commons Non-Commercial license. Access is granted exclusively for scientific, non-commercial research purposes to researchers affiliated with academic institutions and requires a signed data use agreement, which can be obtained through the FDZ Ruhr.

Currently, Wave 1 (2021) and Wave 2 (2022) are available for scientific use. Both can be accessed free of charge via the FDZ Ruhr at RWI as Scientific Use Files. Each wave consists of two separate datasets: *Building Characteristics* and *Socioeconomic Characteristics and Experiments*.[1] The specific input files required for running the tool on the first two waves of the GHHP are listed in Table 1. To complete the setup, users should place these files in the folder `01 Raw/` of the project directory.

Rights Statement

☒ The authors of this manuscript confirm they have lawful access to the data used herein and permission to use them.

Data License

Data are provided under a Creative Commons Non-Commercial license.

[1] The data can be requested via: https://www.rwi-essen.de/forschung-beratung/weitere/forschungsdatenzentrum-ruhr/datenangebot/waerme-und-wohnen-panel.

Table 1: GHHP Input Files

File Name	Source
`ariadne_panel1_buildingchars_eng_update24.dta`	Frondel et al. (2023a)
`ariadne_panel1_experiments_eng_update24.dta`	Frondel et al. (2023b)
`ariadne_panel2_buildingchars_eng.dta`	Frondel et al. (2025a)
`ariadne_panel2_experiments_eng.dta`	Frondel et al. (2025b)

Note: Users must obtain these datasets from the FDZ Ruhr and place the downloaded files in the directory `01_Raw/` before running the tool.

Availability Summary

☒ All data are publicly accessible (subject to the scientific-use access procedure described above).

System Requirements

Installation & Setup

To run the package, ensure that the following software components are installed on your system:

(a) `R` (4.3.3 or newer)

- Download from the CRAN website: `https://cran.r-project.org/`.
- Choose the version appropriate for your operating system.

(b) *RStudio* (or similar IDE for `R`)

- After installing `R`, download RStudio Desktop: `https://posit.co/download/rstudio-desktop/`.
- Select the installer for your operating system.

Additional Learning Resources

- RStudio Education learning paths: `https://education.rstudio.com/learn/#paths`
- *ModernDive* (intro to `R` and data analysis): `https://moderndive.netlify.app/1-getting-started.html`

Memory and Runtime

Summary. Expected end-to-end runtime on a standard 2024 desktop:

☒ $<$ 10 minutes

Details. Last tested on a 6-core Intel i5-8500 (Windows 11 Pro 23H2). Total computation time: 1:20 minutes.

Replication Guide

This section explains how you can run the interactive `App.R` interface to calculate final energy `ebj` and energy costs `kdj` for observations in the GHHP.

Data access and placement

- Obtain the raw survey files listed in Table 1. The GHHP files are archived at the FDZ Ruhr at RWI. See: https://www.rwi-essen.de/forschung-beratung/weitere/forschungsdatenzentrum-ruhr/datenangebot/waerme-und-wohnen-panel. Data are available for wave 1 (2021) and wave 2 (2022).
- Place the downloaded **raw** `.dta` files in `01 Raw/` *without* renaming.
- The parameter Excel files (U-values, window U/g-values, climate coefficients, energy prices, system loss/credit tables, and imputation rules) should be in `02 Parameter/`. Default files are provided and can be replaced/adjusted if needed.

Running the calculations via `App.R`

1. Open `App.R` in R (e.g., RStudio) and click *Run App*. On first launch, the app will install any missing CRAN packages.
2. In the left sidebar, verify the detected *Project root folder*. This should be the directory that directly contains `App.R`.
3. Click **Validate Setup**. The status log will confirm that all subfolders and required scripts are present. Any issues will be listed in the terminal.
4. Select the **Data wave**:
   - `Wave 1 (panel1)` or `Wave 2 (panel2)`. The app will auto-point to the corresponding `.dta` files in `01 Raw/`.
5. (Optional) Adjust **Parameter files**. The text inputs under *Parameter files* accept relative paths (from the project root) or absolute paths to the Excel files in `02 Parameter/`.
6. (Optional) Check **Run missing imputation**. If checked, `01_WuW_Data.R` will apply rule-based replacements using the specified rules in `Fehlende Werte.xlsx`. Missing values (coded as -1 'don't know' or -2 'not asked') were replaced using the most frequent response from Wave 1.
7. Click **Run Pipeline**. The app will calculate final energy `ebj`, costs `kdj` for each observation in specified wave.
8. When complete, the status will show *Run completed*. You can then:
   - **Preview Result:** inspect the first rows of the output.
   - **Histogram:** view the distribution of `ebj` with a summary (N, min/median/mean/max).
   - **Download Result as CSV:** export the full result table.

