

TECHNICAL SPECIFICATION

BER Automation

AI Vision & Geospatial Pipeline for Automated Building Energy Rating Estimation

Version 2.0 • July 2026

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Developed within the CIRCUS project (Interreg North-West Europe)

Python 3.13

Pydantic v2

Claude Vision

OpenCV

Streamlit

8 Countries

1. Overview

1.1 Purpose

BER Automation estimates a **Building Energy Rating** for a dwelling from just an address or postal code (an Irish Eircode, or an address in seven other North-West European countries). It automates a manual workflow that previously required looking up a property on Google Maps, manually measuring building dimensions, visually inspecting Street View imagery to judge construction era and heating system, and hand-entering every parameter into a spreadsheet.

The pipeline replaces that workflow end-to-end: it geocodes the address, fetches satellite and multi-angle Street View imagery, classifies the building with a multimodal AI vision model, extracts its footprint dimensions, and computes an indicative energy rating using a physics-based annual energy balance.

The tool originated as a screening and community-engagement instrument for the **CIRCUS project** (Interreg NWE), which aims to increase energy resilience in rural communities by giving them accessible tools for energy profiling. It is explicitly **not** a substitute for a certified BER/DEAP assessment, which remains required for grants and regulatory compliance.

1.2 Calculation Method

The energy calculation uses the **HWB (Heizwärmebedarf) annual balance method**, as described in *“Leitfaden für die Berechnung des Heizwärmebedarfs”* (Die Umweltberatung, Vienna, 2019). This is a simpler steady-state annual balance well suited to rapid, screening-level assessment — it is distinct from Ireland's official DEAP methodology. Every formula, constant, and lookup table was ported from the source Excel tool *“Building Assessment using Google Maps and Google Street View”* by Benjamin Kaiser (MTU, Jan 2025).

