SAAYA Node v1 — IoT heat-rest monitor and fan controller

Retrofit IoT product for outdoor-worker rest shades · Vellore, Tamil Nadu · VIT B.Tech CSE project · October 2026

1. Real-life scenario

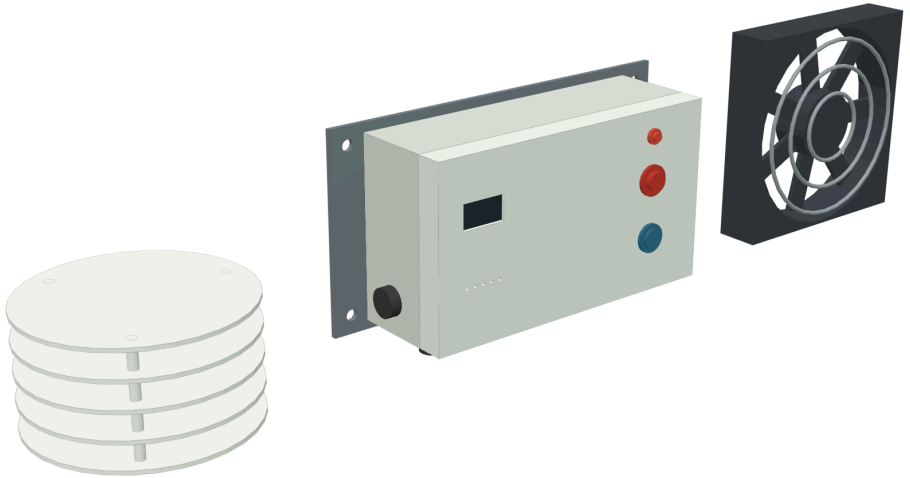
Problem. Construction, road and farm workers in Vellore rest outdoors in pre-monsoon heat (May mean maximum ≈ 39 °C, record 45 °C). Typical rest sheds are bare GI or cement sheets that themselves run 55–70 °C, nobody knows whether the shelter actually helps, and a worker who feels unwell has no reliable way to call for help. India's NDMA draft cooling-centre guidelines (2025) ask for shaded rest structures for outdoor workers; SAAYA Node makes any such shade measurable and safer.

Users. Workers (press buttons, read the display), site supervisor / safety officer (receives help requests, acknowledges), site engineer (reviews logged evidence).

How it operates. The node bolts to the post of an existing shade. Every second it reads seat-zone air (SHT30 in a radiation shield), an outdoor reference (second SHT30), roof underside temperature (DS18B20), water availability (float) and the fan's real speed (tach) and energy (INA219). A worker presses **MODE** for the fan. In automatic mode the fan runs from 32 °C and **stops at ≥ 39 °C**, where published studies show a fan can add heat, and the display says so; manual control is never blocked. **HELP** latches a request (LED + 95 dB buzzer + OLED), survives power cuts, and can only be cleared by the staff **ACK** button on the side. Data go to a laptop over USB, or optionally over site Wi-Fi to the supervisor's dashboard.

Expected benefits. (1) A help request that cannot be lost or silently cleared. (2) Fault awareness: a stalled fan, dead sensor or stale data is reported, never shown as "cooling". (3) Evidence: paired seat-vs-reference and roof readings prove whether a shade upgrade worked. (4) Very low energy: ≈ 34 Wh/day versus 11–13 kWh per shift for a 1.5-ton AC. (5) ≈ ₹5,314 per site instead of building a new ₹94k–1.7 lakh shelter.

Why this design fits. An open shade cannot hold AC-cooled air; shade + air movement + monitoring is the realistic intervention. The node is offline-first (control runs on the ESP32, not the cloud), cheap, weatherproof and retrofittable.



3D model (CadQuery → STEP): IP65 controller box on aluminium bracket, 5-plate radiation shield with SHT30, 120 mm PWM fan with guards.

₹5,314
complete node, listed prices + allowances

3.2 W
typical draw (fan 70 %)

6
measured quantities, 1 actuator, 3 controls

> Status: design, firmware, CAD and simulation package. Firmware compiles in CI and its control logic has native tests; **no unit has been assembled or field-tested yet**. Prices checked online on 20 Oct 2026.

2. Component selection and justification

Selection criteria, in order: **(a) evidence capability** (feedback and measurement, not just control), **(b) cost**, **(c) accuracy adequate for a 1 °C decision margin**, **(d) power**, **(e) operating range for 25–45 °C shaded outdoor air and monsoon humidity**, **(f) 3.3 V / I²C compatibility**, **(g) Indian availability**.

