Cool City: A Public Heat-Safe Route and Cooling-Gap Layer for Heilbronn

Author: Noel Sabia (ORCID 0009-0008-3064-7573)
Affiliation: —
Date: 14 November 2026
Prototype: https://pulse.noelsabia.dev · **Cool City route:** `/cool` (bundle TBD) · **DOI:** TBD

Abstract

Heat is a measurable public-health threat, and Heilbronn already knows where its cool places are, but not how a person reaches them. Cool City is a public heat-safe route built on the existing eight-sensor pulse. A weather-aware global model forecasts the relative footfall index, reaching MAE 3.32, WAPE 27.5%, and R^2 0.777 on a 28-day holdout versus 5.40, 44.7%, and 0.462 for a seasonal-naive baseline. A route and shade layer combines OpenStreetMap walkable ways, the city tree cadastre, and solar position to offer shortest, shaded, and accessible routes with modeled shade coverage, direct-sun minutes, step-free continuity, water, and benches. A cooling-gap layer ranks the eight sensor catchments by relative footfall, shade deficit, access deficit, and—where sourced—vulnerability. The existing retail staffing plan remains one commercial application. Shade is modeled, the cooling gap is relative rather than a measured temperature, and the underlying pulse is estimated devices, not people; route and city values are TBD until the route/shade bundle is frozen.

1. Problem

Heat is not a comfort issue. The Robert Koch Institute estimated about **16,000 heat-related deaths in Germany in 2026 through calendar week 37** (95% prediction interval 14,400–17,600; 19.3 per 100,000) [1]. That is a model estimate, not a count, and it is not a Heilbronn-specific figure. Heilbronn's commissioned FITNAH-3D report gives a citywide physiological equivalent temperature (PET) range of **16.1–44.5 °C**, with unshaded sealed street space exceeding **41 °C PET** [2]. The report does not say that every inner-city street reaches 41 °C; the claim is about unshaded sealed surfaces.

The city already publishes **almost 60 cool places** on a map, with an address list [3]. That is a useful inventory, but it is not a routing or time-aware service: it tells a person where cool places are, not how to reach one at 16:00 with shade, water, benches, and step-free access. A local councillor argues that the map and care-home information do not reach alone-living older people, who carry the greatest risk; we quote that as her assertion, not as an evaluated finding [4]. The 2022–23 summer zones were discontinued, according to local reporting [4].

This is not a city that has done nothing. Heilbronn adopted a climate-adaptation concept in April 2023 with 31 measures across five fields [8] and published a 2025 spatial climate-adaptation concept [9]. The gap is narrower and more actionable: **the person-level route**. The city knows where the cool places are; it does not yet give a person a safe way there, hour by hour, with the access needs that determine whether the route is usable.

The existing eight-sensor pulse is the evidence spine, but it is a **relative device index**, not a count of people. Cool City does not hide that. It uses the index to forecast relative demand and to rank cooling gaps, and it states the measurement limits wherever a decision depends on them. The contribution is the public decision layer over a noisy city index: three routes for a persona, a relative cooling-gap ranking for the city, and the retail staffing plan as one commercial tenant.

2. Data and measurement audit

The delivered PAX CSV contains 192,464 rows: 96,232 density readings and 96,232 battery readings, from 12 device IDs. After merging the two `density-01` IDs and excluding three test sensors, eight usable locations remain in a ~580 m × 280 m inner-city cluster. The **12 June model window** (12 June–7 November 2026) contains **83,156 density values**; the **18 June coverage panel** contains **82,170 readings** and is used for coverage statistics.

The public 2026 Code for Heilbronn `lorax` firmware (commit `e8be8bf`) implements a ~10-second passive BLE scan, a 16-bit dedup key, a 0.7 multiplier, and a 900-second sleep [11]. The deployed 2025 binary may differ. The data confirm the **0.7 scaling and per-wake export**, not the scan duration or the 16-bit truncation: every one of the 83,156 values in the 12 June model window is an exact multiple of 0.7; the reconstructed count has median 12, p95 71, max 418, and **2.70% of those values are zero**.

