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

Author: Noel Sabia (ORCID 0009-0008-3064-7573)
Affiliation: —
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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. On a clear 35.0 °C day (14 August 2026), the route layer combines OpenStreetMap walkable ways, the city tree cadastre, and solar geometry to model three routes from Stadtgalerie to Marktplatz: shortest 359.5 m / 4.8 min, shaded 732.3 m / 9.8 min, and accessible 438.2 m / 5.8 min. At 16:00 the accessible route is recommended for Ruth: 43.8% modeled shade, 3.3 direct-sun minutes, no ramp, and water and benches. The shaded route has a higher shade share (50.0%) but, being twice as long, more direct sun (4.9 min); shade share alone is misleading. A relative socio-spatial screening index ranks the eight 300 m catchments with weights 0.40 footfall, 0.30 shade deficit, 0.20 access deficit, and 0.10 vulnerability; Hagenbuchersee 2 ranks first (0.6471). Vulnerability is the 17.26% 65+ share of Heilbronn Innenstadt (31.12.2016) and is constant across all eight, so it does not differentiate them. Shade is modeled, the screening index is relative rather than a measured heat map, and the pulse is estimated devices, not people.

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 screen relative 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 socio-spatial screening 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.

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. Both endpoints and all street names are OSM-verified. The routes start at the OSM-tagged main entrance of Stadtgalerie on the east side (the official address point is on the west side) and end at the centre of Marktplatz.

Cool City offers three routes:

1. **Shortest** — the direct path via Deutschhofstraße, Fleiner Straße, Kirchbrunnenstraße, and Windgasse.
2. **Shaded** — the detour via the unnamed shaded tunnel at the Deutschhof, the Deutschhof courtyard, and Kiliansplatz.
3. **Accessible** — the step-free route via Sülmerstraße and Falkenstraße that avoids the Marktplatz tram ramp.

The shaded route uses the real OSM tunnel between Eichgasse and the Deutschhof courtyard. OSM has no signed name for it, so the bundle calls it “the shaded passage” and marks the name unverified; “Deutschhof”, “Taubenbrunnen”, and “Kiliansplatz” are OSM-verified. The courtyard is a dead end in OSM—the east/south passage is `access=no` and the north-east gate is `locked=yes`—so the route enters and leaves through the same tunnel. That out-and-back is why it is about twice as long as the shortest option.

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 recommends the accessible route on access grounds, not because it has the least sun.

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 and kerb 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. `access=no/private` ways and locked gates are excluded; steps and `wheelchair=no` ways are forbidden for the accessible route. The bundle covers 854 main building footprints—6 have a `height` tag and 403 have `building:levels`, so **445 use a type default** (the 12 m default for `building=yes` alone covers 314)—and 801 trees: 795 cadastre trees plus 102 OSM trees, deduplicated within 6 m. Tree canopy height is modeled as `min(4.5 + 0.45 × crown_dm, 14) m` and radius as `crown_dm/2`; tree heights are not measured.

Buildings are swept along the shadow vector `height / tan(altitude)`; tree canopies are modeled as horizontal discs offset by `canopy_height / tan(altitude)`. Routes are sampled every 5 m, and a sample counts as shaded if it falls inside a building or tree shadow or on a way tagged `covered=yes/tunnel=yes`. Walking speed is constant at **1.25 m/s**, and `direct_sun_min = duration_min × (1 − shade_pct/100)`. Shade is clear-sky geometry: cloud cover is reported but not applied. The model is not a temperature model—it reports shade coverage and direct-sun minutes, not “degrees cooler.”

Route	Distance / duration	16:00 modeled shade	Direct sun 16:00	Detour vs shortest	Step-free	Water / benches
Shortest	359.5 m / 4.8 min	43.8%	2.7 min	0 m	Yes, but 15% ramp	2 / 8
Shaded	732.3 m / 9.8 min	50.0%	4.9 min	+372.8 m (+103.7%)	Yes, but 15% ramp	2 / 9
Accessible	438.2 m / 5.8 min	43.8%	3.3 min	+78.7 m (+21.9%)	Yes, no ramp	2 / 6

Table 2. Route cards on the clear hot day 2026-08-14 (max 35.0 °C; 0% cloud at all four hours). Shade is modeled, not measured. Water = public drinking-water points within 30 m; benches = OSM benches within 40 m.

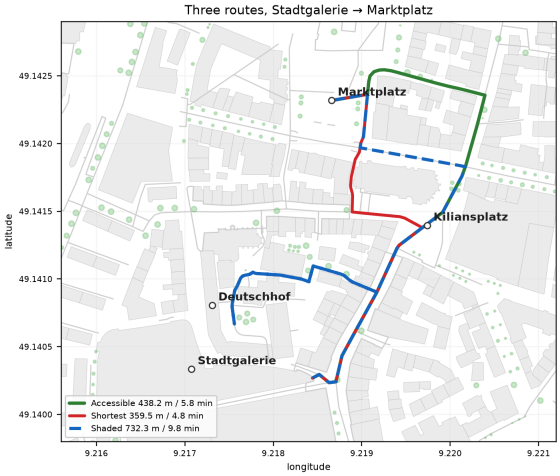


Figure 1. The three routes on the OSM base network (14 November 2026 snapshot; ODbL). Grey = buildings and walkable ways, green dots = tree cadastre and OSM trees. The shaded route’s final approach overlaps the accessible route and is drawn dashed. The map is illustrative; the metrics come from the 5 m shade model.