Function	Selected	Why it meets the criteria	Rejected alternatives and why
Microcontroller	**ESP32-DevKitC (WROOM-32)**	₹499; 2 × I²C, 16 LEDC PWM channels (25 kHz fan PWM), interrupt tach input, Wi-Fi built in, flash for the help latch, hardware watchdog, −40…85 °C	Arduino Uno (no Wi-Fi, 2 kB RAM), Raspberry Pi (SD-card corruption on power loss, ~10× power, no hard real-time), ESP8266 (one ADC, fewer GPIO, no 2nd core for the Wi-Fi task)
Air temperature / RH (×2)	**Sensirion SHT30 on GY-SHT30-D**	Same typical accuracy as SHT31 (±0.2 °C over 0–65 °C, ±2 %RH) at less than half the price (₹179 vs ₹399); digital I²C; 0x44/0x45 lets two share one bus; 0.6 mA while measuring	DHT22 (slower, timing-critical 1-wire, poorer RH stability), BME280 (self-heating, pressure not needed), SHT31 (no accuracy gain in our 25–45 °C range)
Roof underside temperature	**DS18B20 waterproof probe**	₹49; ±0.5 °C (−10…85 °C); stainless, sealed; 1-Wire runs on long cable; one GPIO	IR thermometer (needs emissivity correction on a metal roof), NTC thermistor (needs ADC calibration, lead resistance)
Energy measurement	**INA219 breakout**	₹89; high-side current + bus voltage 0–26 V on I²C; 0.5 % class; measures the fan branch so energy is measured, not estimated	ACS712-5A Hall sensor (185 mV/A: only ≈ 60 mV signal at the 0.33 A fan load, noisy), datasheet power figures (not a measurement)
Actuator	**Arctic P12 Pro, 120 mm, 12 V, 4-wire**	Tach feedback (2 pulses/rev) proves the fan turns; 25 kHz PWM speed control; 0 rpm below 5 % PWM gives a true off; 77 CFM at 0.33 A (~4 W)	2-wire fans (no feedback: a stalled fan looks like a running one), 230 V pedestal fan (shock risk in a wet outdoor space, no feedback, 55–125 W)
Display	**SSD1306 0.96" I²C OLED**	₹130; readable status without a phone; shares the I²C bus; ~20 mA	LCD 16×2 (needs 5 V and 6 GPIO or an extra I²C backpack), phone app only (workers may not carry phones)
Controls	**3 × 12 mm IP65 metal momentary buttons**	Weatherproof, gloved-hand usable; HELP on the front, ACK on the side so only staff clear a request	Membrane keypad (UV/ heat ageing), touch sensor (false triggers with sweat/rain)
Alert	**SFM-27 active buzzer + 5 mm LED**	>95 dB, <12 mA from 12 V via 2N3904; visible + audible help/fault state	Passive piezo (needs tone generation, quieter)
Water status	**PP reed float switch**	Dry contact, no power, cheap; open circuit (incl. broken wire) reads “low / check”	Ultrasonic level sensor (cost, condensation errors), capacitive probe (fouling)
Power	**12 V 2 A SMPS + MP1584 buck to 5 V + 1 A fuse**	12 V feeds the fan directly; buck gives 5 V for the board at high efficiency; fuse protects the field wiring; ~3.6× current margin	Linear 7805 (≈60 % loss at 12→5 V), USB power bank (not for continuous outdoor use)
Enclosure	**ProtechT WPE16 IP65 ABS, 175×100×60**	Purchasable, IP65, room for the 90×70 board + modules; cable glands down + breathable vent manage monsoon rain and condensation	3D-printed PETG box (UV and heat creep near 60–70 °C roof air, not IP-rated)

