

Optimizing Residential Ventilation Using Measured Indoor Contaminants

Too Much, Too Little, Just Right:

ASHRAE 62.2 Addendum C in Passive Buildings

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44

U.S. patents

15 yrs

CEO of Therma-Stor LLC, a dehumidification and ventilation manufacturer

5 yrs

Chief Innovation Officer, 2019 to 2023, Madison Indoor Air Quality LLC, a \$3 billion indoor air quality holding company

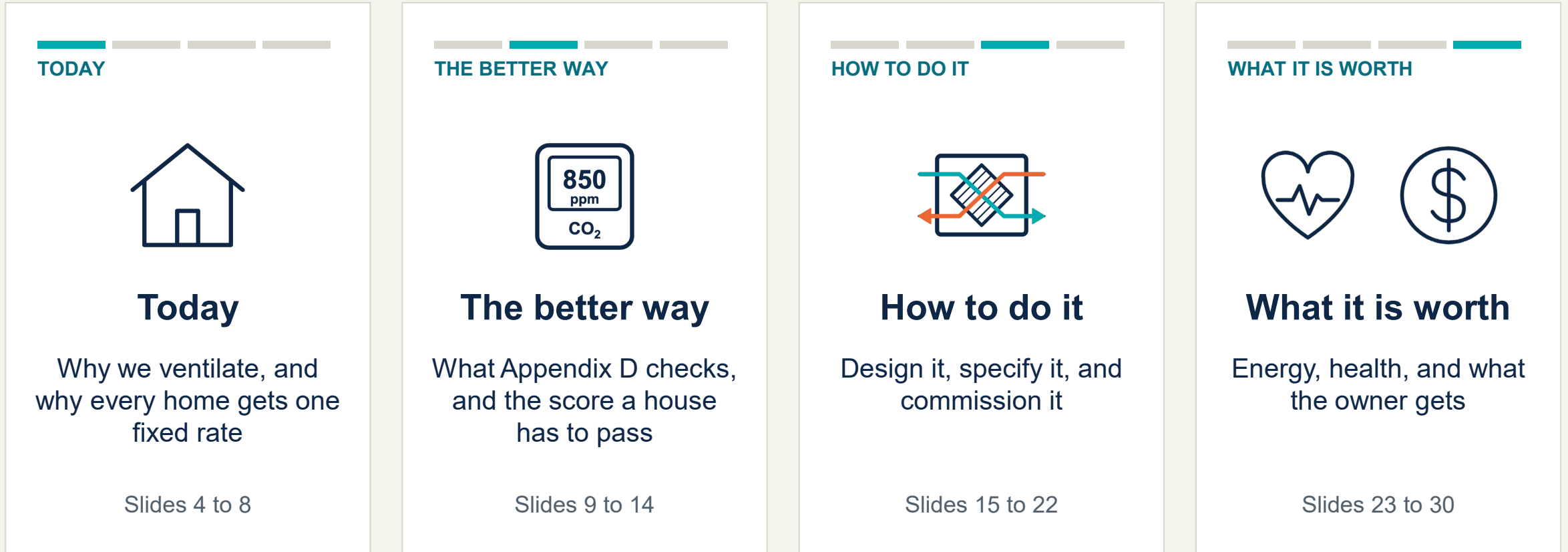
B.S. Mechanical Engineering, Cornell University · M.B.A., Tulane University

DISCLOSURE

The CalNEXT field study in this talk tested a smart ventilation system from Broan-NuTone LLC and Overture Indoor Air Quality LLC. Overture supplied the equipment at a reduced cost. I am the majority owner of Overture Indoor Air Quality LLC. TRC Companies, Inc. ran the study for CalNEXT.

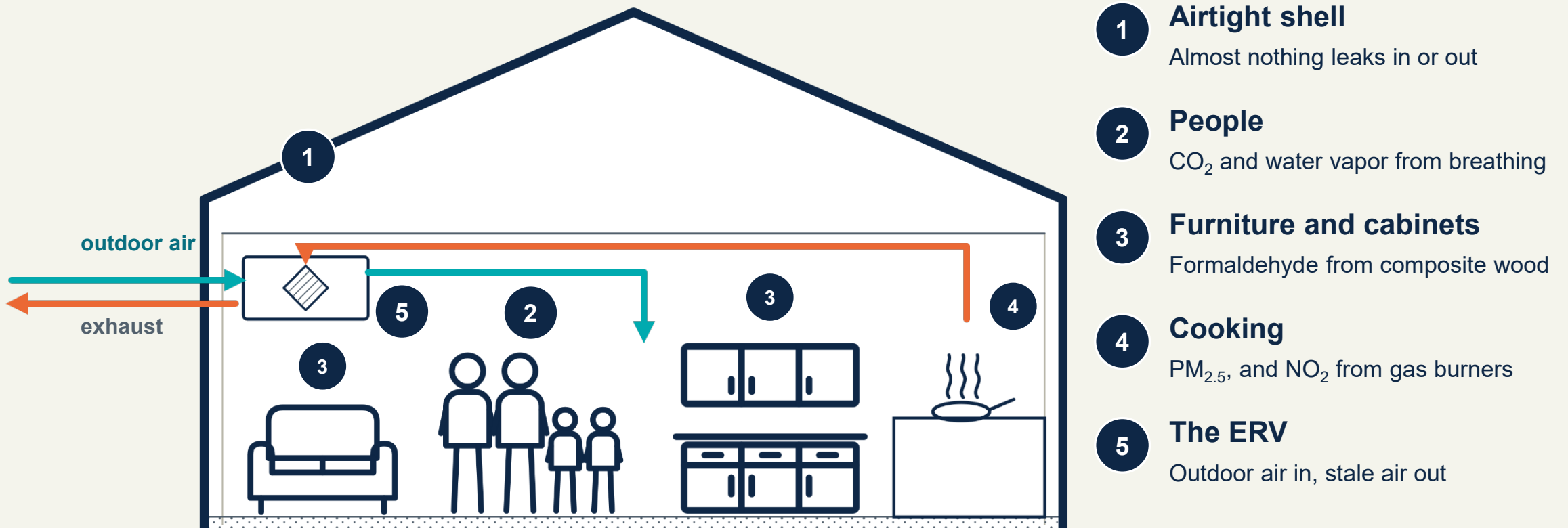
todd@overtureairquality.com

The talk in four parts



The bar at the top of every slide shows which part we are in.

Why ventilate? An airtight home locks in the pollution it makes

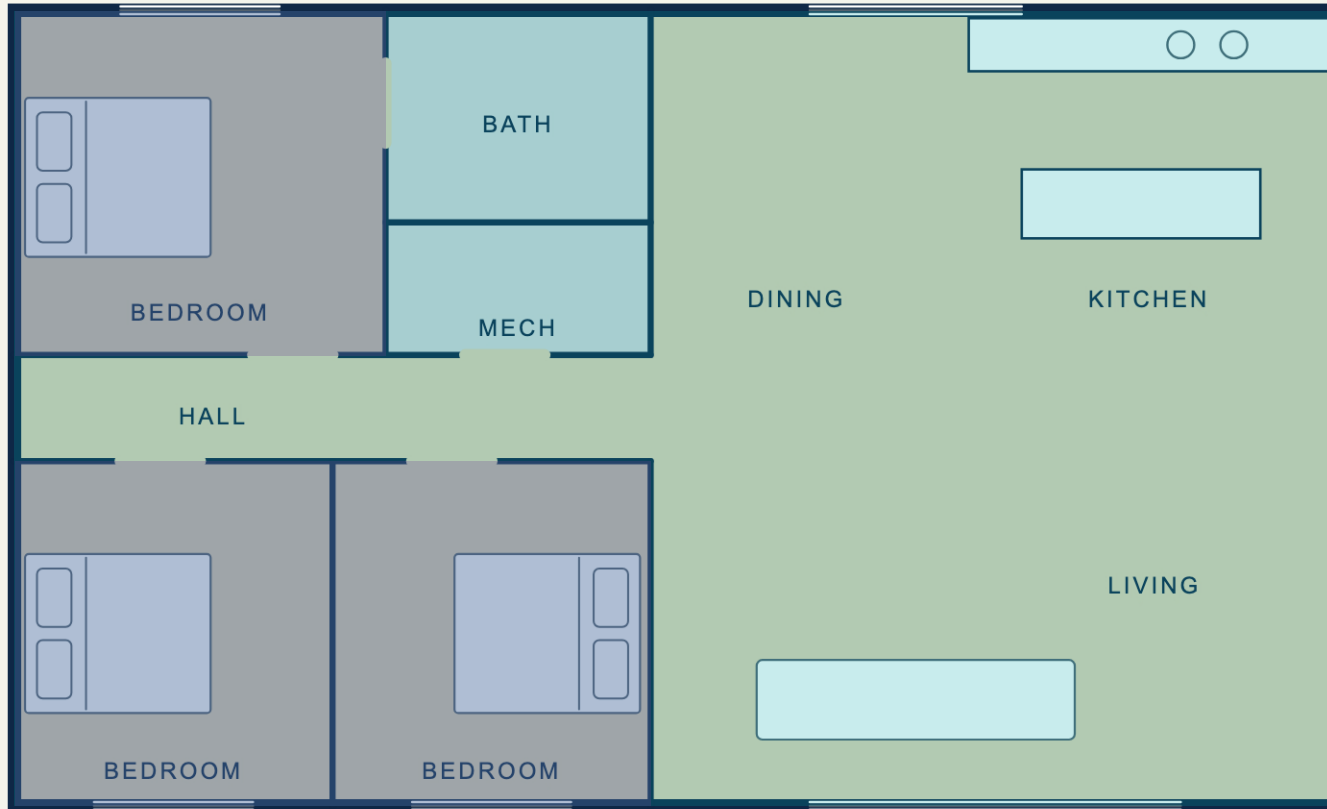


A Phius Certified home leaks almost nothing, so the ventilation system is the only way stale air gets out and fresh air comes in.

[Phius Certification Guidebook v25.1](#): 0.06 cfm50 per ft² of envelope, about 1 ACH50 here. [U.S. EPA, Particulate Matter Basics](#). [U.S. EPA, Facts About Formaldehyde](#).

