

Ventilation of the Vélo Tunnel Québec

Sizing, operation, air quality and costs of a 150 km underground cycling network

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THE ESSENTIALS

A **bike** tunnel is one of the easiest tunnels to ventilate: **no exhaust** to remove. Everyday air quality (CO₂, heat, humidity) is trivial.

- **CO₂**: ~645 ppm at peak, far from the comfort threshold (1,000 ppm) and the safety limit (5,000 ppm).
- **Comfort**: ~17 °C and 55–60 % humidity; the rock at 8–10 °C cools the tunnel for free in summer.
- **Noise**: 60–65 dB(A) with silenced fans.
- **The real challenge**: smoke from a lithium-battery fire — it sizes the fans, not CO₂.
- **Costs**: ~\$600M to build (within the \$8.7B) and ~\$3–4.5M/yr of electricity.

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1 Executive summary

Ventilating a road tunnel is mainly about removing vehicle exhaust and controlling the smoke of a car or truck fire. The Vélo Tunnel Québec has neither: no combustion engines run inside it. The only internal loads to handle are the carbon dioxide, heat and water vapour given off by cyclists — a problem closer to a crowded gym than to an underground motorway.

This analysis shows, through calculation, that everyday air quality is easy to guarantee: a longitudinal breeze of 1.5 m/s keeps CO₂ around 645 ppm even at peak, and the temperature stays comfortable thanks to the natural coolness of the bedrock ten metres down. The factor that actually sizes the system is not everyday air but **smoke control** in the event of a lithium-battery fire. The capital cost, estimated at about \$600M, is realistic, dominated by the surface ventilation shafts; the operating cost (~\$3 to 4.5M/year of electricity) is minor thanks to hydroelectricity.

2 Why a bike tunnel is easy to ventilate

In a motorway tunnel, 80 to 90 % of the ventilation power goes to diluting carbon monoxide, nitrogen oxides and particulates from vehicles, and to clearing the smoke of a fire that can reach 5 to 100 MW of heat output. All of that disappears here.

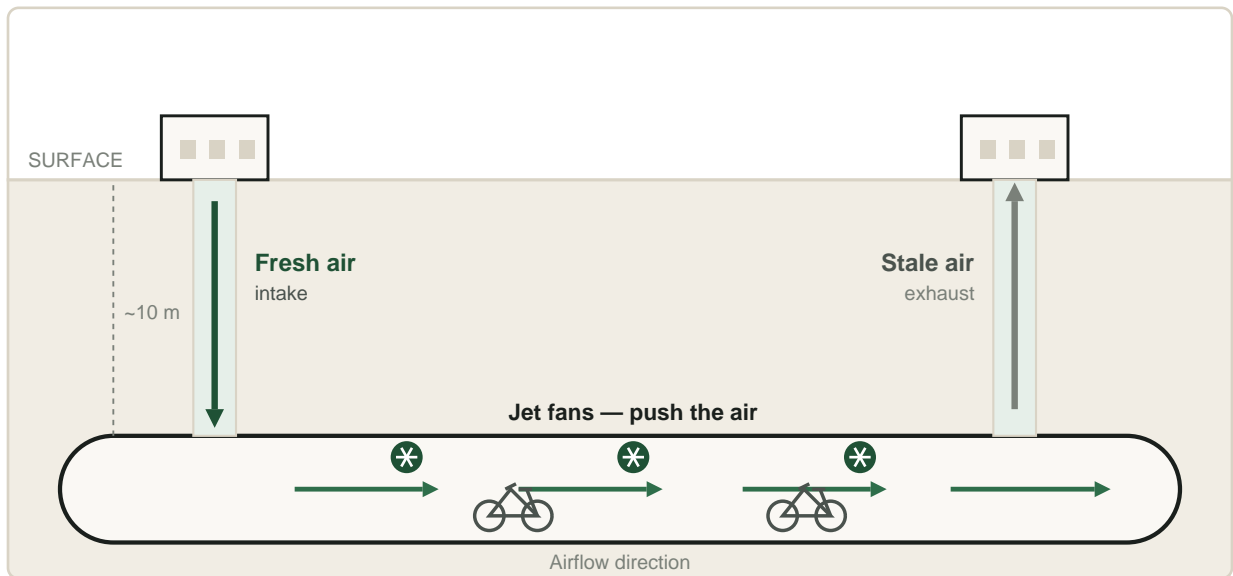
The only internal loads of a bike tunnel are:

- the **carbon dioxide (CO₂)** exhaled by cyclists;
- the **heat** from their metabolism and from e-bike motors;
- the **water vapour** (breathing and sweat).