3. Technical specification sheet

Component	Supply	Current	Range	Accuracy / rating	Interface	Dimensions	Datasheet
ESP32-WROOM-32E (DevKitC)	3.0–3.6 V module; 5 V via board LDO	20–68 mA modem-sleep; Wi-Fi TX 239 mA avg / 379 mA peak; 10 µA deep sleep	−40…85 °C	—	2 × I²C, LEDC PWM, GPIO, Wi-Fi 802.11 b/g/n	board 54.4 × 27.9; module 18 × 25.5 × 3.1	ESP32-WROOM-32E datasheet (Espressif)
SHT30 (×2)	2.15–5.5 V (3.3 V used)	0.6 mA measuring; 0.2 µA idle	0–100 %RH; −40…125 °C	±0.2 °C (0–65 °C), ±2 %RH typ; τ63 RH 8 s	I²C 0x44 / 0x45	small breakout; measure before fixing	SHT3x-DIS datasheet (Sensirion)
DS18B20 probe	3.0–5.5 V	1 mA active; 0.75 µA standby	−55…125 °C	±0.5 °C (−10…85 °C); 12-bit, 750 ms	1-Wire, 4.7 kΩ pull-up	Ø6 × 50 mm probe, 1 m lead	DS18B20 datasheet (Analog Devices)
INA219	3–5.5 V logic; bus 0–26 V	0.7 mA	±3.2 A with 0.1 Ω shunt	0.5 % max (B grade); 0.8 mA LSB	I²C 0x40	≈ 25 × 22 mm	INA219 datasheet (TI)
SSD1306 OLED	3.3–5 V module	≈ 20 mA fully lit, < 5 mA text	−40…85 °C	128 × 64 px, active 21.7 × 10.9 mm	I²C 0x3C	27.5 × 27.5 × 11 mm	SSD1306 controller datasheet
Arctic P12 Pro fan	12 V	0.33 A (~4 W)	600–3000 rpm; 0 rpm < 5 % PWM	77 CFM / 131 m^3/h; 6.9 mmH_2O	4-wire: PWM 25 kHz, tach 2 p/rev	120 × 120 × 25 mm	Arctic P12 Pro listing (specs)
2N3904 (Q1, Q2)	VCEO 40 V	IC 200 mA max	—	hFE 100–300 @ 10 mA; VCE(sat) 0.2 V	4.7 kΩ base, 10 kΩ B-E	TO-92	2N3904 datasheet (onsemi)
MP1584EN buck	4.5–28 V in	3 A out	0.8–20 V out (set 5.0 V)	IC marked NRND → MP2338 for production	—	22 × 17 × 4 mm	MP1584 datasheet (MPS)
SFM-27 buzzer	3–24 V (12 V used)	< 12 mA	—	> 95 dB	via Q2 on IO14	measure before drilling	shop listing
12 mm IP65 button (×3)	—	3 A / 250 V AC contact	—	IP65	to GND, internal pull-up	12 mm panel hole	shop listing
PP float switch	—	0.5 A switching	−10…60 °C	NO reed	IO35 + 10 kΩ pull-up	measure before fitting	shop listing
Enclosure WPE16	—	—	outdoor, shaded mount	IP65	5 × PG7 + M12 vent	175 × 100 × 60 mm	shop listing

3b. Power budget and datasheet design rules

Power budget (12 V input)

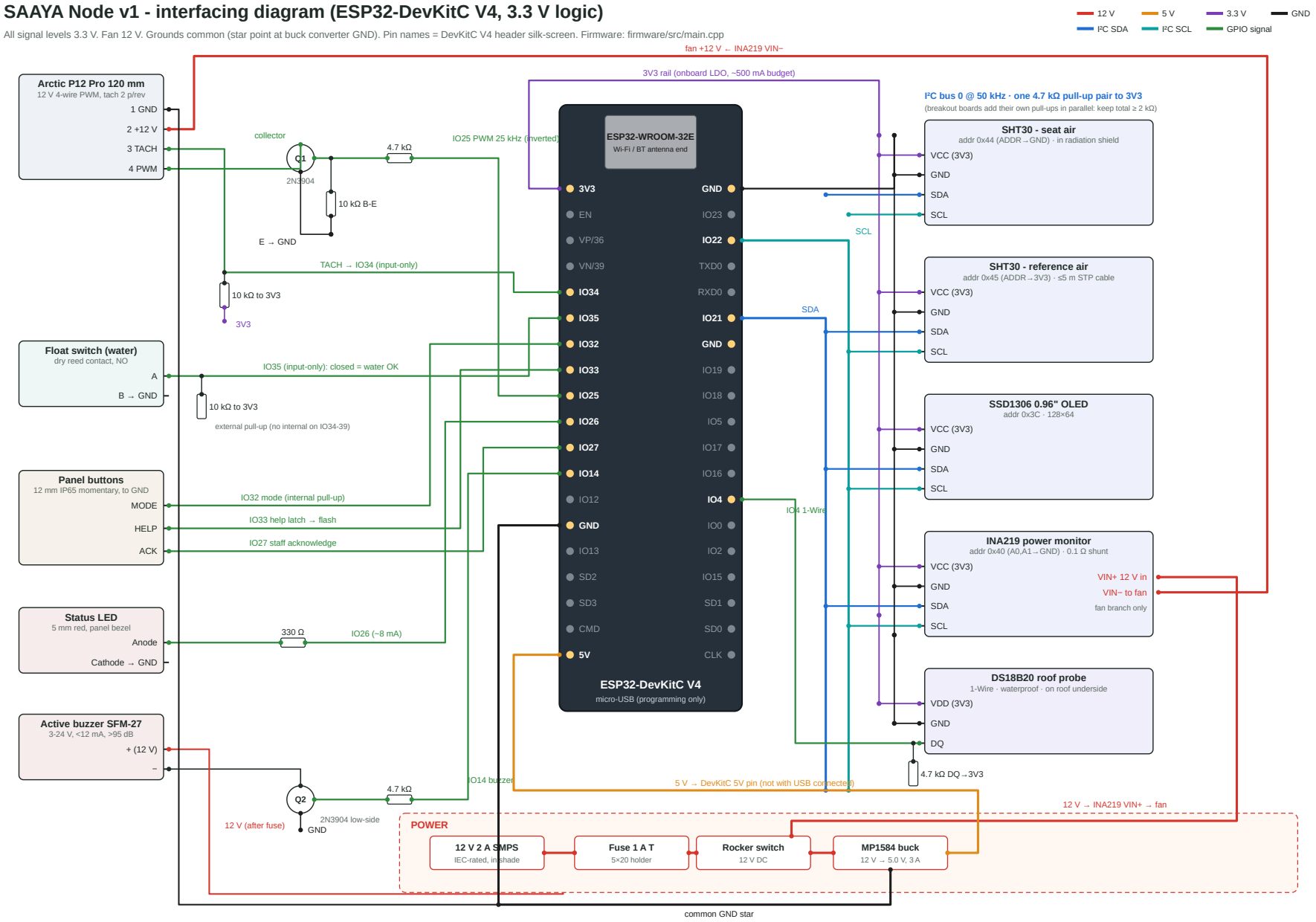
Load	Rail	Typical mA	Peak mA	Note
ESP32-DevKitC (Wi-Fi off)	5 V	70	70	modem-sleep 20–68 mA + LDO
ESP32 Wi-Fi uplink (optional)	5 V	0	380	TX peak 379 mA
OLED	3.3 V	10	20	
SHT30 ×2 + DS18B20 + INA219	3.3 V	3	4	
LED	3.3 V	0	8	only on help/fault
Fan, Arctic P12 Pro	12 V	230	330	70 % / 100 % PWM
Buzzer	12 V	0	12	only on help