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Today: one fan speed, set from the house plans



THE EXAMPLE HOME

1,500 ft², 3 bedrooms, four people

ASHRAE 62.2, Equation 4.1a

Floor area

$$1,500 \text{ ft}^2 \times 0.03 = 45 \text{ cfm}$$

Bedrooms + 1

$$(3 + 1) \times 7.5 = 30 \text{ cfm}$$

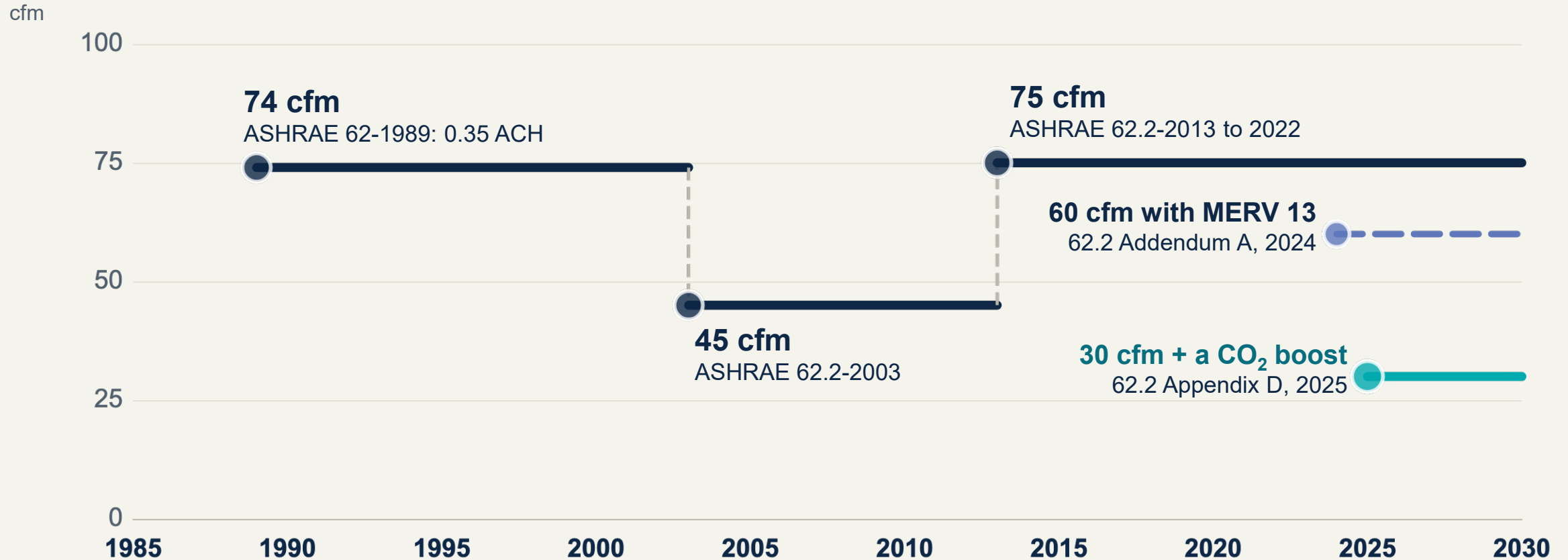
75 cfm

24 hours a day, whoever is home

Phius: 15 cfm per person, 60 cfm, also modeled as continuous

ASHRAE 62.2 reads floor area and bedrooms off the house plans, then runs that one fan speed 24 hours a day, whoever is home.

Same home, five different answers since 1989



The house never changed, but the number changed four times, until Appendix D asked what is in the air.

ASHRAE 62-1989: 0.35 ACH. 62.2-2003: $0.01 \text{ cfm/ft}^2 + 7.5 \times (\text{bedrooms} + 1)$. 62.2-2013: 0.03 cfm/ft^2 . Addendum A: 20% off with MERV 13. Appendix D: D1.1, 30 cfm.

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Why a fixed rate? Sensors were too expensive for homes

WHAT WE HAD



The house plans

Floor area and bedrooms are on the drawings before anyone moves in

WHAT WE HAD



One airflow check

The fan was set once, at start-up. Nothing reported the air after that

WHAT CHANGED

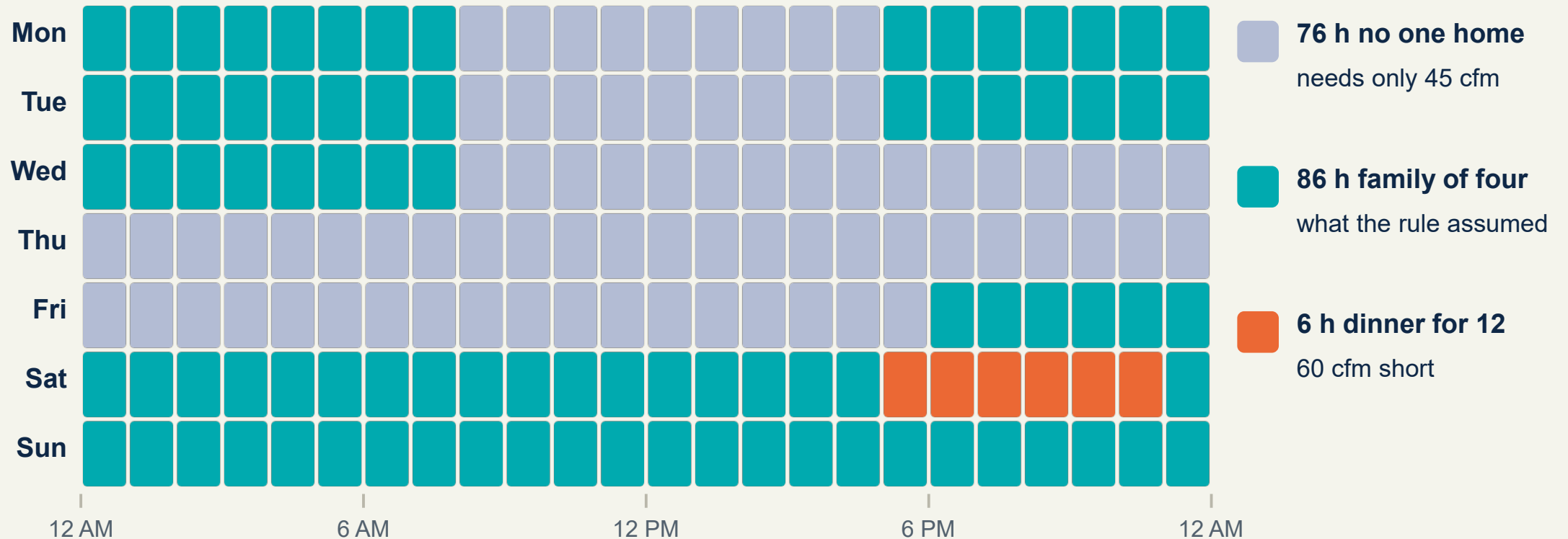


Room sensors

CO₂ and particle sensors were commercial-only. Now they cost little enough for every home

Until recently, CO₂ and particle sensors were commercial-only and too expensive for a home. Now the house can report what is in its air.

One fixed speed for a week that keeps changing



The house gets 75 cfm every hour of the week: too much for 76 hours, too little for 6.

One week of the example home, 168 h. Need from ASHRAE 62.2 Equation 4.1a with the occupants home: 45 cfm empty, 75 cfm for four, 135 cfm for 12.

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The better way: ventilate for what is in the air

FOR THE OCCUPANTS · D1



**Enough outdoor air
for the occupants**

Either $7.5 \text{ cfm} \times (\text{bedrooms} + 1)$, 30 cfm here,
or CO_2 held at 1,600 ppm or less

and

FOR THE HOUSE · D2



**Clean enough air
in the house**

A **contaminant rating (CR)** of 100 or less,
averaged over a year

SAFETY NET · D5

If a sensor or controller fails, the system goes back to a standard fixed rate within 1 hour

Appendix D asks two questions: is there enough outdoor air for the occupants, and is the air in the house clean?

The house check: one score, CR, for three contaminants

$$\text{CR} = 10.3 \times \text{PM}_{2.5} + 1.0 \times \text{NO}_2 + 0.7 \times \text{formaldehyde}$$

contaminant rating

each in $\mu\text{g}/\text{m}^3$, averaged over a year, 100 or less to pass



Cooking, candles, smoke, outdoor air

APPENDIX D DEFAULT

6 $\mu\text{g}/\text{m}^3$

with MERV 13 filtration, 12 without



Gas burners and traffic outdoors

APPENDIX D DEFAULT

10 $\mu\text{g}/\text{m}^3$

20 with a gas range



Composite wood and finishes

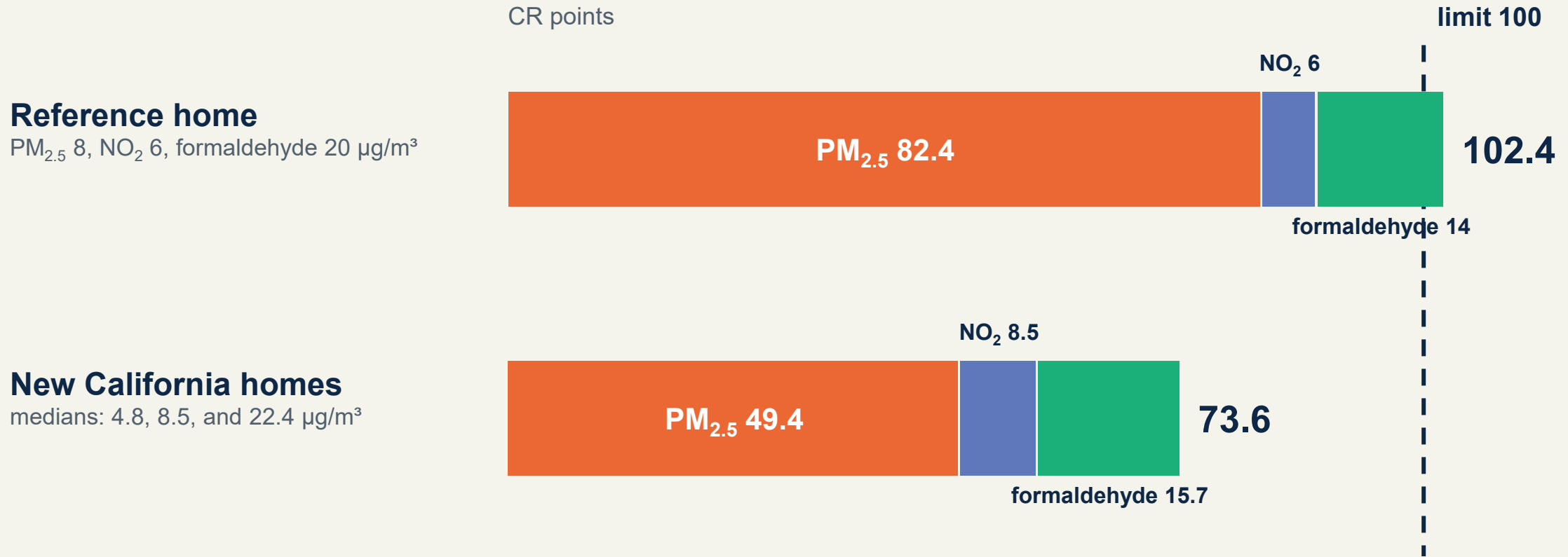
APPENDIX D DEFAULT

25 $\mu\text{g}/\text{m}^3$

with certified wood, 50 without

Per microgram, PM_{2.5} counts 10 to 15 times either gas, so it usually drives the score.