At **10:00** the shortest route has 61.6% shade and 1.8 direct-sun minutes, the shaded route 61.5% and 3.8 minutes, and the accessible route 67.4% and 1.9 minutes. The accessible route has the highest shade share in the morning, but the shortest route still has slightly less total sun because it is 1.0 minute shorter. At **14:00** shade falls to 27.4% (shortest), 42.6% (shaded), and 30.3% (accessible), with 3.5, 5.6, and 4.0 direct-sun minutes. At **16:00** the shaded route has the highest shade share, 50.0%, but 4.9 direct-sun minutes.

The shaded route is not the lowest total sun exposure. It has the highest shade share at 14:00 and 16:00, but it is 2.04× the shortest distance, so its total direct-sun minutes are higher at all four times. The shortest route is lowest at all four times (ties with the accessible route at 12:00). The accessible route is recommended for Ruth because it avoids the **15% rolled-kerb ramp** at the Marktplatz tram crossing (`node/12946835801`, `kerb=rolled`, `ramp:wheelchair=yes`, `incline=15.0%`), which the shortest and shaded routes use. The accessible route enters Marktplatz from the north via Sülmerstraße/Falkenstraße and returns **no kerb or ramp nodes** in the accessibility audit. Against the shortest route it costs **+78.7 m (+21.9%), +1.0 min, and +0.6 direct-sun minutes at 16:00**, in exchange for no ramp, two water stops, and six

benches. The last 34 m on Marktplatz is `surface=sett` (cobblestone): step-free, but not a smooth-surface guarantee. The recommendation is an access preference, not a claim that the route is coolest.

3.3 Cooling-gap screening index

The city layer uses the eight sensor catchments, each a **300 m Euclidean radius** (282,743 m², about a 4-minute walk at 75 m/min) [6]. It computes a **relative socio-spatial screening index** as a weighted sum:

```
Gap = 0.40 × footfall
    + 0.30 × shade_deficit
    + 0.20 × access_deficit
    + 0.10 × vulnerability
```

The footfall, shade, and access components are min–max normalized across the eight catchments; vulnerability is a raw 0–1 share. `footfall` is the published relative device index, scored as 0.4 × min–max(mean) + 0.6 × min–max(p95) because peak footfall coincides with peak heat; its unit, metric, and aggregation interval are **not documented by the API**, so the semantics are assumed. `shade_deficit` is 1 minus a shade score: 0.5 × min(1, building footprint share / 0.45) + 0.5 × min(1, tree canopy share / 0.25), with 0.45 and 0.25 as planning heuristics. This is a **footprint/canopy proxy**, not measured shade and not the route-level shadow model. `access_deficit` is 0.35 water + 0.20 bench + 0.25 toilet + 0.20 step-free, each normalized as `min(distance, 300 m) / 300 m`; step-free is the distance to the nearest `wheelchair=yes` POI or official accessible toilet, not a routed barrier-free path. `vulnerability` is the raw 65+ share for Heilbronn Innenstadt, **17.26% (5,667 / 32,834, 31.12.2016)**. It is **constant across all eight catchments**, so it adds 0.01726 to every score and does **not differentiate them**; the ranking is driven by footfall, shade, and access.

Rank	Catchment	Gap score	Main driver
1	Hagenbuchersee 2	0.6471	Footfall, shade, and access above median; p95 64.4, canopy 1.8%, water 236.5 m
2	Stadtgalerie	0.6306	Highest peak footfall (p95 67.2); building shade 42.4%, water 124.2 m
3	Neckarufer	0.6069	p95 61.6, canopy 2.5%, water 208.1 m
4	Hagenbuchersee 1	0.4979	Canopy 1.2%, toilet 162.4 m, p95 49.7
5	Marahaus	0.3752	Water 233.6 m, canopy 4.7%, p95 38.5
6	Soleo	0.3433	Lowest footfall score (0.025); high shade and access deficits
7	Götzenturm	0.2931	Low footfall score (0.064)
8	Density 01	0.2660	Lowest footfall (0.000); battery 11

Table 3. Top-gap ranking under the base weights 0.40 / 0.30 / 0.20 / 0.10. Ranks 1 and 2 differ by 0.0165 (2.5%) and are treated as co-priority. Vulnerability is constant across all eight, so the ordering is driven by footfall, shade, and access. This is a relative socio-spatial screening index, not a measured heat map.