12 V input ≈ **271 mA typical (3.2 W)**, **578 mA peak (6.9 W)**, assuming 85 % buck efficiency. The 12 V 2 A adapter gives > 3× margin; the 1 A slow fuse clears a wiring short. Daily energy, fan 8 h + controller 24 h ≈ **34 Wh** — a 20 W panel + 12 V 7 Ah battery could run it off-grid (option, not costed).

Design rules taken from the datasheets

- IO34–IO39 are input-only with no internal pull-ups → external 10 kΩ on tach (IO34) and float (IO35).
- 4-wire fan spec (Intel rev 1.2, Noctua): 25 kHz PWM; fan runs at **full speed if the PWM line is undriven**; tach 2 pulses/rev open collector → if the ESP32 crashes the fan fails *on*, not off.
- DevKitC: power from USB *or* 5V pin, never both → USB only for programming.
- INA219 bus ≤ 26 V; placed high-side in the 12 V fan branch only.
- Two SHT30 share one bus via ADDR (0x44 low, 0x45 high); ADDR never left floating.
- MP1584 IC is “not recommended for new designs” → fine for the prototype; MP2338 for production.

4. Interfacing diagram



4b. ESP32 pin map

ESP32 pin	Function	Dir	Conditioning	Connected to
IO21 / IO22	I²C SDA / SCL @ 50 kHz	bidir	4.7 kΩ to 3V3	SHT30 seat 0x44, SHT30 reference 0x45, OLED 0x3C, INA219 0x40
IO25	Fan PWM 25 kHz (LEDC ch 0)	out	4.7 kΩ → Q1 2N3904, 10 kΩ B-E; output inverted in firmware	Fan pin 4 (PWM). ESP32 reset → line floats → fan full speed
IO34	Fan tach	in only	10 kΩ to 3V3 (no internal pull-up)	Fan pin 3, 2 pulses/rev
IO4	DS18B20 1-Wire	bidir	4.7 kΩ to 3V3	Roof underside probe
IO35	Float switch	in only	10 kΩ to 3V3; closed = water OK	Float in water can
IO32	MODE button	in	INPUT_PULLUP, 35 ms debounce	Front panel
IO33	HELP button	in	INPUT_PULLUP; latch stored in flash	Front panel (red)
IO27	ACK button	in	INPUT_PULLUP	Right side wall (staff)
IO26	Status LED	out	330 Ω (≈ 8 mA)	Front panel
IO14	Buzzer	out	4.7 kΩ → Q2 2N3904 low side	SFM-27 on 12 V
5V / GND	Board supply	power	MP1584 5.0 V; never with USB connected	Common GND star at buck
3V3	Sensor/logic supply	power	DevKitC LDO	All I²C modules, DS18B20, pull-ups