These three loads are small and dilute easily. That is what makes the figures in this document so comfortable — and it is a structural advantage of the concept, not circumstantial optimism.

3 How it works

The system relies on **longitudinal ventilation by jet fans**, the standard and least expensive technology for long tunnels. Jet fans fixed to the crown push the air along the tunnel, like a chain of small gusts of wind. Fresh air enters through surface shafts, travels the tunnel slowly picking up CO₂ and heat, then leaves through other shafts.



Fresh air comes down through surface shafts, the jet fans push it along the tunnel, and stale air leaves through other shafts.

Architecture used

Element	Role	Location
Silenced jet fans	Maintain the longitudinal airflow	~ every 250 m
Supply / exhaust shafts	Fresh air in, stale air out, smoke extraction	~ every 2 km, often at stations
Air-quality sensors	CO ₂ , CO, particulates, temperature, humidity, air velocity	every 200 m
Control centre + automation	Modulates fan speed with traffic	central, 24/7
Smoke-stop airlocks	Compartmentalise during a fire	every 500 to 1,000 m

The economic key: modulation

At night, with almost no one in the tunnels, CO₂ and heat are negligible: the fans idle or stop. At peak hours, the sensors ramp them up. This sensor-driven modulation is what keeps the electricity bill low (section 12).

4 Assumptions and baseline data

All the calculations below rest on the values given here. The per-cyclist values are deliberately conservative: an e-bike on pedal assist actually produces less CO₂ than shown.

Parameter	Value used	Note
Tunnel diameter	3.6 m	Prufrock standard
Free cross-section for air	~ 7 m ²	above the deck (geometric calc)
Network length	150 km	—
Bedrock temperature at 10 m	8 to 10 °C	stable year-round (major advantage)

Parameter	Value used	Note
CO ₂ per cyclist	1.5 L/min = 0.09 m ³ /h	conservative (e-bike: ~1.0–1.2)
Heat per cyclist	~ 450 W	metabolism + motor + friction
Water vapour per cyclist	~ 400 g/h	breathing + sweat, cool environment
Air velocity, normal mode	1.5 m/s	barely perceptible breeze
Air velocity, smoke emergency	~ 2.5 m/s	critical smoke-control velocity

Useful benchmark: a cyclist riding at 22 km/h already faces their own 6.1 m/s headwind. A 1.5 m/s ambient breeze is therefore marginal for them.

5 Load to size for 100,000 users

The classic mistake is to size for 100,000 people present *at the same time*. In reality, what matters is the number present **simultaneously in the tunnels at peak hour**, far lower because users are only passing through.

100,000 users/day x 2 trips (round trip)	= 200,000 trips/day
Peak-hour factor (~9% of trips)	= 18,000 trips/peak hour
Mean time in tunnel: 8 km / 22 km/h = 0.36 h	~ 22 minutes
Present at once = 18,000 x 0.36	~ 6,500 cyclists

We keep **~7,000 simultaneous cyclists** at peak (a design value, slightly conservative), spread over 150 km, i.e. a density of **~47 cyclists/km** — one cyclist roughly every 21 m, all directions combined. For a cycling facility at peak hour, that is a steady but free-flowing stream. At full maturity (the 200,000 users targeted by the project), this would rise to ~13,000–14,000 simultaneous — a case covered in section 13.

Since the network is ventilated by **sections**, we reason on a representative 2 km section between two shafts, holding $47 \times 2 = \mathbf{94}$ cyclists at peak.