Outputs

- The main result is written to `05 Final Results/Result_File.dta`. This contains final energy demand for hot water and space heating (`ebj_ww`, `ebj_rh`), their sum (`ebj`), and annual cost estimates (`kdj`).
- Intermediate outputs are saved in `04 Intermediate Results/` for reproducibility and diagnostics (see script descriptions).

Tips and troubleshooting

- If **Validate Setup** flags missing items, confirm the project root path points to the folder that contains the required subfolders and that script names match exactly.
- If you enable *Run missing imputation*, ensure the imputation rules file are readable (`.xlsx`/`.xls`).
- Keep original file names for the GHHP `.dta` inputs; the app relies on the wave-based naming convention.

Description of the `R` Scripts

The folder `/03 R Code` contains separate files for each step of the estimation pipeline. Users don't need to access or change any files in this folder to execute the pipeline (this can be done through `App.R`). The folder is structured as follows: The script `00_Master_File.R` sets the working directory to the project root, defines the global base path `user`, loads packages, sets data and parameter paths and global flags, and then executes the following five scripts:

- `01_WuW_Data.R` Loads and preprocesses GHHP data, keeping key identifiers and relevant variables. It adjusts labels, and (optionally) applies rule-based imputations. It derives heated area, accounts for previous retrofits, filters implausible records, and saves a clean data set.
- `02_Individual_Parameters.R` Imports all engineering and price parameter tables from the files in `02 Parameters`, reshaping them into "look-up" formats keyed by construction type, age class, and building size. Parameters include envelope U-values (by component and period), window U- and g-values, climate coefficients, producer-effort factors, distribution and storage losses as well as credits, and auxiliary electricity needs. The consolidated parameter store is saved.
- `03_System_Technology.R` Defines system-technology codes for space heating (`H*`) and domestic hot water (`W*`). It classifies heat transfer (`Hce`), distribution (`Hd`/`Wd`), storage (`Hs`/`Ws`), generation stages (`Hg1`, `Hg2`, `Wg1`, `Wg2`), and primary energy carriers (`Rhet1`, `WWet1`). Equipment age, building year, and reported retrofits determine efficiency classes and suffixes. The resulting technology map is stored.
- `04_Building_Balance_Sheet.R` Computes the building heat balance and heating requirement. Using the cleaned data and parameter tables, it derives surface areas of the building envelope, selects U/g-values by construction year and past retrofits. It then calculates component-wise transmission losses, ventilation losses, and an efficiency index h that links to climate coefficients. Heating demand per energy reference area q_H is derived and saved.
- `05_System_Balance_Sheet.R` Aggregates building heating/hot water demand and system parameters to final energy. It combines useful heat, distribution/storage losses, heating credits, producer-effort factors, climate scaling, and auxiliary electricity to obtain final energy for hot water and heating services and their sum (saved in `ebj`). It also prices energy carriers to compute approximate annual costs (`kdj`). Results are exported to `05 Final Results` as `Result_File.dta`.

Variable Overview

The following table lists the GHHP variables used to compute final energy demand. These are contained in the files *GHHP — Building Characteristics* and *GHHP — Experiment Data*.

Table 2: Survey Variables Used in the Energy Demand Calculation

Variable Name	**Description**
Ist1	Adjacent buildings
Ist2	Building layout / floor plan
Ist3_num	Number of housing units
Ist4_num	Number of stories
Ist5_num	Heated living area (household)
Ist5a_num	Heated living area (entire building, for apartments)
Ist6	Year of construction
Ist7_1a	Degree of heating in the attic
Ist7_1b	Presence of dormers
Ist8	Degree of heating in the basement
Ist9_1	Roof construction type
Ist9_2	Construction type of top floor ceiling
Ist9_3	Exterior wall construction type
Ist9_4	Construction type of basement ceiling / floor toward ground
Ist10	Year of window installation
Ist11	Type of window glazing
Ist12	Primary heating system
Ist12_1a	Fuel type of heating system
Ist12_2a	Type of heat generation (heat pump)
Ist12_2b	Heat source (heat pump)
Ist12_3a	Heat supply (district heating)
Ist12_5a	Space heating system type
Ist13	Year of commissioning of the heating system
Ist13a	Insulation of heating distribution pipes
Ist13a_1	Year of insulation of heating distribution pipes
Ist14	Domestic hot water system type
Ist14a	Year of commissioning of hot water system
Ist14b	Hot water circulation system
Ist14c	Insulation of hot water pipes
Ist15_1	Insulation level of roof
Ist15_2	Insulation level of top floor ceiling
Ist15_3	Insulation level of exterior walls
Ist15_4	Insulation level of basement ceiling / floor toward ground
Ist16a_2	Use of solar thermal system
san1a_1a	Comprehensive KfW subsidy received
san1a_13_2	KfW subsidy for roof insulation
san1a_23_2	KfW subsidy for top floor / ceiling insulation
san1a_33_2	KfW subsidy for exterior wall insulation
san1a_43_2	KfW subsidy for basement / ground floor insulation
san1a_11	Year of roof insulation
san1a_21	Year of top floor / ceiling insulation
san1a_31	Year of exterior wall insulation
san1a_41	Year of basement / ground floor insulation

Note: These variables are required inputs from the GHHP survey data for running the `Endenergiebedarfe` package.