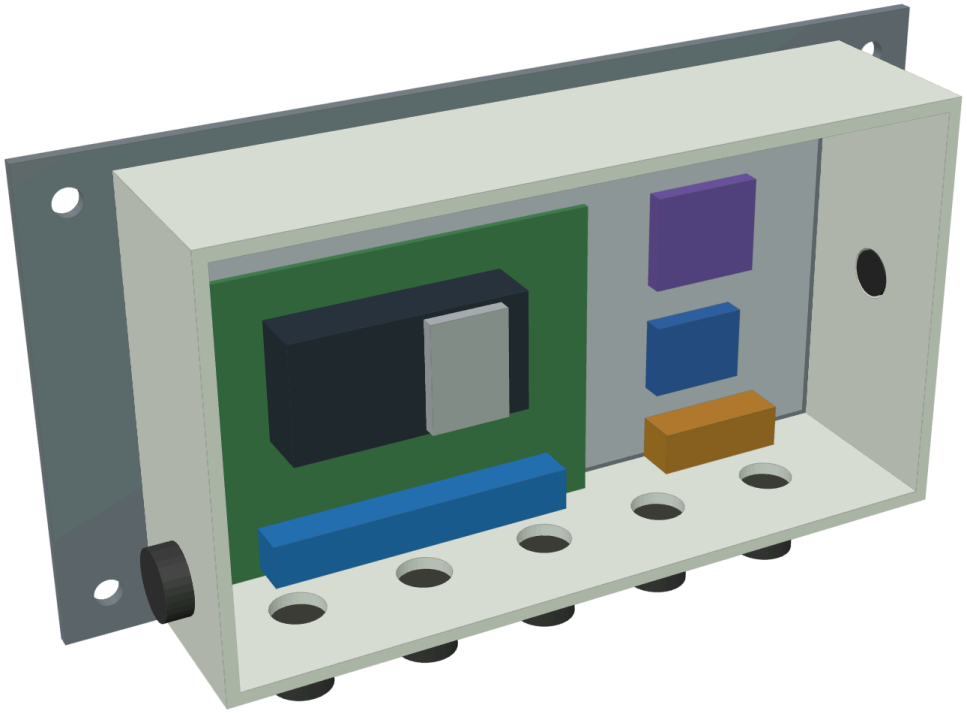
Unused: strapping pins IO0/IO2/IO12/IO15 avoided; IO6–IO11 reserved for flash. Firmware: `firmware/src/main.cpp`, control logic `firmware/include/controller.h`. Bus wiring: one Cat5e STP pair per signal with its own ground (SDA+GND, SCL+GND, 3V3+GND).

4c. Bill of materials and cost (₹, checked 20 Oct 2026)

Function	Part	Qty	Unit	Line	Status
Microcontroller	ESP32-DevKitC, 38-pin, ESP32-WROOM-32	1	₹499	**₹499**	listed
Air T/RH (seat + reference)	GY-SHT30-D module, Sensirion SHT30	2	₹179	**₹358**	listed
Roof surface temperature	DS18B20 waterproof probe, 1 m	1	₹49	**₹49**	listed
Fan power monitor	INA219 module (0.1 Ω shunt class)	1	₹89	**₹89**	listed
Local display	SSD1306 0.96" 128×64 I²C OLED	1	₹130	**₹130**	listed
Actuator	Arctic P12 Pro 120 mm 4-wire PWM fan	1	₹910	**₹910**	listed
PWM + buzzer drivers	2N3904 NPN, TO-92	2	₹6	**₹12**	listed
MODE / HELP / ACK	12 mm IP65 metal momentary (ProMax)	3	₹159	**₹477**	listed
Status light	5 mm red LED + 8 mm bezel	1	₹4	**₹4**	listed
Help sounder	SFM-27 active buzzer, 3–24 V	1	₹60	**₹60**	allowance
Water availability	PP float switch, reed, NO	1	₹175	**₹175**	listed
Power supply	12 V 2 A SMPS adapter	1	₹189	**₹189**	listed
5 V rail	MP1584EN buck module	1	₹49	**₹49**	listed
Enclosure	ProtechT WPE16 IP65 ABS 175×100×60	1	₹949	**₹949**	listed
Cable entries	PG7 nylon cable gland	5	₹15	**₹75**	listed
Protection	5×20 fuse holder + 1 A T fuse	1	₹19	**₹19**	allowance (listed items out of stock)
Board + passives	perfboard 90×70, headers, resistors, terminal blocks	1	₹150	**₹150**	allowance
Power switch / vent	rocker switch + M12 breathable vent	1	₹120	**₹120**	allowance
Field cable	Cat5e STP 10 m (sensor runs)	1	₹250	**₹250**	allowance
Radiation shields	2 × DIY 5-plate PP shield on M5 rods	1	₹300	**₹300**	allowance
Mounting	3 mm Al bracket, M6 anchors / 2 hose clamps, UV conduit	1	₹450	**₹450**	allowance
Total	listed shop prices ₹3,965 + allowances ₹1,349			**₹5,314**	excl. shipping, tools, labour