6 Air quality — carbon dioxide (CO₂)

CO₂ produced in a 2 km section at peak:

$$94 \text{ cyclists} \times 0.09 \text{ m}^3/\text{h} = 8.5 \text{ m}^3/\text{h} \text{ of CO}_2$$

Longitudinal airflow at 1.5 m/s:

$$7 \text{ m}^2 \times 1.5 \text{ m/s} \times 3,600 = 37,800 \text{ m}^3/\text{h} \text{ of air}$$

Rise in CO₂ concentration from one end of the section to the other:

$$8.5 / 37,800 = 0.000225 = 225 \text{ ppm}$$

Air enters at ~420 ppm (outdoor) and leaves at **~645 ppm**. The comparison with reference thresholds is conclusive:

CO ₂ benchmark	Concentration
Outdoor air (intake)	~420 ppm
Our tunnel at peak hour	~645 ppm
Indoor comfort threshold	1,000 ppm
Acceptable transient space	1,500 ppm
Health & safety limit (8 h exposure)	5,000 ppm

Stress test

If we double the density *and* everyone pedals hard at 2 L/min (0.12 m³/h):

$$188 \text{ cyclists} \times 0.12 \text{ m}^3/\text{h} = 22.6 \text{ m}^3/\text{h} \text{ of CO}_2$$

$$22.6 / 37,800 = 598 \text{ ppm} \rightarrow \text{outlet} \sim 1,020 \text{ ppm}$$

Still below the comfort threshold, and far from the safety limit. **Conclusion:** CO₂ is not an issue. A breeze of 1 to 2 m/s is enough in every case.

7 Heat and the role of the ground

Heat released in a 2 km section at peak:

$$94 \text{ cyclists} \times 450 \text{ W} = 42.3 \text{ kW}$$

$$+ \text{LED lighting } (\sim 9 \text{ kW/km}) = 18 \text{ kW}$$

$$\text{Total} \sim 60 \text{ kW}$$

The air's capacity to carry this heat (mass flow × specific heat):

$$37,800 \text{ m}^3/\text{h} = 10.5 \text{ m}^3/\text{s} \times 1.2 \text{ kg/m}^3 = 12.6 \text{ kg/s}$$

$$12.6 \text{ kg/s} \times 1,005 \text{ J/kg.K} = 12.7 \text{ kW per degree C}$$

$$\text{Rise} = 60 / 12.7 = 4.7 \text{ degrees C over the section}$$

Air entering at ~12 °C would therefore leave at ~17 °C — comfortable for the effort.

The decisive asset: the rock

Ten metres down, the rock around the tunnel sits at **8–10 °C year-round** in the Québec region. The walls act as a huge heat sink:

- **Summer:** the tunnel is naturally air-conditioned. Warm surface air is cooled by the rock — a huge advantage during a city heatwave.
- **Winter:** mainly the entrances need tempering (the budget already includes entrance heating), not the tunnel itself.

Conclusion: heat is comfortable, and the passive geothermy of the Québec ground does much of the work for free.

8 Humidity and condensation

Water vapour added in a 2 km section at peak:

94 cyclists x 400 g/h = 37.6 kg/h of water vapour
 Air: 37,800 m³/h x 1.2 kg/m³ = 45,360 kg/h
 Humidity rise = 37,600 g / 45,360 kg = 0.83 g of water / kg of air

That is modest: at 15 °C, going for example from 50 % to ~58 % relative humidity. The cyclists themselves do not “flood” the tunnel.

The real issue: summer condensation

In summer, warm humid outdoor air drawn into a 10 °C tunnel reaches its dew point against the cool walls, causing condensation, slippery floors and mould risk. The remedy:

- **drainage and pumping** of the tunnel (already budgeted);
- **conditioning / dehumidification of the supply air** at the shafts during summer humidity peaks;
- slope and gutters to drain the water.

In winter, very dry outdoor air makes the tunnel pleasantly dry instead. **Conclusion:** the cyclists' contribution is minor; the main task is controlling summer condensation through drainage and supply-air treatment.

9 Noise

A raw jet fan is loud: 85 to 95 dB(A) at 1 m. As is, that would be unacceptable for cyclists passing beneath it. The solution, standard wherever there are pedestrians or cyclists, is to use **silenced fans (attenuators)**, combined with the acoustic absorption of the walls (textured concrete and rock-wool panels already planned).

Environment	Sound level
Quiet library	~40 dB(A)
Tunnel, off-peak (fans idling)	~55–60 dB(A)
Tunnel, peak hour (fans working)	~62–68 dB(A)
Normal conversation	~60 dB(A)
Vacuum cleaner, at 1 m	~70 dB(A)
Annoyance threshold, prolonged exposure	~70+ dB(A)
Jet fan WITHOUT silencer, at 1 m (to avoid)	85–95 dB(A)

A continuous background of 60–65 dB(A) is not only acceptable, it is rather pleasant: the “soft hum” described on the Acoustics page, a white noise that masks stray sounds and softens the echo. **Point to write into the tender:** silenced jet fans, failing which the level exceeds 85 dB.