Coverage is uneven. In the 18 June panel, only **28.2%** of 15-minute slots have all eight sensors; the modal count is seven (4,117 slots). Aggregating to 30, 60, or 120 minutes raises complete coverage to 63.4%, 69.7%, and 71.0%. Across all 96,232 density rows, 5.18% are zero, 10.36% are <1, and 39.57% are <5; in the 12 June window the shares are 2.70%, 8.32%, and 35.86%. Gaps reach four to six days per sensor and are not random. The 12 June panel has median 8.4, p95 49.7, and p99 79.8; across all 96,232 rows the values are 7.7, 46.9, and 78.4.

The forecast is a global `HistGradientBoostingRegressor` trained on hourly means of the published index, with calendar, lag, Open-Meteo weather [12], and sensor-identity features. On the 28-day holdout, the production 7-day model reaches **MAE 3.32, WAPE 27.5%, and R^2 0.777**; the day-ahead weather model reaches **3.36, 27.8%, and 0.763**; the seasonal-naive baseline is **5.40, 44.7%, and 0.462**. Weather is the main driver: removing it raises day-ahead MAE from 3.36 to 3.96. The holiday flag changes 3.96 to 3.84, a small effect. These are single-site, 28-day results.

Audit layer	Finding	Population / caveat
Sensor network	8 usable locations, ~15 min cadence, ~580 m × 280 m	Inner-city cluster, not city-wide
Values	`0.7 × U`; 100% multiples of 0.7	12 June model window (83,156 values)
Coverage	28.2% all-eight slots; 4,117 modal-seven slots	18 June coverage panel (82,170 readings)
Zeros / low counts	5.18% zero, 10.36% <1, 39.57% <5	All 96,232 density rows
Model	MAE 3.32, WAPE 27.5%, R^2 0.777	28-day holdout; production 7-day model
Unit	Estimated devices, not people; 0.7 factor unvalidated	The core caveat for every downstream layer

Table 1. The measurement audit. Cool City inherits every limit in this table; it does not turn the index into people or into temperature.

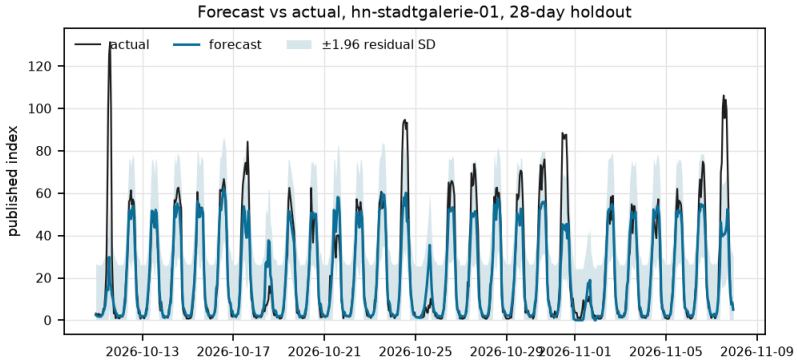


Figure 1. Forecast versus actual for one sensor over the 28-day holdout. The model captures the daily/weekly shape but misses spikes; the band is a planning aid, not a calibrated 95% interval unless coverage is reported.

3. Cool City

3.1 A person, three routes, and a clock

The demo persona is **Ruth, 78, who lives alone**. She is a clearly labelled composite, not a real person; the prototype can later use a real local story with consent. Her trip is **Stadtgalerie → Marktplatz**: short, ordinary, and exactly the kind of trip that heat turns into a risk. The route geometry and place names must be verified on OSM before the demo.

Cool City offers three routes:

1. **Shortest** — the fastest path, with no shade or access preference.
2. **Shaded** — the cool route via the Deutschhof passage / Kiliansplatz (verify the exact geometry).
3. **Accessible** — a route that prefers step-free continuity, water, benches, and toilets (verify tags and continuity).

A time slider at **10:00, 12:00, 14:00, and 16:00** changes the recommendation as the sun moves. Each route card shows modeled shade coverage, direct-sun minutes, distance, duration, step-free status, water stops, and bench stops. The shade values are **modeled**, not measured. The audience vote is a comprehension device, not a data source: the room picks a route for Ruth, and the stage shows the split next to the model's recommendation. Most people take the shortest; the model takes the cool, accessible one.