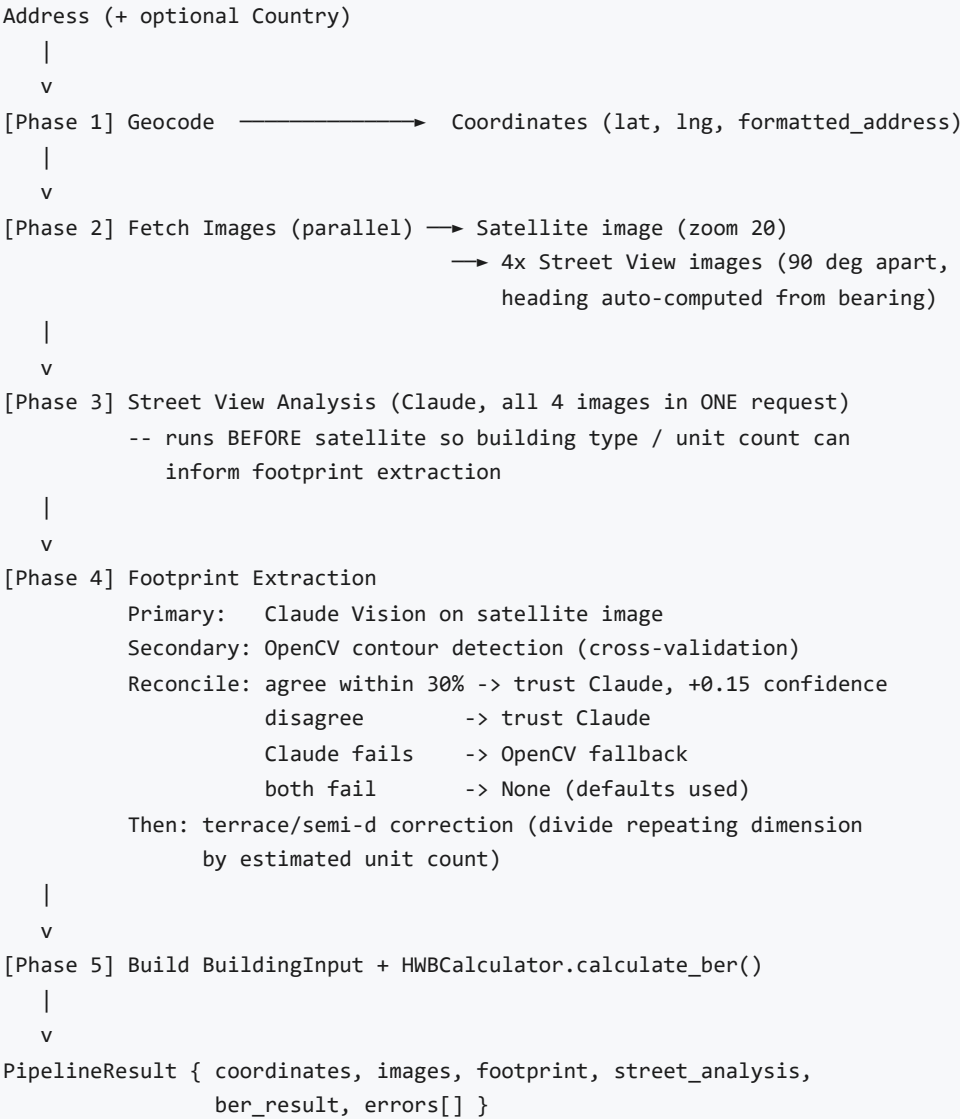
1.3 Technology Stack

Layer	Technology
Language	Python 3.13
Data models & validation	Pydantic v2
Configuration	pydantic-settings + <code>.env</code>
HTTP client	httpx (async)
Computer vision (fallback footprint)	OpenCV (headless)
AI vision & classification	Anthropic Claude (<code>anthropic.AsyncAnthropic</code>)
Geocoding & imagery	Google Maps Platform (Geocoding, Static Maps, Street View Static APIs)
Web UI	Streamlit
Testing	pytest + pytest-asyncio + respx

2. System Architecture

2.1 Five-Phase Async Pipeline

The core orchestrator is `BERPipeline` (`ber_automation/pipeline.py`). `run(address, country, retrofit, overrides)` executes five sequential phases, each degrading gracefully on failure so a single API error never crashes the whole assessment:



2.2 Reanalyse Flow

A second entry point, `reanalyse(existing_result, country, retrofit, overrides, satellite_uploaded)`, reruns phases 3–5 only, reusing images already saved to disk. This supports a Streamlit UI flow where a user manually replaces a poor-quality satellite or Street View image and recomputes without re-geocoding or re-fetching from Google. When `satellite_uploaded=True`, GPS-derived pixel scale is skipped in favour of visual-reference scale estimation, since an uploaded image has no reliable zoom/lat metadata.

2.3 Graceful Degradation

Phase Failure	Fallback Behaviour
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Geocoding	Pipeline returns immediately with an error; no further phases run
Satellite image fetch	Footprint extraction skipped; default dimensions used
Street View image fetch	Claude street analysis skipped; default classification used
Footprint extraction (both methods)	Default 10m x 8m footprint
Claude street analysis (confidence < 0.4)	Default: Detached, before 1980, 2 storeys, gas boiler
BER calculation	Error appended to <code>result.errors</code> ; no <code>ber_result</code>

3. Data Model

3.1 Core Enumerations

Enum	Values
<code>BuildingType</code>	detached, semi_d_length, semi_d_width, terraced_length, terraced_width
<code>ConstructionEpoch</code>	before_1980, 1980_1990, 1990_2000, 2000_2010, after_2010
<code>HeatingSystem</code>	oil_boiler, gas_boiler, biomass, electric_direct, heat_pump_air, heat_pump_ground, heat_pump_water, district_heating
<code>Country</code>	ireland, france, germany, belgium, netherlands, luxembourg, switzerland, austria — the seven Interreg NWE (CIRCUS) programme countries plus Austria