10 Fire safety: smoke, the real sizing factor

Everything above is easy. The system is in fact sized by the worst credible fire, which, in a bike tunnel, is a **lithium-ion battery thermal runaway** (e-bike or e-scooter).

	Lithium battery fire	Car fire	Truck fire
Heat release	tens to a few hundred kW	5–8 MW	30–100 MW

	Lithium battery fire	Car fire	Truck fire
Smoke	dense, highly toxic, fast	toxic	very toxic
Extinguishing	difficult, re-ignition	manageable	difficult

The power stays far below a vehicle's, but the smoke is dense, toxic and fast. The strategy:

- **Push the smoke to one side** at the critical velocity (~2.5 m/s) to keep the other side breathable — the jet fans already installed easily reach this regime.
- **The real difficulty is two-way traffic:** users downstream of the fire end up in the plume. Hence the importance of the measures already planned: emergency exits (200–300 m), refuge niches (100 m), smoke-stop airlocks (500–1,000 m) and control-centre management.
- **Smoke extraction at the shafts** (drawing it up to the surface): the cleanest solution, to be shared with the fire-suppression budget.

Conclusion: manageable with proven methods, but this is THE engineering challenge. It is the critical velocity (~2.5 m/s), not CO₂, that sets the fan size.

11 Capital cost

Bottom-up reconstruction of the budget's "Ventilation and air filtration" line (\$600M):

Component	Quantity	Unit cost	Subtotal
Silenced jet fans (installed)	~1,200	~\$60,000	\$72M
Surface shafts (supply / exhaust / smoke)	~75	~\$5M	\$375M
Air-filtration units	~40	~\$1M	\$40M
Air-quality sensors	~750	~\$5,000	\$3.75M
Automation, SCADA, dampers, wiring	—	—	~\$40M
Bottom-up subtotal			~\$531M
Internal engineering margin			~\$70M
Total (~ project budget)			~\$600M

An honest reading

- The **jet fans themselves are cheap** (~\$72M, 12 % of the line). That is deceptively reassuring.
- The **surface shafts dominate** (~\$375M, ~63 %). In a dense urban setting, a shaft with a surface structure, a large axial fan, land acquisition and permits is expensive. Co-locating with the ~150 stations lowers the marginal cost — that is the argument that makes the \$600M tenable.
- **Upside risk:** a shaft every 1.5 km (~100 shafts) or costlier urban land could push the line to \$700–800M. The 20 % project contingency (\$1.45B) absorbs this kind of gap.

Conclusion: the \$600M is realistic but it is the most optimistic line in the budget, and its sensitive point is the number and cost of urban shafts.

12 Operating cost

Installed fan power:

Jet fans: $\sim 1,200 \times \sim 15 \text{ kW} = \sim 18 \text{ MW}$

Shafts : $\sim 75 \times \sim 75 \text{ kW} = \sim 5.6 \text{ MW}$

Total : ~ 22 to 24 MW installed

Real load factor (modulation): ~ 25 to 30%

-> Average power ~ 5 to 6.6 MW

-> Annual energy: $44,000$ to $58,000 \text{ MWh/yr}$

The project budget uses **44,000 MWh/yr**, which corresponds to aggressive modulation (fans nearly off at night). A less optimistic estimate gives $\sim 58,000 \text{ MWh/yr}$. Reality is probably within this range. At Hydro-Québec's tariff (~ 7 to 10 cents/kWh for this kind of large power):

$44,000$ to $58,000 \text{ MWh} \times \sim \$0.07\text{--}0.10/\text{kWh} = \$3\text{--}4.5\text{M/yr}$

Conclusion: $\sim \$3$ to 4.5M/yr , a minor item thanks to hydroelectricity. Since energy is only $\sim 5\%$ of the annual operating budget ($\$174\text{M}$), even a large underestimate of ventilation consumption would have a negligible effect on the total. The budget is not fragile on this point.