3.2 Route and shade model

The route layer uses the OpenStreetMap walkable network (footways, pedestrian streets, paths, steps, crossings, buildings, trees, benches, drinking water, toilets, and wheelchair tags; ODbL) [10], the city tree cadastre from January 2026 (crown diameter; dl-de/by-2.0) [5], and solar position for the selected hour. Buildings and tree crowns cast modeled shade; the route cost combines travel time with penalties for direct sun, steps, and missing water/bench stops:

```
cost(route) = travel_time
            + λ_sun × direct_sun_minutes
            + λ_step × step_free_penalty
            + λ_water × water_gap
```

The weights `λ` and the route bundle are **TBD** until the route/shade data is frozen. The route is not a temperature model: it reports shade coverage and direct-sun minutes, not "degrees cooler." A temperature claim would require a validated radiant-temperature model and field data. The exact route metrics are also TBD; Table 2 defines the slots they will fill.

Route	Character	Shade coverage	Direct-sun min	Detour	Step-free	Water / bench stops
Shortest	Fastest path	TBD	TBD	0 by definition	TBD	TBD
Shaded	Via Deutschhof / Kiliansplatz (verify)	TBD	TBD	TBD	TBD	TBD
Accessible	Step-free, water, benches (verify)	TBD	TBD	TBD	TBD	TBD

Table 2. Route cards. Values are TBD until the route/shade bundle is frozen; the paper does not invent route metrics.

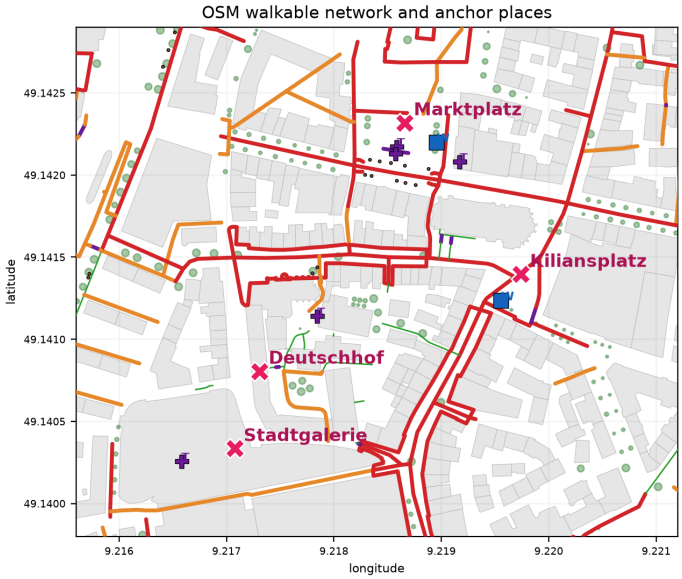


Figure 2. OpenStreetMap base network for the focus area (14 November 2026 snapshot; ODbL). Orange = footway, red = pedestrian street, purple = steps, grey = buildings, green = trees, blue = drinking water, brown = benches, pink crosses = labelled anchor places. This is a base network, not the final route or shade layer.

3.3 Cooling-gap index

The city layer uses the eight sensor catchments (300–500 m). It computes a **relative cooling-gap index**:

```
CG = normalize(footfall) × normalize(shade deficit)
   × normalize(access deficit) × normalize(vulnerability)
```

`footfall` is the published relative device index; `shade deficit` comes from the modeled shade layer; `access deficit` combines missing water, benches, step-free continuity, and toilets; `vulnerability` is included **only where sourced** and is otherwise set to 1. Population by age is available at planning-district level [6], and disability statistics are citywide (11,730 people in 2023; the city says “almost 12,000”) [7]. Those are aggregate inputs, not block-level diagnoses. The index is normalized 0–1 and shown as a rank with a one-line reason. The weights and the final ranking are **TBD** until the city bundle is frozen. It is a relative model, not a measured temperature map, and it must not be presented as a city-wide heatmap.