Parameter and Results Catalog

The following tables summarize parameters as well as intermediate and final outputs, including short descriptions, units (where applicable), and the script in which they are used.

Table 3: **Parameters Used in the Energy Demand Calculation**

Variable Name	Description	Unit	R Script
kfwEM_roo	KfW subsidy for roof insulation	Binary (1 = subsidy received)	2,4
kfwEM_tf	KfW subsidy for top floor ceiling insulation	Binary (1 = subsidy received)	2,4
kfwEM_ext	KfW subsidy for exterior wall insulation	Binary (1 = subsidy received)	2,4
kfwEM_base	KfW subsidy for basement and ground floor insulation	Binary (1 = subsidy received)	2,4
kfwEH	KfW subsidy for complete retrofit	Binary (1 = subsidy received)	2,4
q_Fa	Façade area coefficient		4
p_Fa	Façade area coefficient (by floor plan)		4
f_TBDG	Partial heating factor for attic (pitched roof)		4
p_Da	Roof area coefficient for pitched roofs		4
p_OG	Top floor area coefficient		4
f_Ga	Correction factor for dormers		4
f_TBKG	Partial heating factor for basement floor		4
f_L	Air volume factor		4
f_DDa	Insulation level of roof	Fraction (0–1)	4
f_DOG	Insulation level of top floor ceiling	Fraction (0–1)	4
f_DAW	Insulation level of exterior walls	Fraction (0–1)	4
f_DFB	Insulation level of basement / ground floor	Fraction (0–1)	4
ins_roof	Added insulation thickness (roof)	cm	4
u_roof_min	Minimum technical requirement (roof U-value)	W/m^2K	4
u_roof_ref	Reference U-value (roof)	W/m^2K	4
ins_uf	Added insulation thickness (top floor)	cm	4
u_uf_min	Minimum technical requirement (top floor ceiling U-value)	W/m^2K	4
u_uf_ref	Reference U-value (top floor ceiling)	W/m^2K	4
ins_wall	Added insulation thickness (exterior wall)	cm	4
u_wall_min	Minimum technical requirement (exterior wall U-value)	W/m^2K	4
u_wall_ref	Reference U-value (exterior wall)	W/m^2K	4
ins_floor	Added insulation thickness (floor)	cm	4

Table 3: **Parameters Used in the Energy Demand Calculation (continued)**

Variable Name	Description	Unit	R Script
u_floor_min	Minimum technical requirement (floor U-value)	W/m^2K	4
u_floor_ref	Reference U-value (floor)	W/m^2K	4
p_fb	Floor area parameter		4
p_fe	Window surface parameter		4
Ft_OG	Reduction factor for top floor		4
Ft_AW	Reduction factor for exterior wall against ground		4
Ft_FB	Reduction factor for lowest floor		4
U_WBZ	U-value for thermal bridge losses		4
theta_Soll	Target indoor temperature	°C	4
f_z	Reduction factor for intermittent heating		4
f_r	Reduction factor for partial heating		4
f_n	Utilization factor		4
eta_G	Heating system efficiency		4
u_io	Original U-value (by year of construction), $i = \{\text{Da, OG, AW, FB}\}$		4
u_iKFW	U-value adjusted for KfW subsidy, $i = \{\text{Da, OG, AW, FB}\}$		4
u_iI	Initialized U-values where no standard assumption is possible, $i = \{\text{Da, OG, AW, FB}\}$		4
q_w	Useful heat demand	$kWh/(m^2a)$	5
q_wd	Heat loss through distribution	$kWh/(m^2a)$	5
q_ws	Heat loss through storage	$kWh/(m^2a)$	5
alpha_wg1	Generator 1 coverage share (domestic hot water)		5
e_wg1	Generator effort factor 1 (domestic hot water)		5
alpha_wg2	Generator 2 coverage share (domestic hot water)		5
e_wg2	Generator effort factor 2 (domestic hot water)		5
q_wdhe	Auxiliary energy for hot water distribution	$kWh/(m^2a)$	5
q_wshe	Auxiliary energy for hot water storage	$kWh/(m^2a)$	5
q_wghe1	Electricity demand of hot water generator 1	$kWh/(m^2a)$	5
q_wghe2	Electricity demand of hot water generator 2	$kWh/(m^2a)$	5
q_hwd	Distribution heat loss (credited to heating)	$kWh/(m^2a)$	5
q_hws	Storage heat loss (credited to heating)	$kWh/(m^2a)$	5
q_hce	Heat loss from heat emission	$kWh/(m^2a)$	5
q_hd	Heat loss from heat distribution	$kWh/(m^2a)$	5
q_hs	Heat loss from heat storage	$kWh/(m^2a)$	5
f_HP	Correction factor for heating period		5
alpha_hg1	Generator 1 coverage share (space heating)		5
e_hg1	Generator effort factor 1 (space heating)		5
alpha_hg2	Generator 2 coverage share (space heating)		5