The top-3 set—Hagenbuchersee 2 (0.6471), Stadtgalerie (0.6306), Neckarufer (0.6069)—is stable under equal, shade-heavy, and access-heavy weights; only ranks 2 and 3 swap under shade-heavy weighting. Shade deficits cluster in a narrow 0.500–0.651 band, so footfall and access drive most rank differences. The index is relative to these eight inner-city sensors only: all lie within ~585 m of each other, 300 m catchments overlap by up to **87.8%**, and there is no outer-district coverage. **All eight catchments are inner city; this is not a citywide neighbourhood ranking.** Citywide disability statistics (11,730 people in 2023; the city says “almost 12,000”) [7] are too coarse for catchment-level differentiation. The index is **not a measured temperature or heat map** and must not be presented as one.

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 screening layer, not a retailer dashboard.

4. Evaluation

Route-level metrics. The frozen bundle reports modeled shade coverage, direct-sun minutes, detour, duration, step-free status, water stops, and bench stops for each route at four times. At 16:00 the accessible route gives 43.8% shade and 3.3 direct-sun minutes for a 438.2 m / 5.8 min walk, +21.9% detour against the shortest route, with no ramp and two water and six bench stops. The shortest route is lower in total sun (2.7 minutes) but uses the 15% ramp. The shaded route is the longest (732.3 m, +103.7%) and has the most sun (4.9 minutes) despite having the highest shade share at 16:00 (50.0%). The route-level goals are therefore met in part: the accessible option meets the access and shade-share target, not the minimum-sun target; the shortest option meets minimum sun, not the no-ramp target. Reporting both numbers is the point. Step-free continuity is from OSM tags, not a field survey.

City-level screening. The eight catchments score from 0.6471 (Hagenbuchersee 2) to 0.2660 (Density 01). Ranks 1 and 2 are a co-priority (0.0165 apart, 2.5%), and the top-3 set is stable under the tested weight variants. The sensitivity analysis shows the screening is not decision-grade for individual positions 2–3 under shade-heavy weights, but the top-3 priority set is stable. This is a **relative socio-spatial screening index over eight inner-city catchments**, not a citywide neighbourhood ranking and not a measured heat map.

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 43.8–50.0%, direct sun 2.7–4.9 min at 16:00, detour 0 to +103.7%, stops, steps	Measured on frozen bundle
Screening	Score 0.2660–0.6471; top-3 stable; ranks 1–2 co-priority; vulnerability constant	Ranked; sensitivity run
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 4. Evaluation status. Shade is modeled; the screening index is relative and socio-spatial; 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. **445 of 854 main building footprints use type-default heights** (the 12 m default alone covers 314), tree heights are inferred from crown diameter, the model is 2D in plan view, and clear-sky geometry ignores clouds, awnings, facade reflections, and indoor shade. The bundle flags the **42.6% shade / 5.6 direct-sun minutes for the shaded route at 14:00** as its least-certain value. OSM is a 14 November 2026 snapshot, not an official city dataset; benches, water, toilets, and kerb tags may be incomplete; step-free status comes from tags, not a field survey; the accessible route's last 34 m is cobblestone; and the Deutschhof courtyard is an out-and-back. The route metrics are suitable for comparing options, not for safety or medical advice.

The screening index has separate limits. Catchments are Euclidean 300 m circles, not network isochrones, and do not model the Neckar, rail, or major-road barriers. Footfall semantics—unit, metric, and aggregation interval—are assumed because the API does not document them. The shade component is a footprint/canopy-share proxy without building heights or solar geometry; it is not the route-level shadow model. Step-free access is proxied by distance to a `wheelchair=yes` POI, not a barrier-free route. Vulnerability is a **2016 district-level 65+ share, constant across all eight catchments**; it does not vary at catchment scale and does not differentiate them. All eight sensors sit within ~585 m and catchments overlap by up to 87.8%, so the screening is relative and local, not a citywide neighbourhood ranking. 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 screening 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—3 routes, 12 route/time records, 35 segments, 92 place features, 87.5 KiB—and the screening weights are 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 bundle is frozen, but the live page and its fallback were not verified for this paper	Verify the deployed `/cool` page, failure state, and data version
Vote / route-page latency	New endpoint not measured	Run the same k6/SSE protocol; report open success, tally accuracy, and p95
Comprehension test	Plan only; no participants yet	Recruit older adults/caregivers with the city; publish tasks and results
Field verification of tags and surfaces	Step-free status, kerb/ramp, water, bench, and toilet tags are OSM-based, not surveyed; the accessible route's last 34 m is cobblestone	Walk all three routes; check the 15% ramp, the tunnel, and the toilet tags
Field validation of modeled shade	Clear-sky 2D geometry with default building heights and inferred tree heights	Radiometer transects on the same routes; compare modeled and measured direct sun
Production licence for city-map layers	The official cool-place, toilet, and water layers have no explicit open-data licence	Confirm permission with the city before production
DOI	Event draft has no DOI yet	Mint on Zenodo after the event

Table 5. Open items. These are deliberately not filled with plausible-looking numbers.

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