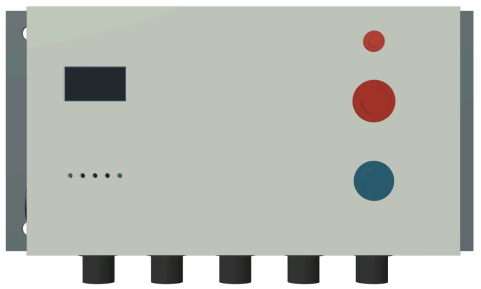
“listed” = price read on the linked Indian shop page; “allowance” = estimate. Cheaper options: P12 PWM PST fan (≈ ₹568 each in a 5-pack, 56 CFM) instead of P12 Pro; generic IP65 box instead of WPE16. Not cut: the tach fan, the paired reference sensor and calibration time — without them the node can no longer prove anything.

5. 3D model design (CadQuery, STEP + STL)

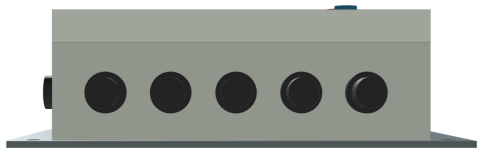


Lid removed: 90×70 perfboard with ESP32-DevKitC and field terminals (left); INA219, MP1584 and fuse (right); M12 vent on the left wall; ACK button on the right wall; 5 PG7 glands underneath.

Feature	Dimension (mm)	Reason
Enclosure	175 × 100 × 60, wall 3.0, lid depth 15	Purchased IP65 box; fits board + modules with ≥ 10 mm wiring space
OLED window	25 × 14 at x 15, z 62	Covers the 21.7 × 10.9 active area with margin; top-left = first thing read
HELP / MODE / LED	Ø12 / Ø12 / Ø8 on x = 140, z = 62 / 30 / 86	One vertical column at the right hand; LED above HELP so the request state is next to the button
ACK (side)	Ø12 on right wall, y 38, z 50	Deliberate staff action; not reachable by accident from the front
Buzzer grille	5 × Ø2, pitch 5, at x 27.5, z 32	Sound path without a large water entry
Cable glands	5 × PG7 Ø12.5, x = 25, 55, 85, 115, 145, y 38	All entries face down → rain drains away; 30 mm pitch leaves spanner room
Breather vent	M12 Ø12.5 left wall, y 38, z 18	Equalises pressure, prevents condensation pumping in day/night cycles
Back bracket	215 × 110 × 3 Al; 4 × Ø6.5 on 194 × 90; 4 slots 8 × 16	M6 anchors to wall, or two hose clamps round a 40–90 mm post
Radiation shield	5 plates Ø110, 14 pitch, 3 × M5 rods; SHT30 at centre	Blocks sun and hot-roof radiation while letting air through
Fan	120 × 120 × 25, wire guards both faces	Aimed at the seated torso from ≈ 1 m, 30–45° down



Front panel



Underside: 5 PG7 glands, vent on the left wall

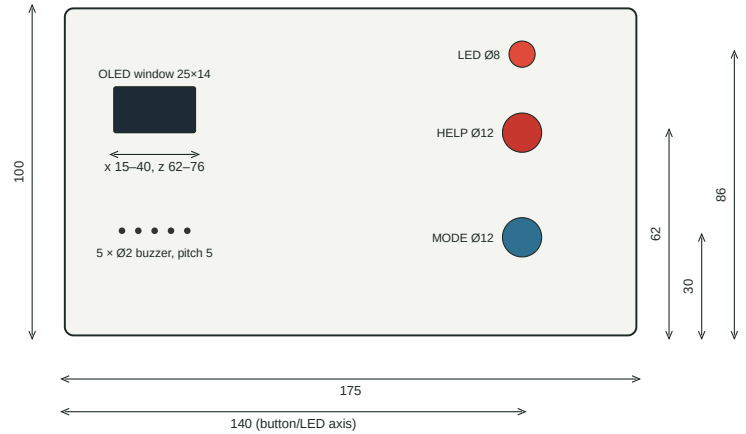
Interference check over all 23 solids: none above 1 mm³. Interactive model: **saaya-verify.vercel.app/node.html**; files: `cad/node/`.

5b. Dimensioned enclosure drawing

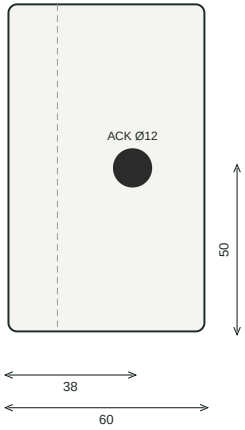
SAAYA Node v1 - enclosure drilling and mounting drawing

All dimensions in mm. Datum: front-left-bottom corner. Purchased IP65 ABS box 175 × 100 × 60 (ProtechT WPE16); machine holes to this plan.