Table 3: **Parameters Used in the Energy Demand Calculation (continued)**

Variable Name	**Description**	**Unit**	**R Script**
e_hg2	Generator effort factor 2 (space heating)		5
q_hcehe	Electricity demand for heat emission	kWh/(m^2a)	5
q_hdhe	Electricity demand for heat distribution	kWh/(m^2a)	5
q_hshe	Electricity demand for heat storage	kWh/(m^2a)	5
q_hghe1	Electricity demand of heating generator 1	kWh/(m^2a)	5
q_hghe2	Electricity demand of heating generator 2	kWh/(m^2a)	5
p_wwet1	Energy price: domestic hot water generator 1	€	5
p_rhet1	Energy price: space heating generator 1	€	5

Note: These are parameters, which are constructed based on the input data, used during the estimation process of the `Endenergiebedarfe` package.

Table 4: **Intermediate Calculation Variables**

Variable Name	Description	Unit	R Script
n_G	Number of heated floors		4
A_HS	Area of heated floor(s)	m^2	4
A_FB	Area of lowest heated floor	m^2	4
A_Da	Roof area	m^2	4
A_OG	Top floor area	m^2	4
A_Fe	Window area	m^2	4
A_AWK	Exterior wall area against ground	m^2	4
A_AW	Exterior wall area	m^2	4
A_tH	Total building envelope area	m^2	4
A_EB	Energy reference area (heated floor area)	m^2	4
V_L	Air volume of heated space	m^3	4
H_TDa	Transmission heat loss through roof	W/K	4
H_TOG	Transmission heat loss through top floor ceiling	W/K	4
H_TAW	Transmission heat loss through exterior walls	W/K	4
H_TAWK	Transmission heat loss through exterior walls against ground	W/K	4
H_TFB	Transmission heat loss through lowest floor	W/K	4
H_TFe	Transmission heat loss through windows	W/K	4
H_TWBZ	Heat loss due to thermal bridges	W/K	4
H_T	Total transmission heat loss	W/K	4
H_V	Ventilation heat loss	W/K	4
f_GT	Degree-day factor	kKh/a	4
Q_L	Total heat loss	kWh/a	4
Q_S	Solar heat gain	kWh/a	4
Q_I	Internal heat sources	kWh/a	4
q_h	Space heating demand (per reference area)	kWh/(m^2a)	4

Table 4: **Intermediate Calculation Variables (continued)**

Variable Name	**Description**	**Unit**	**R Script**
q_wstar	Total heat demand for domestic hot water (DHW)	kWh/(m^{2}a)	5
q_ew1	Final energy demand for DHW, generator 1 (without auxiliary energy)	kWh/a	5
q_ew2	Final energy demand for DHW, generator 2 (without auxiliary energy)	kWh/a	5
q_hew	Total auxiliary energy demand for DHW	kWh/a	5
q_ww	Total final energy demand for DHW (heat + auxiliary)	kWh/a	5
q_hw	Credited heat gains (from DHW)	kWh/(m^{2}a)	5
q_hstar	Total heat demand for space heating	kWh/(m^{2}a)	5
q_eh1	Final energy demand for space heating, generator 1 (without auxiliary energy)	kWh/a	5
q_eh2	Final energy demand for space heating, generator 2 (without auxiliary energy)	kWh/a	5
q_heh	Total auxiliary energy demand for space heating	kWh/a	5
q_rh	Total final energy demand for space heating (heat + auxiliary)	kWh/a	5
p_wwet1	Energy price for DHW generator 1	€	5
K_ww	Total cost of domestic hot water supply	€	5
p_rhet1	Energy price for space heating generator 1	€	5
K_rh	Total cost of space heating	€	5

Note: These variables are created during the calculation process within the `Endenergiebedarfe` package.

Table 5: **Final Output Variables**

Variable Name	Description	Unit	R Script
nbj	Useful heat requirement	kWh/(m^{2}a)	5
ebj_ww	Final energy demand for domestic hot water	kWh/(m^{2}a)	5
ebj_rh	Final energy demand for space heating	kWh/(m^{2}a)	5
ebj	Total final energy demand	kWh/(m^{2}a)	5
kdj	Annual total energy costs	€/a	5

Note: These variables are attached to the input data in the final results file generated by the `Endenergiebedarfe` package.

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