13 Sensitivity and robustness

What happens at full maturity, when the network reaches the $200,000$ users targeted? Simultaneous occupancy doubles to $\sim 13,000\text{--}14,000$ cyclists, i.e. ~ 93 cyclists/km and ~ 186 per 2 km section. At unchanged air velocity (1.5 m/s):

$186 \text{ cyclists} \times 0.09 \text{ m}^3/\text{h} = 16.7 \text{ m}^3/\text{h}$ of CO_2

$16.7 / 37,800 = 442 \text{ ppm}$ -> outlet $\sim 862 \text{ ppm}$

Still below the $1,000 \text{ ppm}$ comfort threshold, without even increasing ventilation. And if needed, raising the breeze to 2 m/s would bring the rise below 330 ppm . The system therefore absorbs a doubling of ridership with a wide margin.

The real uncertainty levers are not air quality, but: (1) the number and cost of ventilation shafts; (2) the smoke-extraction capacity required by the fire study; (3) actual electricity consumption, whose budget impact stays small thanks to the hydro tariff.

14 Summary

Aspect	At peak (100,000 users)	Verdict
CO_2	$\sim 645 \text{ ppm}$ (1.5 m/s breeze)	Non-issue. Huge margin to $5,000 \text{ ppm}$.
Heat	$+4.7 \text{ }^\circ\text{C/section}$; outlet $\sim 17 \text{ }^\circ\text{C}$	Comfortable, free cooling from the rock.
Humidity	$+0.8 \text{ g/kg}$ (cyclist input)	Modest; real work = summer condensation.
Noise	$60\text{--}68 \text{ dB(A)}$	Pleasant if jet fans are silenced (to specify).
Smoke (Li-ion fire)	critical velocity $\sim 2.5 \text{ m/s}$	The real challenge; sizes the fans.

Aspect	At peak (100,000 users)	Verdict
Capital	~\$600M (incl. ~\$375M of shafts)	Realistic but optimistic; covered by contingency.
Operating	~\$3–4.5M/yr	Minor, thanks to hydroelectricity.

Key takeaway

A bike tunnel is almost trivial to ventilate day to day (no engines = no exhaust), naturally cool thanks to the deep ground, and cheap to run. Engineering rigour must focus on **smoke control in two-way traffic against battery fires**, and the cost item to watch is the **surface shafts in an urban setting**.

15 Limitations and the detailed study to come

The figures in this document are preliminary engineering estimates, intended to make the case for the project. A detailed study by an engineering firm specialised in tunnel ventilation should clarify:

- **The exact number and location of the ventilation shafts**, and which are co-located with stations (the main cost lever).
- **A smoke-control study** for two-way traffic against a lithium-battery fire — this study governs the fan size.
- **A summer anti-condensation strategy**: dehumidification capacity at the supply, slope and drainage.
- **An acoustic specification for the fans** (silenced jet fans) written into the tender, to guarantee the 60–65 dB(A).
- **The extent of supply-air filtration**, to support the “air potentially purer than at the surface” claim (filtration removes particulates, but only fresh air dilutes CO₂).

16 Appendix: formulas and factors used

The calculations rest on the following relationships.

Airflow in a section

$$\text{Airflow (m}^3/\text{h)} = \text{free cross-section (m}^2\text{)} \times \text{velocity (m/s)} \times 3,600$$

CO₂ concentration rise

$$\text{CO}_2 \text{ rise (fraction)} = \text{CO}_2 \text{ production (m}^3/\text{h)} / \text{airflow (m}^3/\text{h)}$$

1 ppm = 0.000001 as a volume fraction

Temperature rise

$$\text{Temperature rise (deg C)} = \text{power (W)} / (\text{mass flow} \times \text{specific heat})$$

$$\text{mass flow} = \text{flow (m}^3/\text{s)} \times 1.2 \text{ kg/m}^3$$

$$\text{specific heat of air} = 1,005 \text{ J/kg.K}$$

Simultaneous occupancy

Present at once = peak hourly flow (trips/h)
x mean trip time (h)

Factors and conversions

1 L/min = 0.06 m³/h
CO₂ produced = O₂ consumed x respiratory quotient (~0.9)
1 L O₂/min ~ 350 W of metabolic power
Air density = ~1.2 kg/m³
Free section 7 m² = 3.6 m bore, segment above the deck

Vélo Tunnel Québec — a citizen project by Philippe Leblond. This document is provided for information. Final values require a detailed study by an engineering firm specialised in tunnel ventilation.