Why 100? It is the standard's reference home



**The committee set 100 at a home that meets today's fixed rate.
Recent California homes measured lower, about 74.**

What average PM_{2.5} levels look like in real homes

Homes in 77 studies

median, 1995 to 2010

Appendix D reference home

the home that scores CR 100

Outdoor air at U.S. monitors

average, 2024

New California homes

median, built 2011 to 2017

3,977 U.S. homes

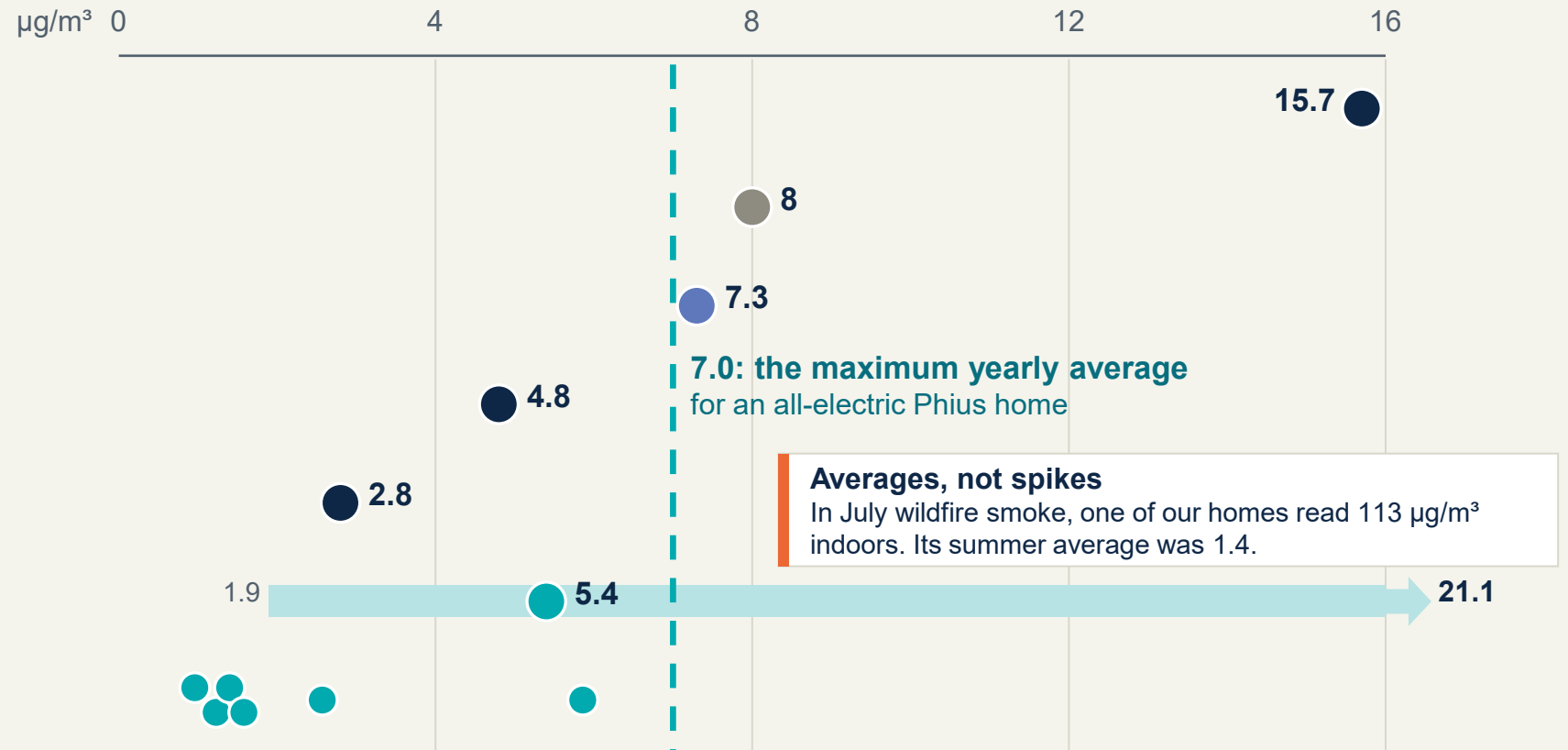
median, 2021 to 2022

177 apartments, our sensors

measured July to September 2026

Six homes, our sensors

measured May to September 2026



Recent homes mostly average 1 to 6 µg/m³.

An all-electric Phius home can average up to 7.0 over a year and still score CR 100 or less.

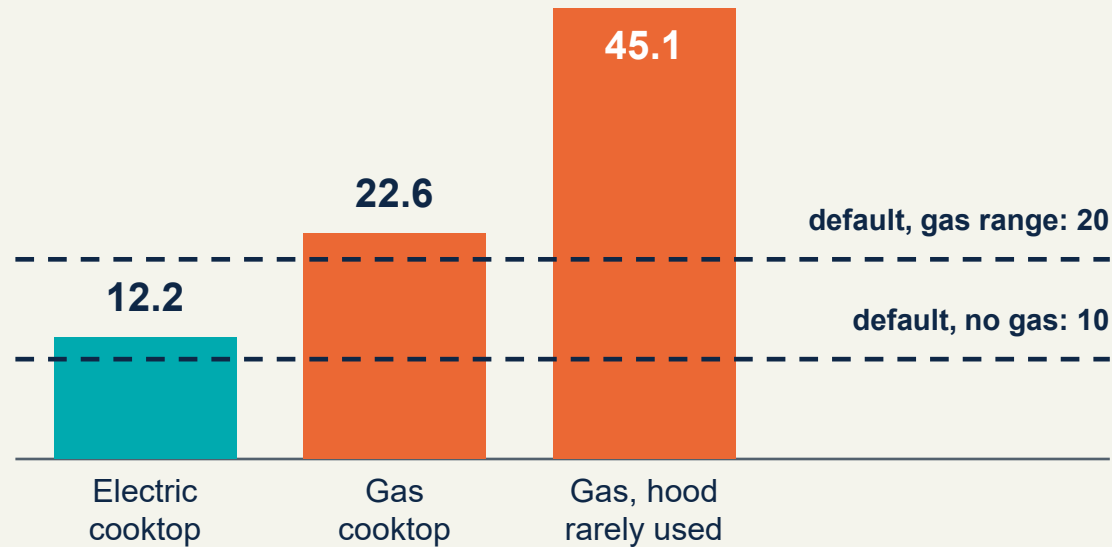
[Logue et al. 2011](#). Addendum C foreword. [EPA Air Trends](#), 2024. [Singer et al. 2020](#). [Lunderberg et al. 2023](#). Ours: light-commercial grade sensors, hourly means.

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The two gases: all-electric and certified wood

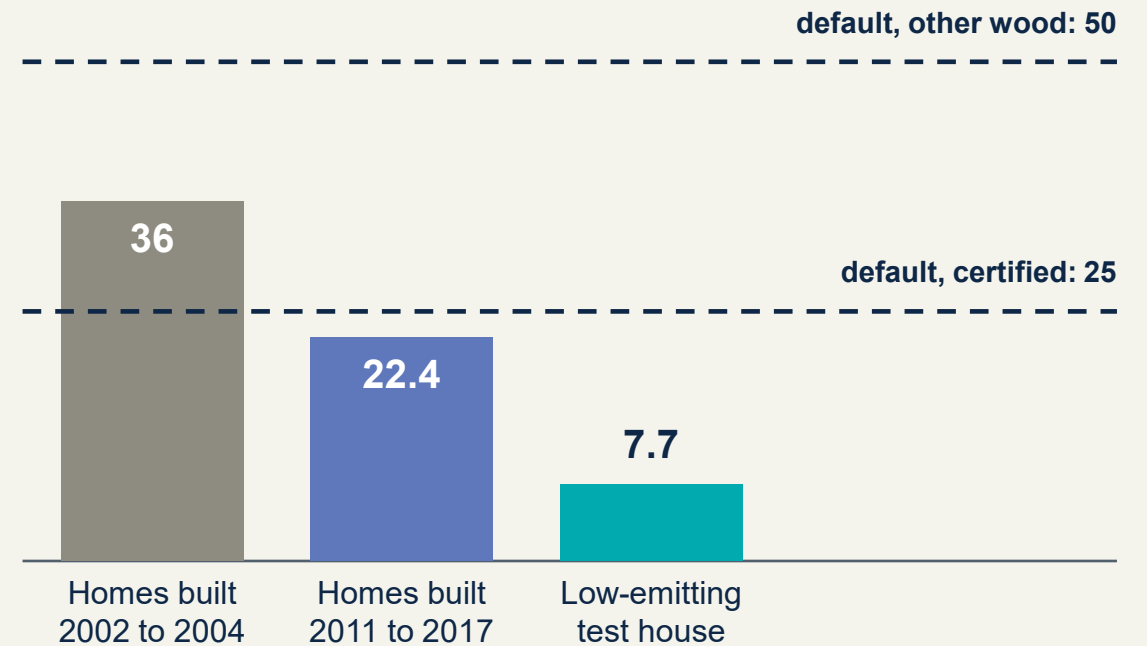
NO₂: cook with electricity

California homes in winter, bedroom medians, µg/m³



Formaldehyde: certified wood

New homes and one test house, µg/m³



All-electric and certified wood can use the low defaults: $10 + 0.7 \times 25 = 27.5$ of the 100 CR points.