FRONT VIEW (lid)

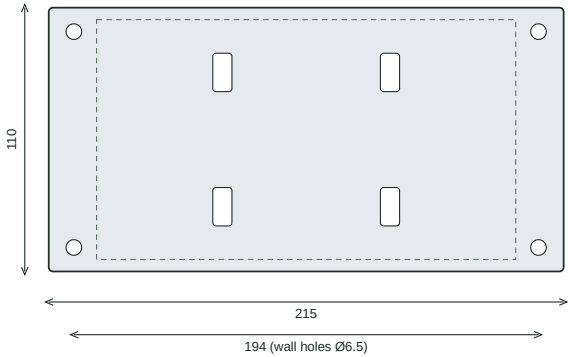


RIGHT SIDE VIEW (staff ACK button)



Front (lid) on the left. Bracket 3 mm behind the back face.

BACK BRACKET (3 mm aluminium)



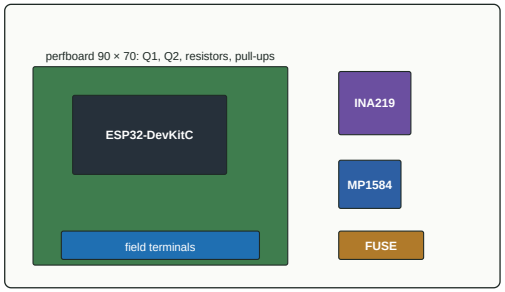
4 × Ø6.5 for M6 anchors, 194 × 90 centres
4 × 8 × 16 slots for two stainless hose clamps (post Ø 40–90)
dashed: box outline 175 × 100

BOTTOM VIEW (cable entries face the ground)



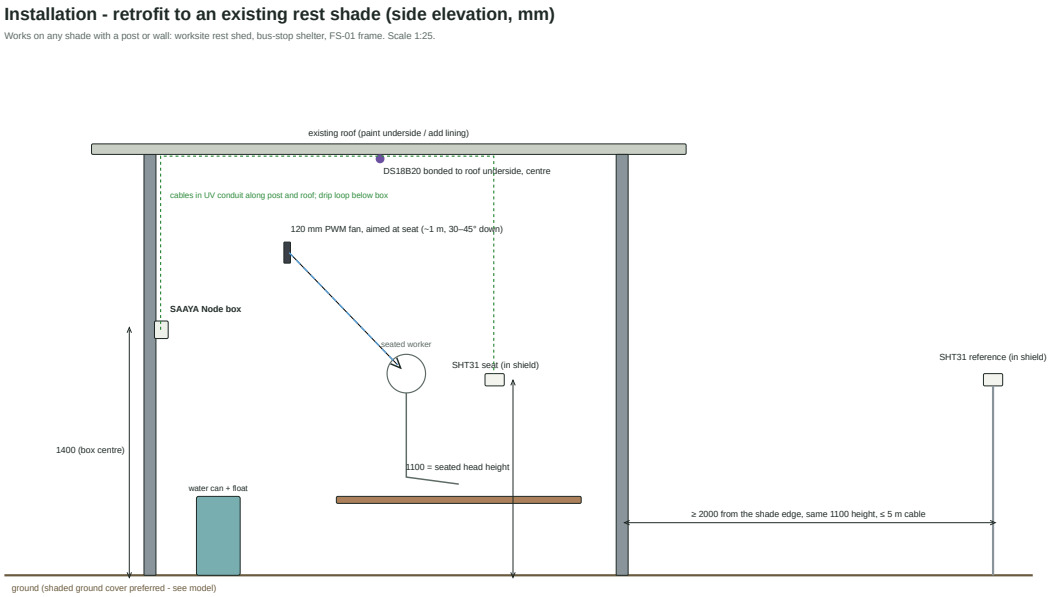
5 × PG7 Ø12.5 at x = 25, 55, 85, 115, 145 on y = 38 (centre of the body). PG7 nut ≈19 across corners: 30 mm pitch leaves 11 mm for a spanner.
M12 breathable vent Ø12.5 on the LEFT wall at y = 38, z = 18.

INTERNAL LAYOUT (on 160 × 86 back plate)



Antenna end of the WROOM can stays ≥15 mm from metal; cables enter from below only.

6. Deployment capability



Retrofit to an existing shade. Box centre 1400 mm (reachable seated or standing, above splash); seat sensor 1100 mm (seated head height); reference ≥ 2 m outside the shade at the same height; roof probe bonded to the underside centre.