3.2 Key Pydantic Models

Model	Purpose / Notable Fields
<code>Coordinates</code>	<code>lat</code> , <code>lng</code> , <code>formatted_address</code>
<code>BuildingInput</code>	length, width, heated_storeys, storey_height, building_type, construction_epoch, country, quantity, residents (auto = area/52 if unset), window_door_areas, heating_system, hot_water_electric_separate
<code>RetrofitInput</code>	wall_insulation_cm (default 12), roof_insulation_cm (default 20), window_u_value (default 1.0), heating_system_after, hot_water_electric_separate_after
<code>FootprintResult</code>	length_m, width_m, area_m2, confidence [0-1], source (opencv / claude_vision / fallback), building_shape, contour_points
<code>StreetViewAnalysis</code>	construction_epoch, building_type, estimated_storeys, heating_system_guess, adjacent_side, estimated_units_in_row (ge=1), confidence, reasoning
<code>HWBResult</code>	floor_area, heated_volume, envelope_area, transmission/ventilation heat loss, solar/internal gains, heating_demand_kwh, hwb, final_energy_kwh/(m2), hot_water_kwh, co2_kg/(m2)
<code>BERResult</code>	ber_band (Irish scale), kwh_per_m2, color_hex, hwb_result, building_input, native_epc_band/scale/color, retrofit_* comparison fields
<code>PipelineResult</code>	address, coordinates, satellite/streetview image paths, footprint, street_analysis, ber_result, errors[]

4. Calculation Logic — HWB Method

The HWB (heating energy demand) is a steady-state annual balance:

$$Q_{\text{heating}} = \text{Heat Losses (Transmission + Ventilation)} \\ - \text{Usable Gains (Solar + Internal)}$$

4.1 Geometry

Quantity	Formula
Gross floor area	length × width × storeys
Net floor area	gross × 0.8
Envelope area	((L+W) × 2) × storeys × storey_height
Roof / floor area	L × W
Window/door area	envelope × fraction (15% detached / 14% semi-d / 13% terraced), split 25% each to N/E/S/W
Party walls	0 (detached); length or width × storeys × height for semi-d; ×2 for terraced, depending on adjacency side
External walls	envelope – windows – party walls
Heated volume	net_area × (storey_height – 0.35) × storeys

4.2 Transmission Heat Loss

$$L_e = U_{\text{win}} \cdot A_{\text{win}} + U_{\text{roof}} \cdot A_{\text{roof}} + U_{\text{floor}} \cdot A_{\text{floor}} \cdot 0.7 + U_{\text{wall}} \cdot A_{\text{extwall}} \\ U_{\text{mean}} = L_e / (A_{\text{win}} + A_{\text{roof}} + A_{\text{floor}} + A_{\text{extwall}}) \\ L_{\text{psi}} = \max(0.2 \cdot (0.75 - U_{\text{mean}}) \cdot L_e, 0) \quad \# \text{ thermal bridge supplement} \\ L_t = L_e + L_{\text{psi}} \\ Q_t = 0.024 \cdot L_t \cdot \text{HDD} \quad [\text{kWh/yr}] \quad (0.024 = 24\text{h} / 1000)$$

4.3 Ventilation Heat Loss

$$L_v = 0.34 \cdot 0.4 \cdot \text{Volume} \quad (0.34 \text{ Wh/m}^3\text{K air heat capacity, } 0.4 \text{ ACH}) \\ Q_v = 0.024 \cdot L_v \cdot \text{HDD}$$

4.4 Internal Gains

$$Q_i = 0.024 \cdot 3.75 \cdot \text{net_area} \cdot \text{heating_days} \quad (3.75 \text{ W/m}^2 \text{ of net area})$$

4.5 Solar Gains

$$g_{\text{eff}} = g_{\text{value}} \cdot 0.9 \text{ (frame)} \cdot 0.98 \text{ (dirt)} \\ Q_s = (\text{Irr}_N \cdot A_N + \text{Irr}_E \cdot A_E + \text{Irr}_S \cdot A_S + \text{Irr}_W \cdot A_W) \cdot 0.75 \text{ (shading)} \cdot g_{\text{eff}}$$

4.6 Heating Demand, Hot Water & Final Energy

```

Q_heating    = max(0, Q_t + Q_v - Q_i - Q_s)
HWB          = Q_heating / gross_area           [kWh/m2/yr]
Q_hotwater   = residents * 40 L/day * 365 * (4.2/3600) * 45K  ~= 765 kWh/person/yr
final_energy = Q_heating/system_efficiency + Q_hotwater/hw_efficiency
primary_energy = final_energy * Primary_Energy_Factor(system, country)
CO2          = final_energy * CO2_factor(system, country)
BER band     = lookup(primary_energy / gross_area)

```

Note: the Excel-faithful HWB method applies **no gain-utilisation factor (η)**, unlike EN 13790 / ISO 52016. Solar and internal gains are subtracted directly, which can over-credit well-insulated buildings relative to the official DEAP/EPBD methods.