NO₂: [Mullen et al. 2016](#), 352 California homes. Formaldehyde: [Offermann 2009](#), [Singer et al. 2020](#), [Poppendieck 2015](#). Defaults: Appendix D, D2.4.1 and D2.5.

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Two design choices set the maximum yearly PM_{2.5} average

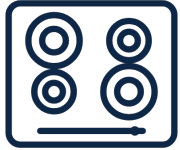
	CR points, 100 in all			Maximum yearly average
All-electric certified wood	NO ₂ 10	formaldehyde 17.5	room for PM _{2.5} : 72.5 points	7.0 µg/m ³
Gas range certified wood	NO ₂ 20	formaldehyde 17.5	room for PM _{2.5} : 62.5 points	6.1 µg/m ³
All-electric other wood	NO ₂ 10	formaldehyde 35	room for PM _{2.5} : 55 points	5.3 µg/m ³
Gas range other wood	NO ₂ 20	formaldehyde 35	room for PM _{2.5} : 45 points	4.4 µg/m ³

An all-electric home with certified wood can average up to 7.0 µg/m³ of PM_{2.5} over a year. With gas and uncertified wood, the maximum drops to 4.4 µg/m³.

Maximum yearly PM_{2.5} average = (100 – NO₂ points – formaldehyde points) ÷ 10.3. Defaults: NO₂ 10 or 20 µg/m³ (D2.5), formaldehyde 25 or 50 µg/m³ × 0.7 (D2.4.1).

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Design it in: three choices in the specifications



All-electric kitchen

Induction range and heat pumps, no combustion anywhere in the house

NO₂ default: 10 µg/m³



Certified composite wood

TSCA Title VI labels on cabinets, doors, and trim, submittals kept on file

Formaldehyde default: 25 µg/m³



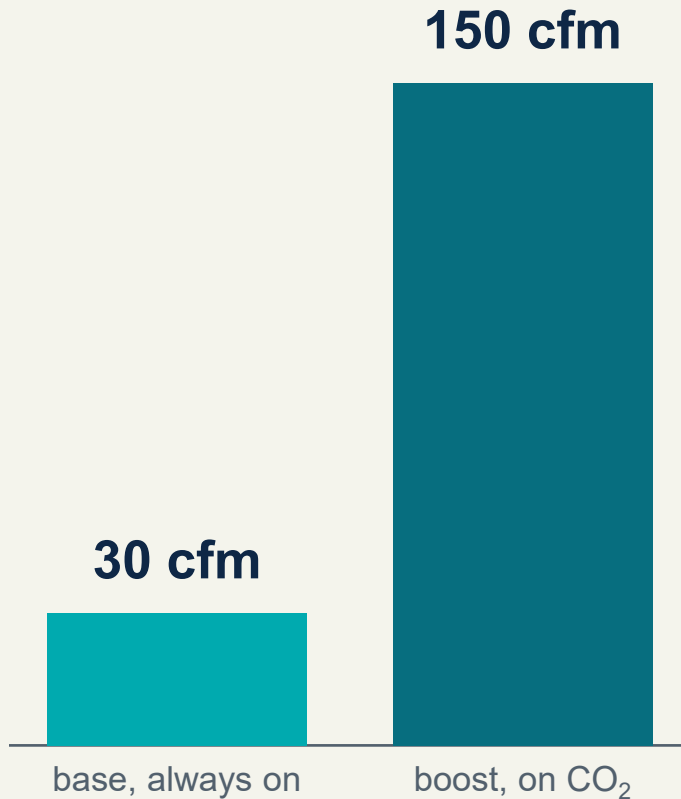
Filter and hood

MERV 13 or better on recirculated air, and a ducted hood that comes on when cooking

PM_{2.5}: the variable you measure

Three choices in the specifications hold the two gases at their low defaults and stop most of the particles before anyone moves in.

Why keep a 30 cfm base under the boost?

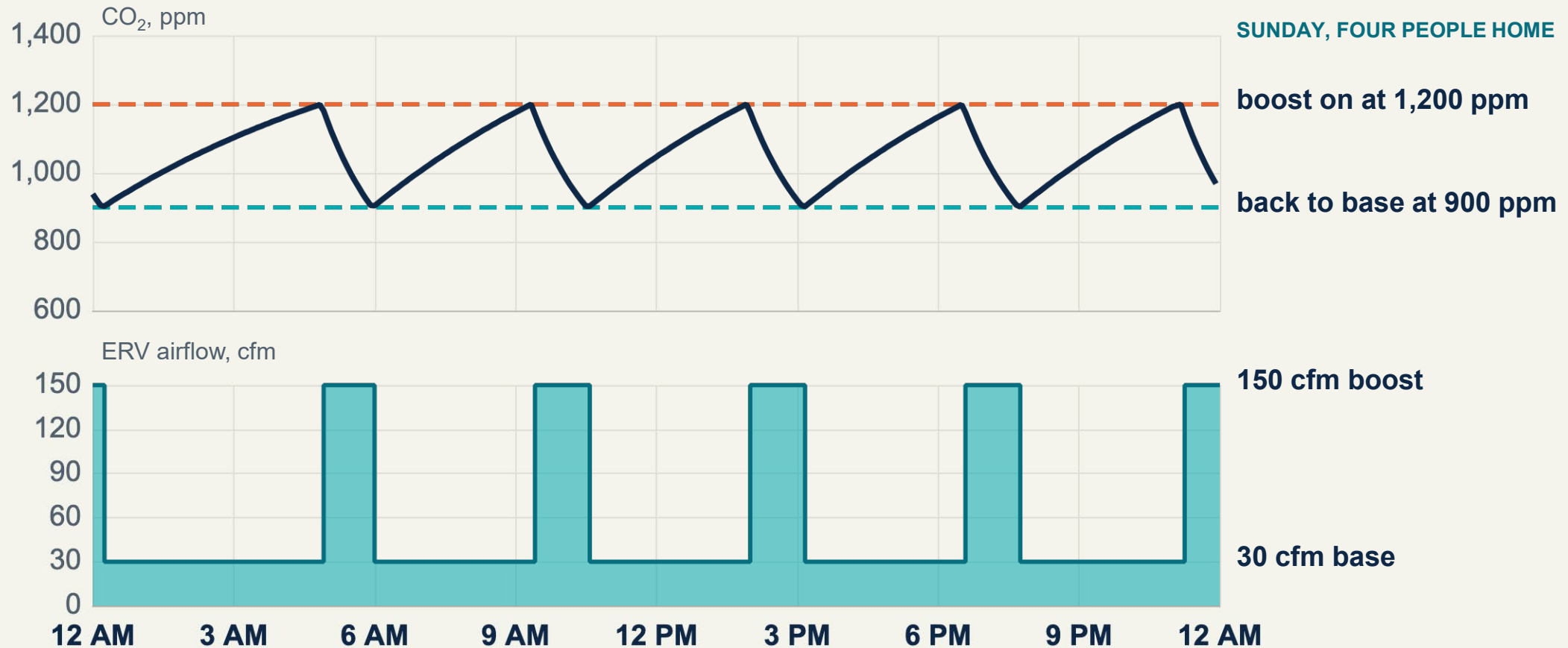


- 1 It meets the occupant requirement by itself**
 $7.5 \text{ cfm} \times (3 \text{ bedrooms} + 1) = 30 \text{ cfm}$ satisfies D1.1 with no sensor at all
- 2 A failed CO₂ sensor changes nothing**
The base alone still meets D1, so no D5 revert is needed
- 3 The empty house still gets air**
The base keeps diluting what the materials give off while no one is home

The 30 cfm base meets Appendix D by itself.
The CO₂ boost adds air only when the occupants need it.

Appendix D: D1.1, $7.5 \text{ cfm} \times (\text{bedrooms} + 1)$ with the floor-area term set to zero. D5: revert within 1 h unless D1 and D2 are still met without the failed part.

How it runs: CO₂ switches the ERV between two speeds



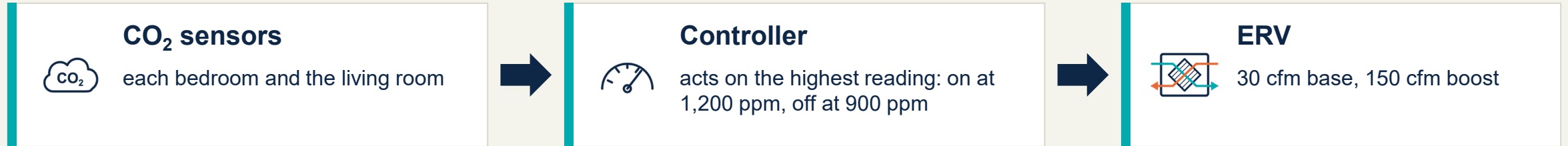
With four people home all day, the ERV boosts 5 times, 5.7 hours in all, and averages 59 cfm.

Model: 12,750 ft³, 4 people, CO₂ 0.0045 L/s each awake, 0.0039 asleep ([Persily and de Jonge 2017](#)), 420 ppm outdoors. Base 30 cfm, boost 150 cfm.