3.4 Retail staffing as one application

The existing staffing plan remains a separate module. The same forecast schedules store staff; a retailer pays for that module. In this paper it is a commercial tenant, not the hero. The live plan is currently a snapshot with unstable scenario/window behavior, so we do not report its plan numbers here; the module is described qualitatively until the plan window and scenarios are stabilized. The Cool City paper’s contribution is the public route and cooling-gap layer, not a retailer dashboard.

4. Evaluation

Route-level metrics. The route evaluation will report shade coverage (%), direct-sun minutes, detour versus the shortest route, step-free continuity, water stops, and bench stops for each route at each time. All values are **TBD** until the route/shade bundle is frozen. The target direction is explicit: more shade, fewer direct-sun minutes, acceptable detour, continuous step-free access, and at least one water/bench option on the accessible route.

City-level ranking. The cooling-gap index will be reported as a rank across the eight catchments with a one-line reason, plus the input layers. The rank is **TBD**. The evaluation will show the sensitivity of the rank to the shade/access weights and to the vulnerability input; a rank that flips under plausible weights is not a decision-grade result.

System metrics. The inherited SSE path was measured at **120/120 connections opened and closed, zero errors, p95 event 331 ms, p95 scenario 646 ms, presenter POST 49.60 ms, over 4m57.9s** on v1.1. The Cool City route page and vote endpoint are new: their latency, vote tally accuracy, and stage behavior are **TBD**. The retail plan module’s cold generation is 19 ms; that number belongs to the retail module, not the route layer.

Comprehension test plan. A small task-based test with older adults and caregivers will ask participants to (1) choose a route for Ruth at 16:00, (2) explain why it is cooler or more accessible, (3) compare the 10:00 and 16:00 recommendations, and (4) find water, benches, and step-free access. The sample, recruitment, and results are **TBD**; this is a plan, not a completed study.

Evaluation layer	Metrics	Status
Route	Shade coverage, direct-sun minutes, detour, step-free continuity, water/bench stops	TBD
City	Cooling-gap rank, input layers, weight sensitivity	TBD
System	SSE 120/120, p95 event 331 ms, p95 scenario 646 ms, presenter 49.60 ms	Measured on inherited v1.1 path
Vote / route page	Open success, tally accuracy, route render latency	TBD
Comprehension	Task success, explanation quality, route preference	Plan only; TBD

Table 3. Evaluation status. Shade is modeled; the cooling gap is relative; no temperature or causal claim is made.

5. Privacy and limits

Cool City uses aggregate device counts only. It does not store MAC addresses or PII, does not require accounts, and does not upload a visitor’s location. The audience vote is aggregate; a random session ID in local storage is enough. A production deployment needs a DPIA and a documented legal basis before collecting MAC-derived counts, with the city as controller and a legal review before launch. The existing index is estimated devices, not people; device penetration is unknown; the 0.7 factor is unvalidated; and only 28.2% of 15-minute slots in the 18 June panel have all eight sensors.

The route layer has its own limits. Shade is modeled from buildings and tree crowns, not measured with radiometers; tree cadastre and OSM coverage are incomplete; OSM is a 14 November 2026 snapshot, not an official city dataset; and the route geometry and place names still need verification. The cooling-gap index is a relative ranking, not a measured temperature map, and it does not establish that an intervention will cause a health improvement. We make no “4 °C cooler” claim and no causal claim for shade, water, or bench interventions. The current prototype is a decision-support layer over a noisy index, not a validated public-health instrument.

6. Future

The next step is a city-owned public trust: the city controls the route and cooling-gap layer, the underlying data is open where licensing allows (tree cadastre, OSM, city cool places, aggregate population), and the retail module is a commercial tenant rather than the product’s owner. The route/shade bundle and the cooling-gap weights should be published with the paper, tested with older adults and caregivers, and transferred to a second city with a different street network. Field validation of modeled shade and a small route-choice study would turn the current design into evidence. The long-term vision is a public heat-safe wayfinding layer that any city can adopt, with the retail staffing module as one paying application.