4.7 Retrofit Overlay

```

R_new = R_old + (thickness_cm / 100) / 0.035    (insulation conductivity)
U_new = 1 / R_new

```

Window U-values are directly substituted; heating system and hot-water configuration can also be swapped for the "after retrofit" scenario, which is calculated and compared side-by-side with the baseline.

5. Multi-Country Support

Originally Ireland/Eircode-only, the pipeline now geocodes any address via `geocode_address(address, country)` and applies country-specific climate data, electricity grid carbon intensity, primary energy factors, and native energy-rating scales.

5.1 Climate Data by Country

Country	HDD (base 15.5°C)	Heating Days/yr	Reference Location
Ireland	2149.1	219	Mullingar / Birr
France	1462.0	187	Le Mans / Rennes (NW)
Germany	2157.1	211	Paderborn / Münster (NW)
Belgium	1825.5	209	Beauvechain / Ukkel
Netherlands	1921.3	212	Herwijnen / De Bilt
Luxembourg	2140.0	218	Luxembourg City
Switzerland	2415.0	225	Basel-Binningen (NW)
Austria	3400.0 (placeholder)	260 (placeholder)	— not in source Excel

5.2 Country-Specific Electricity Factors

Country	Grid CO2 (kg/kWh)	Primary Energy Factor
Ireland	0.210	2.08
France	0.052 (nuclear-dominated)	2.58
Germany	0.385	1.80
Belgium	0.163	2.50
Netherlands	0.290	1.45
Luxembourg	0.197	2.00
Switzerland	0.029	2.00
Austria	0.156	2.60

Applied only to electric heating systems (electric_direct, heat_pump_air/ground/water); combustion systems (oil, gas, biomass, district heating) use fixed factors from the source Excel regardless of country.

5.3 Native EPC Rating Scales

In addition to the Irish BER A1–G band (used as the tool's common reference scale), `get_native_epc()` maps the same primary energy figure onto each country's own certificate scale:

Country	Native Scale	Bands
Ireland	BER	A1–G (15 bands)
France	DPE	A–G

Germany	Energieausweis	A+--H
Belgium (Flanders)	EPC	A+--F
Netherlands	Energielabel	A++++--G
Luxembourg	Energiepass	A+--G
Switzerland	GEAK	A--G
Austria	Energieausweis	A+--G+

6. Vision & Geospatial Processing

6.1 Multi-Angle Street View Capture

`fetch_streetview_images()` fetches 4 images at 90° intervals around an auto-computed base heading — the great-circle initial bearing from the Street View camera position to the building coordinate (`geospatial/scale.py::initial_bearing()`). All 4 images are sent to Claude in a **single request** so it can cross-reference angle-specific features (oil tanks, heat pump condenser units, gas meters, shared/party walls) that may only be visible from certain sides.

6.2 Claude Vision Street View Analysis

`analyze_streetview()` (async, `anthropic.AsyncAnthropic`) sends the image set with a structured, country-aware prompt describing construction-era visual indicators, and returns JSON: construction epoch, building type, storey count, heating system guess, adjacent side, estimated units in row, confidence, and reasoning. A confidence gate requires ≥ 0.4 before the pipeline trusts the classification — below that (e.g. a hedge-obscured façade), safe defaults are used instead.

6.3 Two-Tier Footprint Extraction

Tier	Method
Primary	Claude Vision on the satellite image, given computed scale (m/px at the given lat & zoom), ground coverage, and typical building-size priors; optionally seeded with building type / adjacent side / unit count from the street view analysis
Secondary	OpenCV: grayscale → bilateral filter → CLAHE → Canny edges → dilate → contour scoring (0.15 area, 0.30 solidity, 0.30 centrality, 0.25 rectangularity) → minAreaRect → convert px → m

Scale conversion (Web Mercator): $mpp = 40,075,016.686 * \cos(lat) / 2^{(zoom+8)}$. At Dublin (lat 53.35°), zoom 20 $\approx$ 0.089 m/px, i.e. a 640×640 image covers roughly 57m × 57m.

Reconciliation and terrace correction logic are described in section 2.1. Final dimensions are clamped to [4m, 25m] and total area must fall in [20, 500] m² before being trusted; otherwise the pipeline falls back to a default 10m × 8m footprint.