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CO₂ runs the fan; PM_{2.5} and the two gases set the CR

D1 · THE OCCUPANTS: CO₂ RUNS THE FAN



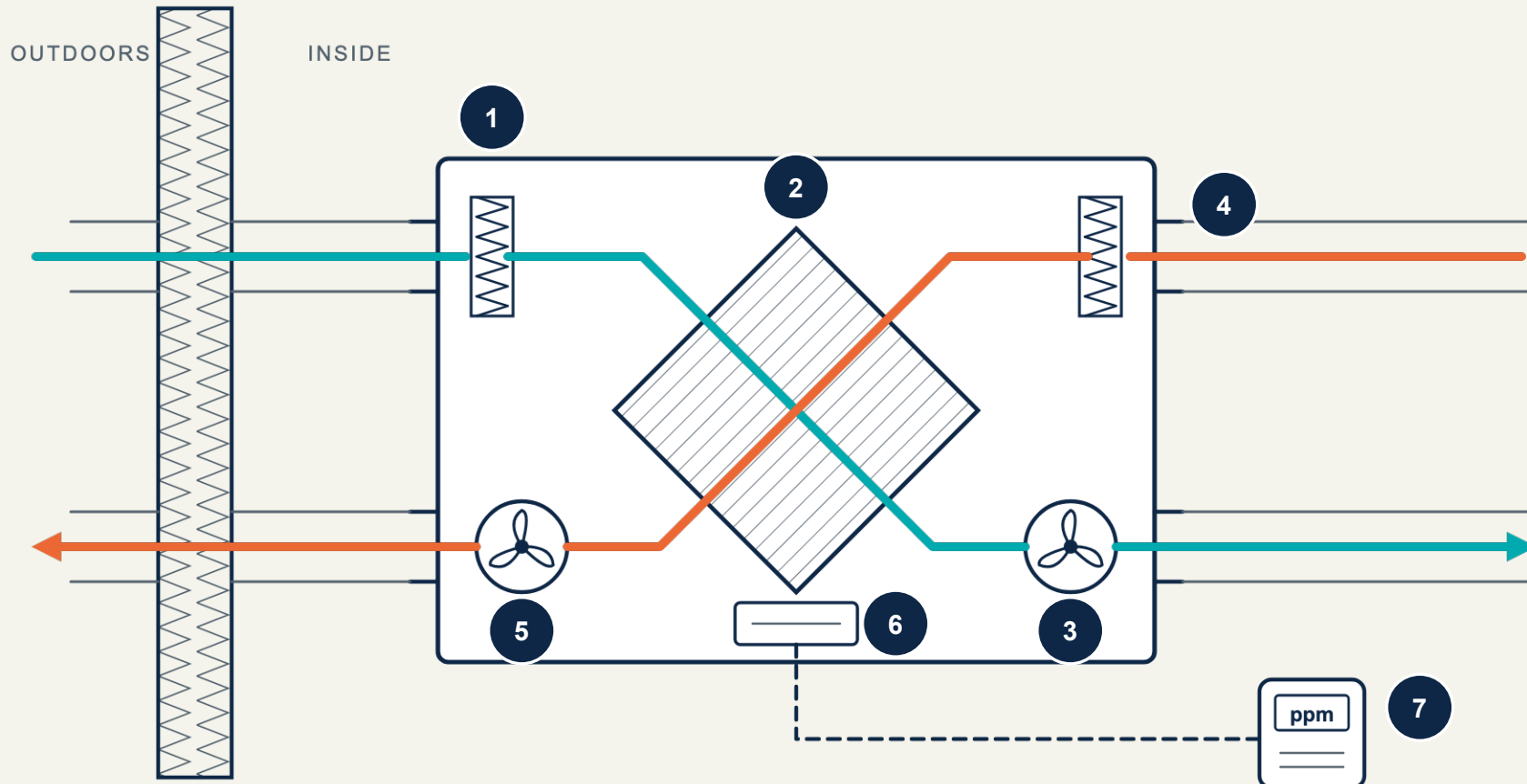
D2 · THE HOUSE: THE CR SCORE



Only the year's average has to be 100 or less. D2.2 asks for a means to lower the CR, such as the boost, a filter fan, or an air cleaner, not a reaction to every reading.

**CO₂ runs the fan minute to minute.
The CR is measured PM_{2.5} plus the two gases, averaged over a year.**

Set up the ERV: two speeds and a CO₂ contact

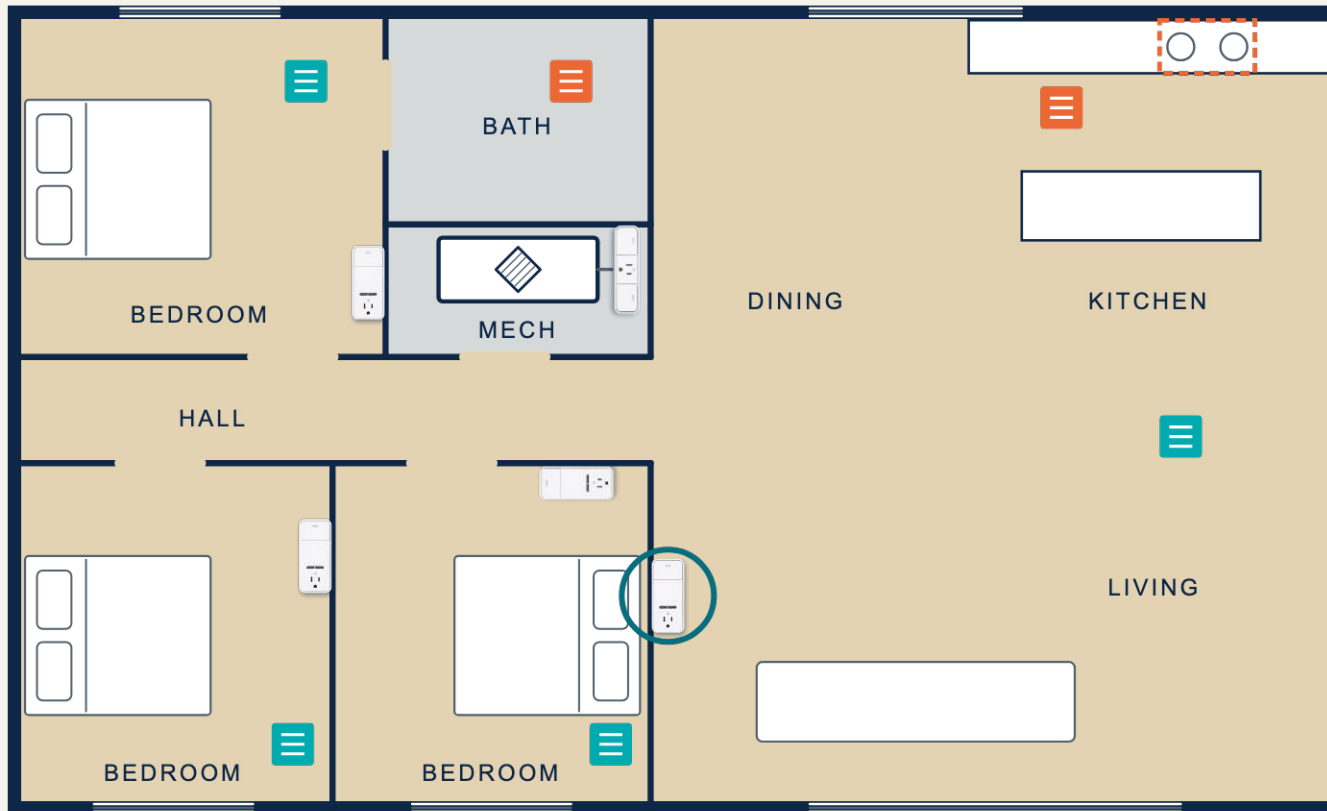


- 1 **Filters:** MERV 13 on the outdoor air, a second on the return
- 2 **Core:** passes heat and water vapor, the air streams never mix
- 3 **Supply fan:** to the bedrooms and living room
- 4 **Return:** stale air from the bath and kitchen
- 5 **Exhaust fan:** stale air out through the wall
- 6 **Board:** holds the two speeds, 30 and 150 cfm
- 7 **CO₂ controller:** boost on at 1,200 ppm, off at 900 ppm

**Specify an ERV with two adjustable speeds and a boost input.
The CO₂ controller only has to close a switch.**

A balanced ERV with a two-speed boost input, both speeds set at start-up from its own airflow readings. Controller output: a dry contact on the boost terminals.

Where the grilles, the sensors, and the smart plug go



-  Supply grille in each bedroom and in the living room
-  Extract grille in the bathroom and kitchen, not over the range
-  Range hood ducted outdoors, comes on when cooking, interlocked makeup air
-  ERV in the mechanical room. Its smart plug switches base and boost
-  CO₂ sensor in each bedroom and the living room, or one central sensor near the thermostat (D1.2)
-  One PM_{2.5} monitor in the living area

**CO₂ sensors go where people sleep and sit, or one central sensor in mixed air.
One PM_{2.5} monitor in the living area covers the house.**