7. TBD register

Item	Why it is TBD	Next step
`/cool` route deployment	The route/shade bundle is not frozen	Verify the live `/cool` page and fallback
Route geometry (Deutschhof / Kiliansplatz, step-free continuity)	OSM tags and passage geometry need field verification	Walk the route; check steps, crossings, water, benches
Route metrics (shade %, direct-sun min, detour, duration, stops)	Route/shade bundle not frozen	Freeze the bundle; report values on the four time slices
Cooling-gap weights and rank	City bundle and weight sensitivity not frozen	Publish weights; run sensitivity; report rank and reason
Vote / route-page latency	New endpoint not measured	Run the same k6/SSE protocol; report open success and p95
Comprehension test	Plan only; no participants yet	Recruit older adults/caregivers with the city; publish tasks and results
DOI	Event draft has no DOI yet	Mint on Zenodo after the event
OSM/tree coverage	14 Nov 2026 OSM snapshot; cadastre may be incomplete	Document query date; compare with city tree data

Table 4. Open items. These are deliberately not filled with plausible-looking numbers.

References

[1] Robert Koch-Institut. *Hitzemortalität in Deutschland 2026*. https://www.rki.de/DE/Themen/Gesundheit-und-Gesellschaft/Gesundheitliche-Einflussfaktoren-A-Z/H/Hitze/Bericht_Hitzemortalitaet.html

[2] Stadt Heilbronn. *FITNAH-3D-Abschlussbericht zur Raumstruktur- und Klimaanpassung*, 2025. https://www.agenda21-hn.de/wp-content/uploads/2025/07/034_2025_DS_034_2025_Anlage_5_Abschlussber_Raumstrukt_Klimaanpassung.pdf

[3] Stadt Heilbronn. *Gesundheit und Hitze: kühle Orte*. https://www.heilbronn.de/leben/gesundheit/staedtisches-gesundheitsamt/gesundheit-und-hitze.html

[4] Rhein-Neckar-Zeitung. “Hitze in Heilbronn: und nicht genug Hilfe,” 2026. https://www.rnz.de/region/sinsheim-kraichgau_artikel,-Kampf-gegen-hohe-Temperaturen-Hitze-in-Heilbronn-und-nicht-genug-Hilfe-_arid,2401501.html

[5] Stadt Heilbronn. *Baumkataster Januar 2026*, dl-de/by-2.0. https://opendata.heilbronn.de/dataset/baumkataster

[6] Stadt Heilbronn. *Bevölkerung nach Altersgruppen*, Planungsbezirke. https://opendata.heilbronn.de/dataset/bev%C3%B6lkerung-nach-altersgruppen-11

[7] Stadt Heilbronn. *Menschen mit Behinderung* (11,730 in 2023); city page “knapp 12.000.” https://opendata.heilbronn.de/dataset/menschen-mit-behinderung · https://www.heilbronn.de/leben/barrierefreiheit-inklusion-leben-mit-behinderung.html

[8] Stadt Heilbronn. *Klimaschutzteilkonzept zur Anpassung an den Klimawandel*, adopted 27 April 2023, 31 measures. https://www.heilbronn.de/umwelt-mobilitaet/klima-klimaschutz/anpassung-an-den-klimawandel.html

[9] Stadt Heilbronn. “Hitze im Blick: konkretisiertes Klimaanpassungskonzept,” 2025. https://www.heilbronn.de/kommunikation/pressemitteilungen/details/artikel/hitze-im-blick-konkretisiertes-klimaanpassungskonzept-zeigt-wege-fuer-besseres-stadtklima.html

[10] OpenStreetMap contributors. *OpenStreetMap*, ODbL. https://www.openstreetmap.org/copyright

[11] Code for Heilbronn. `lorax` / `sensor-pax` firmware, commit `e8be8bf5c11e1b76c88c3f176382c6df99eea989` (develop, 18 June 2026). https://codeberg.org/cfhn/lorax/commit/e8be8bf5c11e1b76c88c3f176382c6df99eea989

[12] Open-Meteo. *Historical and forecast weather APIs*, CC BY 4.0. https://open-meteo.com/