7. BER Rating Scale (Irish reference bands)

Band	Max kWh/m²/yr	Typical Building
A1	25	Passive house / NZEB

A2	50	High-performance new build
A3	75	Modern well-insulated
B1	100	Post-2010 standard
B2	125	2000s build
B3	150	Well-retrofitted older home
C1	175	1990s semi-detached
C2	200	Average Irish home
C3	225	1980s housing
D1	260	Pre-1980 with some upgrades
D2	300	Typical pre-1980 detached
E1–E2	340–380	Poor insulation, old windows
F	450	Very poorly insulated
G	>450	Uninsulated, single glazing

8. Testing

75 automated tests across 6 pytest suites, all passing:

File	Tests	Scope
<code>test_calculator.py</code>	19	BER band lookup (parametrized), HWB calculation logic, retrofit overlay
<code>test_geocoder.py</code>	11	Eircode validation and address geocoding
<code>test_pipeline.py</code>	4	End-to-end manual mode across epochs / countries / heating systems
<code>test_satellite_analysis.py</code>	29	Claude satellite & street view analysis (mocked async API), footprint reconciliation, <code>_build_input()</code> confidence gating
<code>test_bearing.py</code>	8	Great-circle initial bearing calculation for Street View heading
<code>test_streetview_heading.py</code>	4	Multi-angle heading generation (4 images at 90° steps)

`tests/test_streetview_countries.py` is a standalone diagnostic script (not a pytest suite) that checks geocoding and Street View metadata availability for representative addresses across all 8 supported countries.

Not covered by automated tests: live Google Maps / Anthropic API calls, OpenCV extraction against real imagery, and Streamlit UI rendering — these require live credentials and/or manual verification.

9. Known Limitations

Limitation	Severity
Uses the HWB method, not Ireland's official DEAP methodology — results are estimates, not certified ratings	High
No EN 13790 gain-utilisation factor (η); may over-credit solar/internal gains for well-insulated buildings	Medium

U-values sourced from Austrian OIB standards, not Irish/national building regulations	Medium
Buildings modelled as rectangular boxes; L-/T-shaped or irregular footprints unsupported	Medium
Footprint accuracy limited by satellite image quality, vegetation, shadows, and adjacent structures	High
AI classification confidence is self-reported by the model, not independently calibrated	High
Street View coverage is sparse in rural areas / new developments; pipeline falls back to defaults	Medium
One climate data point per country (e.g. a single station for all of Ireland); no sub-regional variation	Medium
Single thermal zone; no distinction between heated/unheated rooms, extensions, or conservatories	Low
No cooling load calculated (heating demand only)	Low
No result caching/persistence; every run re-fetches images and re-calls the AI APIs	Medium

10. Deployment & Configuration

10.1 Required Credentials (`.env`)

```
GOOGLE_MAPS_API_KEY=AIzaSy...      # Geocoding, Static Maps, Street View Static APIs
ANTHROPIC_API_KEY=sk-ant-api03-...  # Claude Vision (satellite + street view analysis)
```

10.2 Entry Points

```
python main.py manual --length 10 --width 8 --storeys 2 \
    --epoch before_1980 --heating oil_boiler    # no API keys needed

python main.py pipeline "D02 X285" --country ireland # full pipeline

python main.py app                                # Streamlit web UI
# or: streamlit run app/streamlit_app.py
```

10.3 Local Verification

```
pip install -r requirements.txt
cp .env.example .env      # then fill in API keys
python -m pytest tests/ -v # 75 tests should pass
```

10.4 Cloud Deployment (Streamlit Cloud)

1. Push to GitHub
2. `packages.txt` provides OpenCV's native dependencies (`libgl1-mesa-glx` , `libglib2.0-0`)
3. Connect the repo at share.streamlit.io, main file `app/streamlit_app.py`
4. Set `GOOGLE_MAPS_API_KEY` and `ANTHROPIC_API_KEY` in the app's Secrets

BER Automation Technical Specification — generated from the current codebase (ber_automation/, tests/) and project documentation (docs/DOCUMENTATION.md, CONTEXT.md). Source of truth for formulas and constants: "Building Assessment using Google Maps and Google Street View" (B. Kaiser, MTU, Jan 2025) and the HWB Leitfaden (Die Umweltberatung, Vienna, 2019).