What to write into the specification

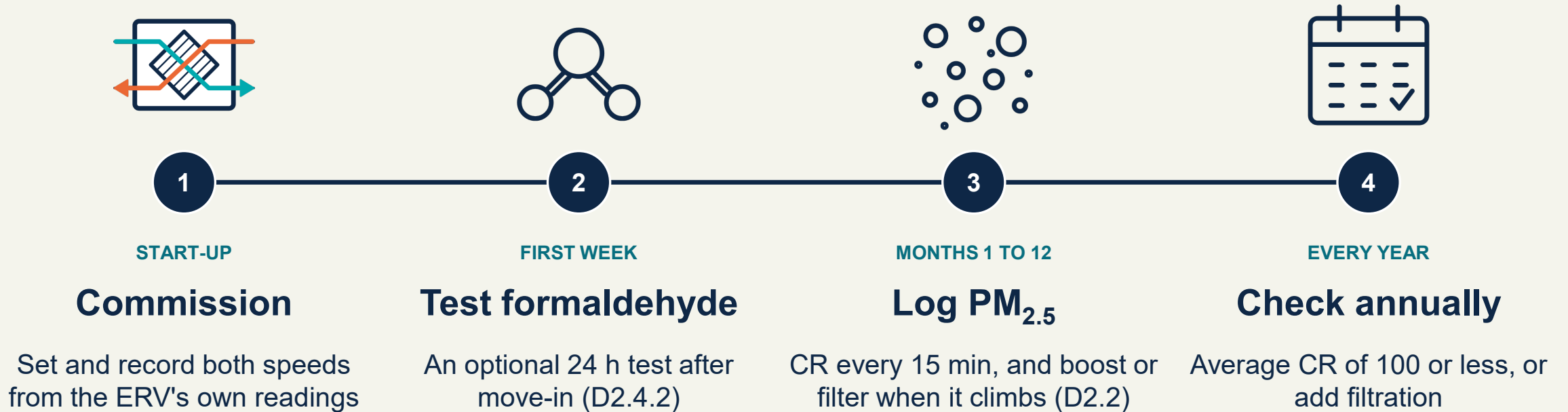
ERV	Balanced, two speeds, 30 cfm base and 150 cfm boost, a boost input, holds the base if a sensor fails (D5)
CO₂ control	Each bedroom and the living room, boost on at 1,200 ppm and off at 900 ppm, on the highest reading (D1.2)
Monitors	PM _{2.5} in the living area, CR every 15 min and logged for the year (D2.2), NO ₂ and formaldehyde sensors optional
Filtration	MERV 13 on the ERV's outdoor air, a 4-inch MERV 13 or better on recirculated air, and a bypass HEPA on the return
Kitchen	Induction range, hood ducted outdoors, 200 cfm measured, comes on when cooking, interlocked makeup air
Composite wood	TSCA Title VI certified, labels and submittals kept for the file (D2.4.1)
Commissioning	Both speeds set and recorded at start-up, optional 24 h formaldehyde test (D2.4.2), CR check every year
Phius review	Phius specifies 60 cfm continuous, no boost: agree on the 30 cfm base with your Phius reviewer at design review

Eight lines in the specification cover Appendix D. Settle the 30 cfm base with Phius early.

Appendix D: D1.2, D2.2, D2.4, D3.2, and D5. ASHRAE 62.2 Section 7.6. [EPA Indoor airPLUS v2](#) (hood). [Phius Certification Guidebook v25.1](#) (ventilation).

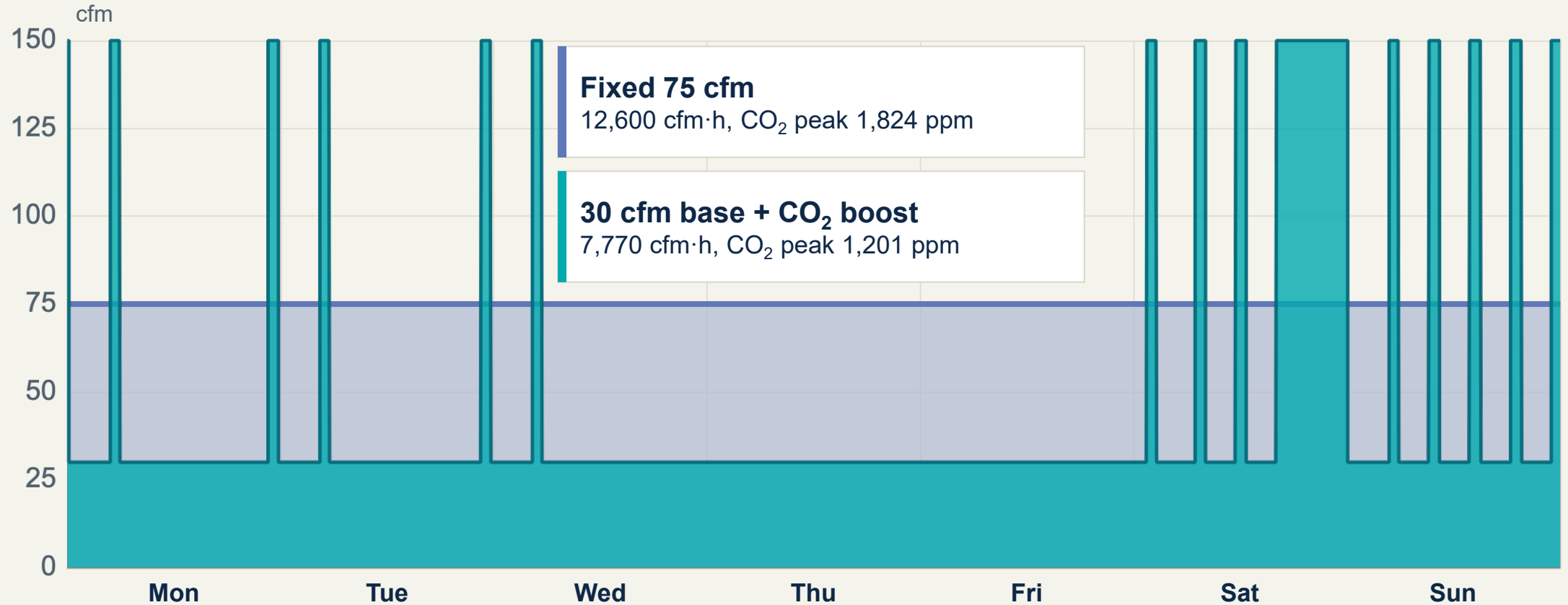
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Commission, measure, then check every year



**Appendix D sets no date and names no one for the annual check.
Write both into the commissioning plan.**

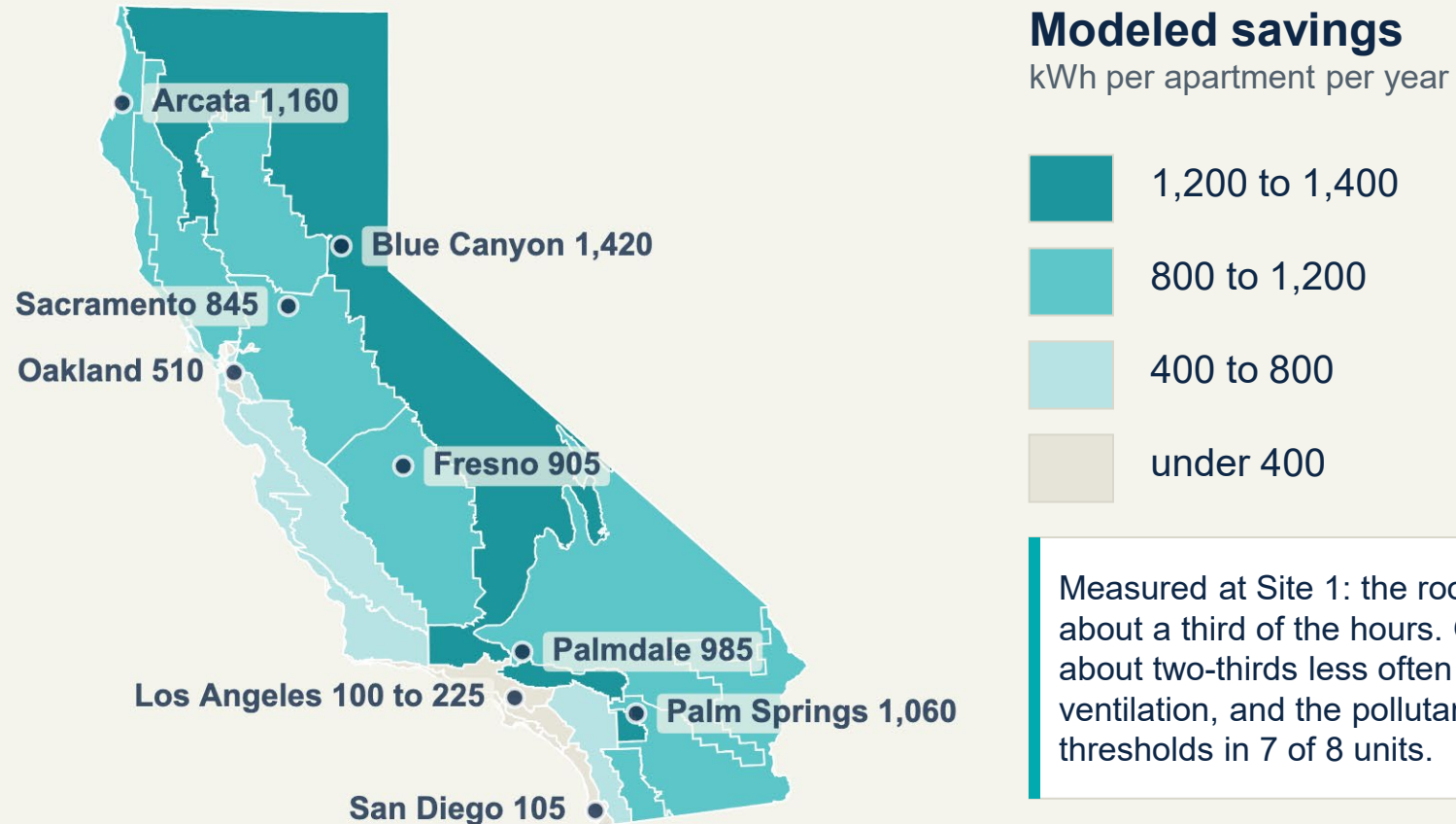
Same home, same week: 38% less outdoor air



The controlled week supplies 38% less outdoor air, and CO₂ peaks at 1,201 ppm instead of 1,824.

Model: the week on slide 8, 12,750 ft³, CO₂ generation from [Persily and de Jonge 2017](#), 420 ppm outdoors. $7,770 \div 12,600 = 0.62$.