Item	Placement
Node box	Shaded side of a post or wall, 1400 mm, glands down, drip loop under the box
Seat sensor	In shield beside the bench, 1100 mm, ≈ 0.4 m from the head, ≤ 2 m cable
Reference sensor	In shield on its own pole, ≥ 2 m from the shade edge, same height, ≤ 5 m STP cable
Roof probe	Bonded with thermal tape to the roof underside centre, shielded from direct sun
Fan	On the post or a roof member, ≈ 1 m from the seat, 30–45° down
Float	Inside the drinking-water can; wire leaves through the lid

Installation area

Construction or road-work site, farm, bus-stop or factory yard with an existing shade of ≈ 2.4 × 2 m for 4–6 seated workers; one node per rest shade. Larger rest areas (e.g. a 30–60 worker site with several sheds) use one node per shed.

Mounting

Four M6 anchors into a wall or two stainless hose clamps on a 40–90 mm post; no welding or drilling of the structure. Cables run in UV-stabilised conduit.

Power availability

Site 230 V socket → 12 V 2 A adapter kept in shade (≤ 7 W peak). Off-grid option: 20 W panel + 12 V 7 Ah battery (daily need ≈ 34 Wh).

Connectivity

Offline-first: all control on the ESP32. Data: USB serial to a laptop running the local API, or the optional Wi-Fi build (env `esp32dev_wifi`) posting each frame to the supervisor's laptop on site Wi-Fi with a device token; Wi-Fi runs in a separate task so a weak signal can never delay buttons or the fan. No cloud account or SIM needed; GSM/LoRa is a later option.

Environmental conditions

Shaded air 25–45 °C, monsoon rain, dust, 43–51 % afternoon RH in hot months. All parts rated ≥ 60 °C (ESP32, OLED −40…85 °C); IP65 box, glands down, breather vent; box and adapter kept out of direct sun.

Maintenance

- **Weekly:** wipe radiation shields and fan guard; check float and water can.
- **Monthly:** check gland tightness, cable chafe, fan tach vs. command on the display.
- **Quarterly:** co-locate the two SHT30s for 20 min and record the offset; repaint/clean the roof top coat if soiled.
- **On fault:** OLED states the fault (sensor / fan feedback / water); parts are plug-in and swap in minutes.

7. Operating logic, verification and online tools

State / event	System response
Air < 32 °C, AUTO	Fan off (hysteresis: starts ≥ 32 °C, stops < 31 °C)
32–37 °C, AUTO	Fan 50 % PWM; display normal
37–39 °C	Fan allowed; display "FAN: LIMITED BENEFIT" (older / medicated users)
≥ 39 °C	AUTO fan stops (restarts < 38.5 °C); display "HOT: FAN MAY ADD HEAT"; MANUAL still allowed
MODE pressed	Toggle manual 70 % ↔ off
HELP pressed	Latch → LED + buzzer + OLED; stored in flash; survives reboot
ACK (staff)	Clears the latch; HELP wins if pressed together
Fan commanded, tach < 100 rpm after 3 s	"FAN FEEDBACK FAULT"; any cooling claim invalidated
Sensor missing / invalid	"SENSOR FAULT"; readings unavailable (never zero); AUTO inhibited
Float open (or wire broken)	"WATER LOW / CHECK"
Firmware stall	5 s hardware watchdog restart; help latch restored

What has been verified

- ESP32 firmware compiles in GitHub Actions (PlatformIO, espressif32 6.10.0).
- Control logic: native C++ tests (latch, manual, fault, start-up grace, timer rollover, hysteresis, fan-benefit screen); identical rules tested in Python and JavaScript.
- CAD: 23 solids valid, no interference > 1 mm^3; STEP/STL exported.
- Evidence API: 89 Python tests; browser tests on the public site.

Online tools used

- **Wokwi** (ESP32 simulator): `firmware/diagram.json` wires the same pins to an ESP32-DevKitC V4, SSD1306, DS18B20, buttons, LED, buzzer and float switch. Wokwi has no SHT3x/INA219/fan part, so the simulation exercises the fault paths (sensor fault, fan-feedback fault, help latch). Prepared, not yet run.
- **GitHub Actions** (CI compile + tests), **Vercel** and GitHub Pages (live 3D model and documentation), manufacturer datasheets and Indian shop listings (linked below).

> **Not yet proven:** real air speed at the seat, sensor-shield bias, buck efficiency in heat, IP rating after drilling, and any health benefit. Next step: build two units, co-locate sensors, then run paired trials on three clear days.

Sources

ESP32-WROOM-32E datasheet (Espressif): https://documentation.espressif.com/esp32-wroom-32e_esp32-wroom-32ue_datasheet_en.pdf
ESP32 series datasheet (Espressif): https://documentation.espressif.com/esp32_datasheet_en.pdf
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Other figures: Vellore climate (IMD normals via Wikipedia), NDMA draft Guidelines for Cooling Centers (2025), fan-use thresholds (Morris et al. 2021, WHO), AC input power (Blue Star / Voltas spec p ages) — full citations in docs/DEFENSE.md.