What CalNEXT's model found in California

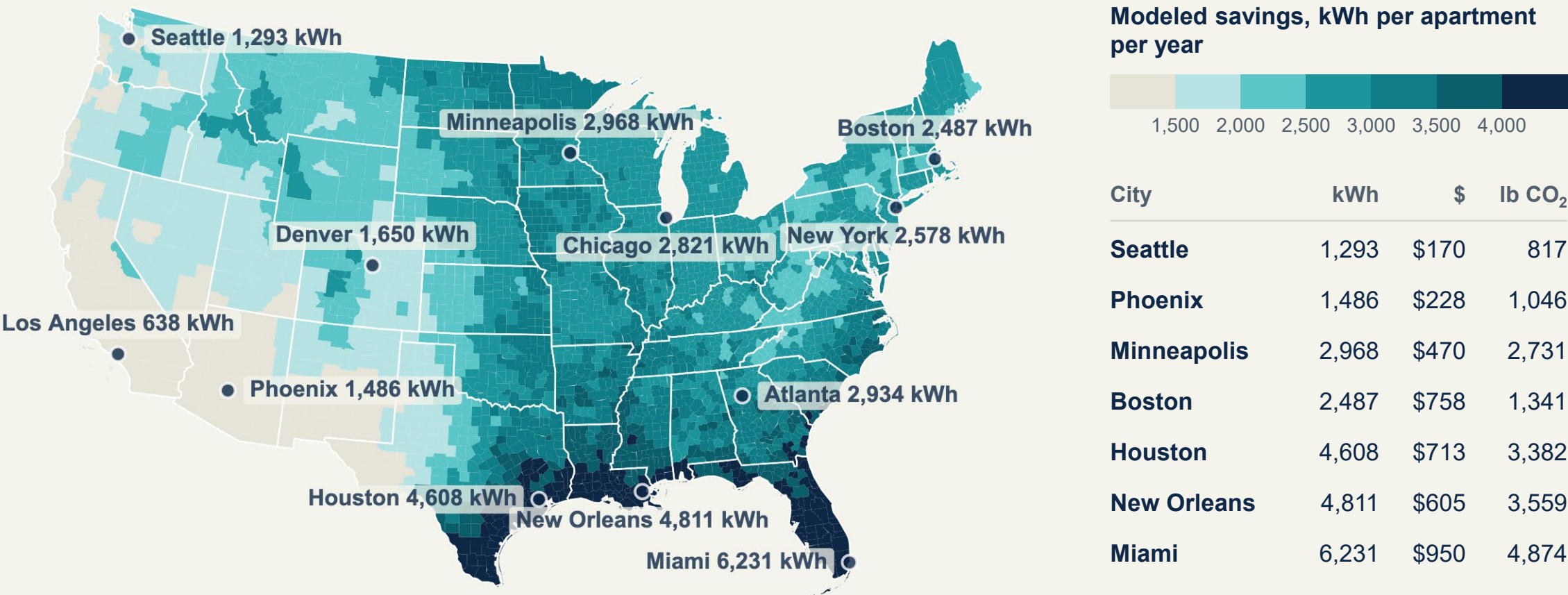


CalNEXT's model saved 800 to 1,400 kWh a year per apartment in California's hot and cold zones, and about 100 to 225 on the mild coast.

CalNEXT [ET24SWE0015](#) (TRC), report Case 1: 150 cfm balanced, no heat recovery, 0.27 W/cfm, heat pumps, measured fan runtime. California climate zones (CEC).

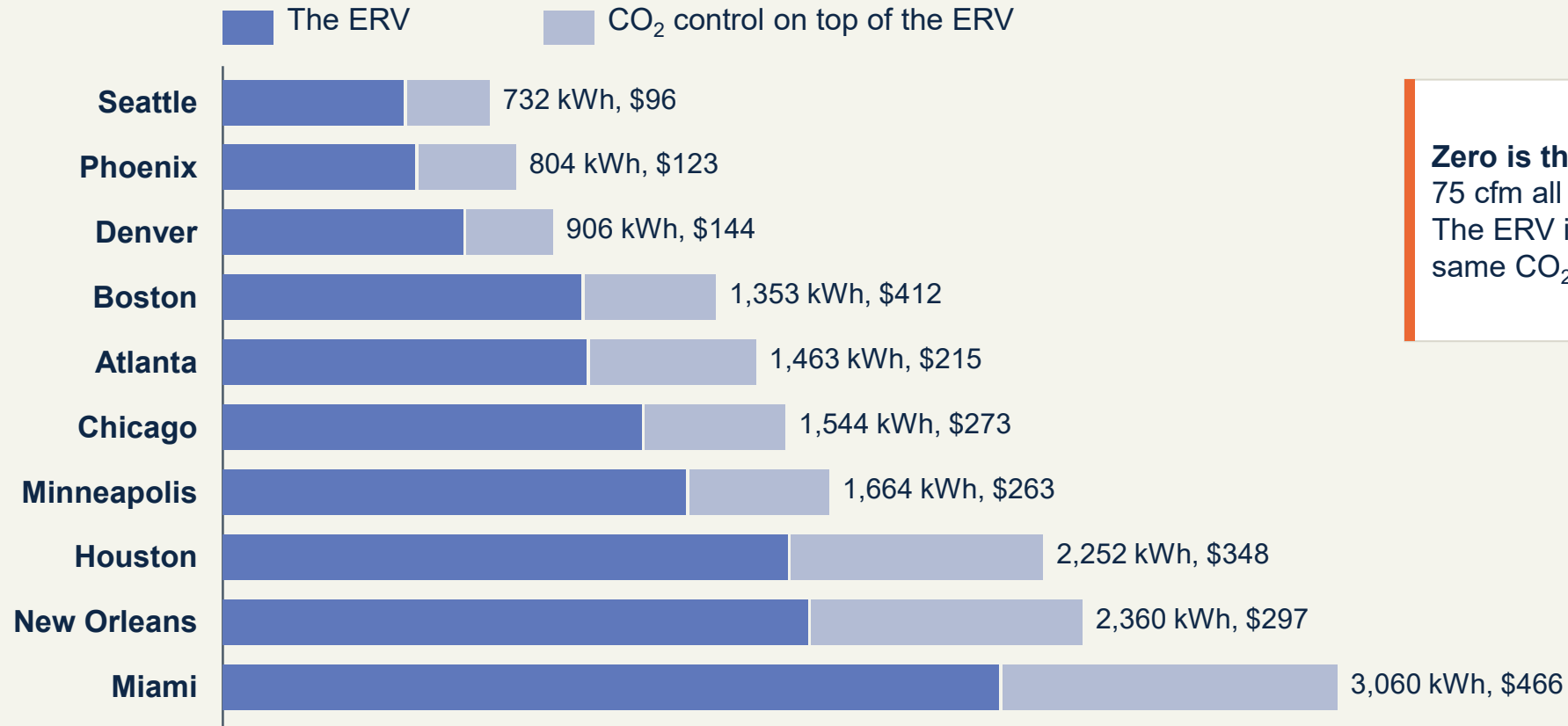
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Across the US: the same apartment, modeled



Outside California the same apartment saves about 1,200 to 6,200 kWh a year, \$160 to \$950. The humid South saves the most: each cfm brings in water vapor.

What the ERV and CO₂ control save in an ASHRAE 62.2 code home



Zero is the code home as built
75 cfm all day, no heat recovery
The ERV is added first, then the
same CO₂ control on top of it

**In a code home, the ERV and CO₂ control together save about \$100 to \$470 a year.
A Phius home already has the ERV, so what is left comes from the hours no one is home.**

Model: the week on slide 8, CO₂ control 30/150 cfm. ERV 75% sensible, 50% latent. Heat pump COP 3.0 and 3.5, dehumidifier COP 1.2. Prices: [EIA 2025](#).

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Energy savings in a Phius home follow the hours no one is home

Energy saved in a Phius home, \$ a year, modeled

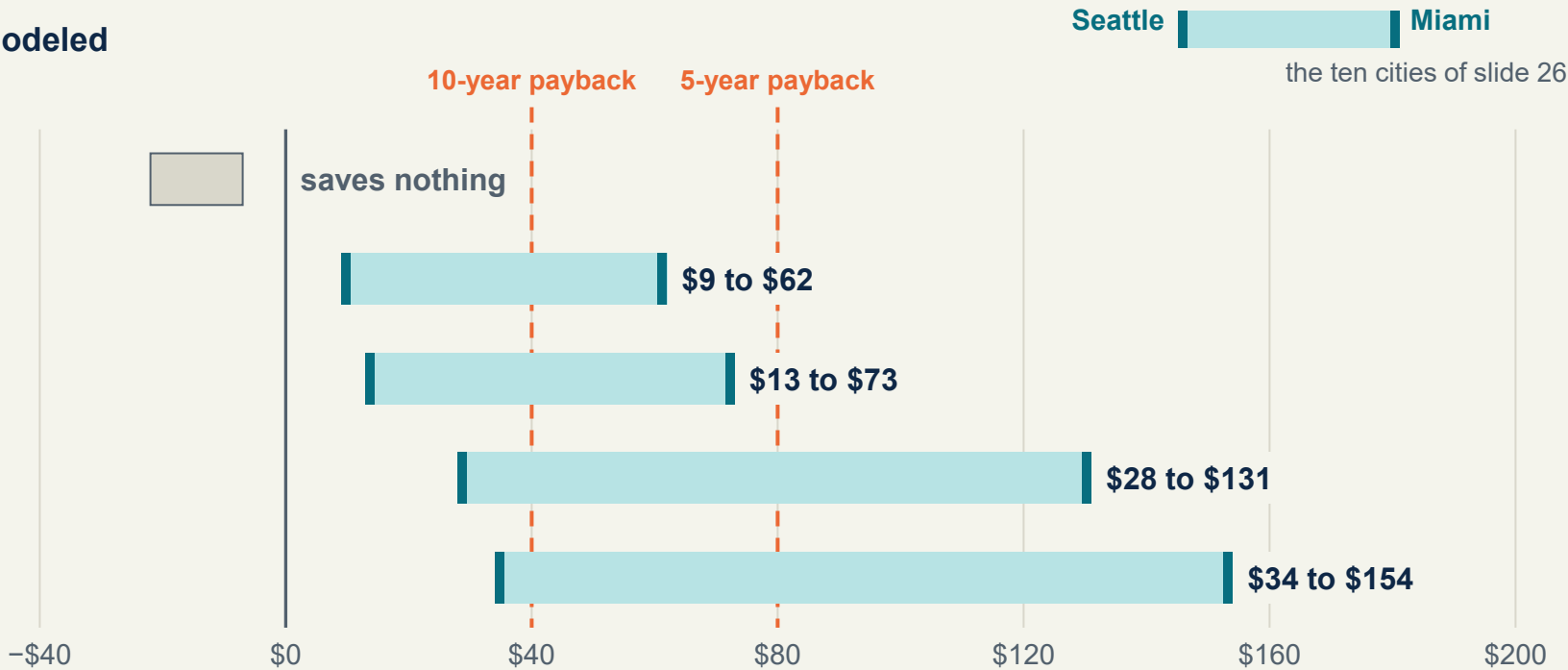
Home all day
never empty

Working family, out 8 to 5
empty 2,349 h of 8,760 a year

Second home, used half the year
empty 4,368 h of 8,760 a year

Empty nights and weekends
empty 6,150 h of 8,760 a year

Empty all year
empty all 8,760 h a year



Zero is the Phius home as built
60 cfm around the clock through the ERV, about \$60 a year in Seattle and \$300 in Miami.
Empty hours run at 30 cfm.

Energy only
The health value of fewer particles comes next

The energy savings follow the empty hours: about \$10 to \$60 a year for a working family, \$30 to \$130 for a house empty nights and weekends.

What the health side is worth: the particles carry it

The arithmetic, from Appendix D's own harm rate

60 DALYs a year

per 100,000 people, for each $\mu\text{g}/\text{m}^3$ of $\text{PM}_{2.5}$ in their air.
A DALY is a year of healthy life lost

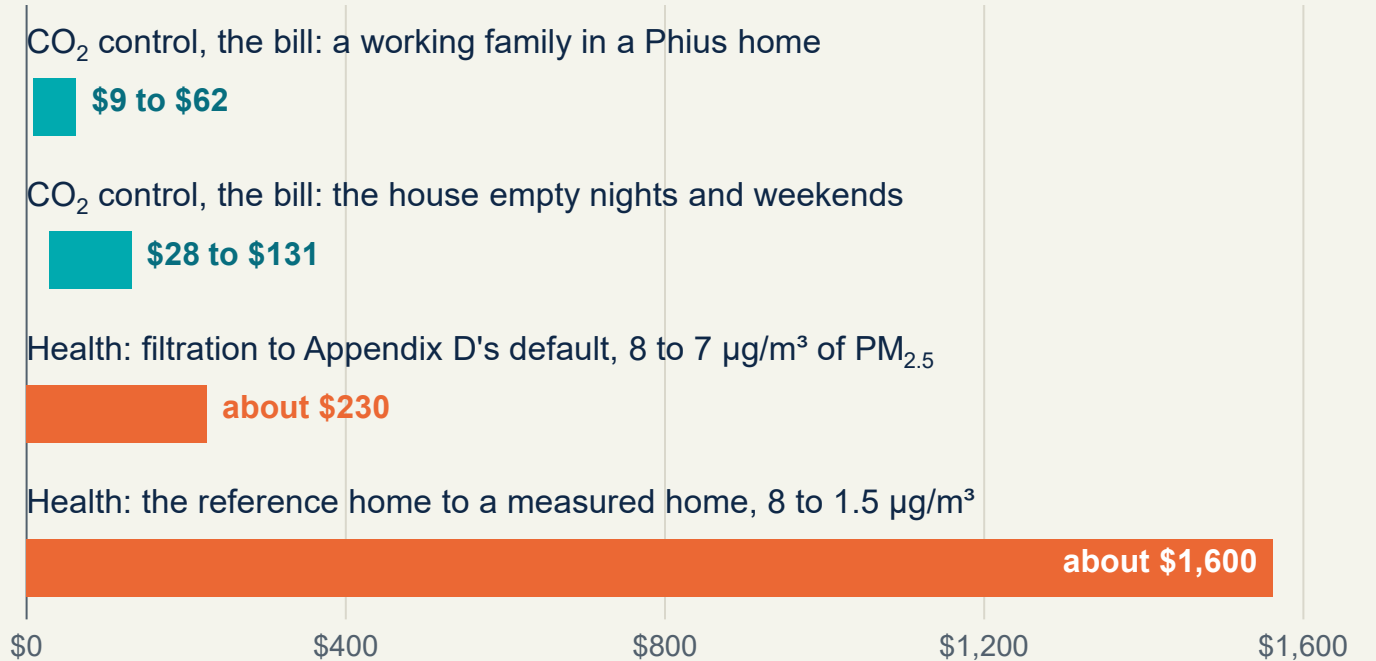
\$100,000 per DALY

the low end of what a year of healthy life is valued at in the US, \$100,000 to \$150,000 (NEJM, 2014)

\$240 a year per $\mu\text{g}/\text{m}^3$

for a family of four: $60 \div 100,000 \times \$100,000 = \60 a person. Healthy years valued, not money back on a bill

Dollars a year, a family of four



One $\mu\text{g}/\text{m}^3$ of $\text{PM}_{2.5}$ is worth about \$240 a year to a family of four, more than CO₂ control saves on the bill anywhere. Across the US it is about \$20 billion a year.

[Morantes et al. 2024](#) (harm per $\mu\text{g}/\text{m}^3$, in DALYs). [Neumann, Cohen, and Weinstein, N. Engl. J. Med. 2014](#) (\$100,000 to \$150,000 per QALY). [U.S. Census Bureau, 2024](#). Estimated.

What the owner gets



Air for the occupants

The boost brings outdoor air for guests. The base runs while the house is empty



Better health outcomes

Fewer particles, measured: about \$240 a year per $\mu\text{g}/\text{m}^3$ of $\text{PM}_{2.5}$ for a family of four



Proof it works

CO_2 readings prove the ventilation works, and a year of $\text{PM}_{2.5}$ gives the house its CR



Savings when no one is home

Modeled: \$10 to \$60 a year for a working family, more the longer the house is empty



A quieter house

The ERV runs at its 30 cfm base for 86% of the week



Better humidity

Modeled: 5 RH points higher in a Minneapolis January, 6 lb a day less moisture in Houston



Early warning

The sensors catch a wildfire smoke day, a hood left off, or an appliance going bad

The owner gets air for the occupants, the health that comes with fewer particles, proof that it works, and savings that grow when the house sits empty.

Modeled week, slide 23: 22.8 h of 168 at boost. Health: slide 28. Savings: slide 27. Humidity: a working family against 60 cfm continuous, modeled. CR: Appendix D, D2.

Five steps for your next Phius project

1

Design out the gases

All-electric, TSCA Title VI certified composite wood



2

Filter the particles

MERV 13 or better on recirculated air, a hood that comes on when cooking



3

Specify a two-speed ERV

30 cfm base, 150 cfm boost, a boost input for the CO₂ controller



4

Place the sensors

CO₂ in each bedroom and the living room, one PM_{2.5} monitor



5

Commission, log, check annually

Set both speeds at start-up, log the year, check the CR every year



**Design out the gases, filter the particles, and let CO₂ run the fan.
Then the first year of data shows the result.**

Measure the air Ventilate for the occupants

Questions

Todd DeMonte

The slides are yours to share. Contact details are on slide 2.

References

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19. U.S. EPA. Indoor airPLUS Verification Requirements, Version 2. EPA, 2024. epa.gov
20. U.S. EPA. Particulate Matter (PM) Basics, and Facts About Formaldehyde. epa.gov/pm · epa.gov/formaldehyde

Appendix

The measured homes, the slides for questions, the references, and the glossary, each shown complete

The measured homes, May to September 2026

Home	Where	Sensors	Days	Hours covered	Mean, $\mu\text{g}/\text{m}^3$	Median, $\mu\text{g}/\text{m}^3$	Hours at 12 $\mu\text{g}/\text{m}^3$ or more	CR points, $\text{PM}_{2.5}$
A	Wisconsin	4 rooms	92	69%	1.4	0.6	2.0%	14
B	Wisconsin	3 rooms	92	81%	1.0	0.5	0.7%	10
D	Florida	1 bedroom	98	95%	2.6	0.8	4.3%	27
E	Colorado	3 rooms	72	95%	1.2	0.6	0.1%	13
F	Arkansas	10 rooms	46	53%	1.6	1.4	0.0%	16
G	not recorded	1 room	38	93%	5.9	4.4	5.7%	60
H	not recorded	1 room	30	28%	6.0	3.2	6.5%	62

Home H: its sensor reported 28% of the hours, so its mean is the least certain

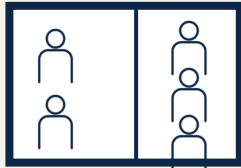
In five of the homes, $\text{PM}_{2.5}$ used 10 to 27 of the 100 CR points over the summer. The 12 $\mu\text{g}/\text{m}^3$ default alone uses 124.

Light-commercial grade $\text{PM}_{2.5}$ sensors, hourly means, May 21st to September 27th, 2026. CR points = $10.3 \times \text{mean}$. A summer, not a full year.
ASHRAE 62.2 Appendix D in passive buildings · PhiusCon 2026

ASHRAE 62.2 counts bedrooms, not people

A Phius apartment

$$0.03 \times 700 + 7.5 \times (1 + 1) = 36 \text{ cfm}$$



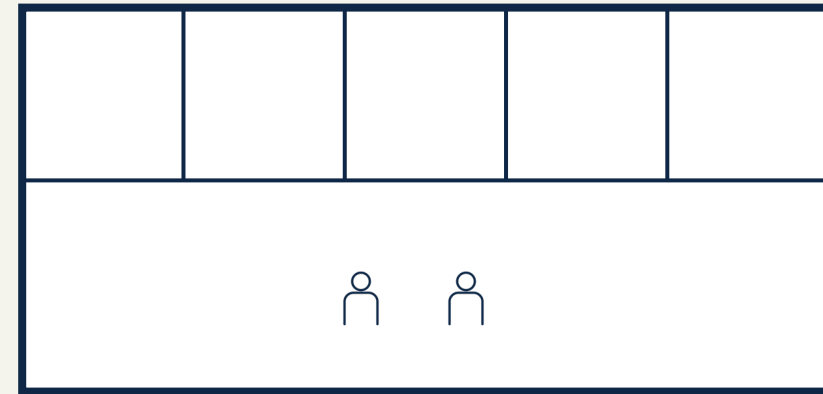
too little

700 ft², 1 bedroom, 5 people: 36 cfm

7 cfm per person, CO₂ about 1,745 ppm

A Phius custom home

$$0.03 \times 6,000 + 7.5 \times (5 + 1) = 225 \text{ cfm}$$



too much

6,000 ft², 5 bedrooms, 2 people: 225 cfm

112 cfm per person, CO₂ about 505 ppm

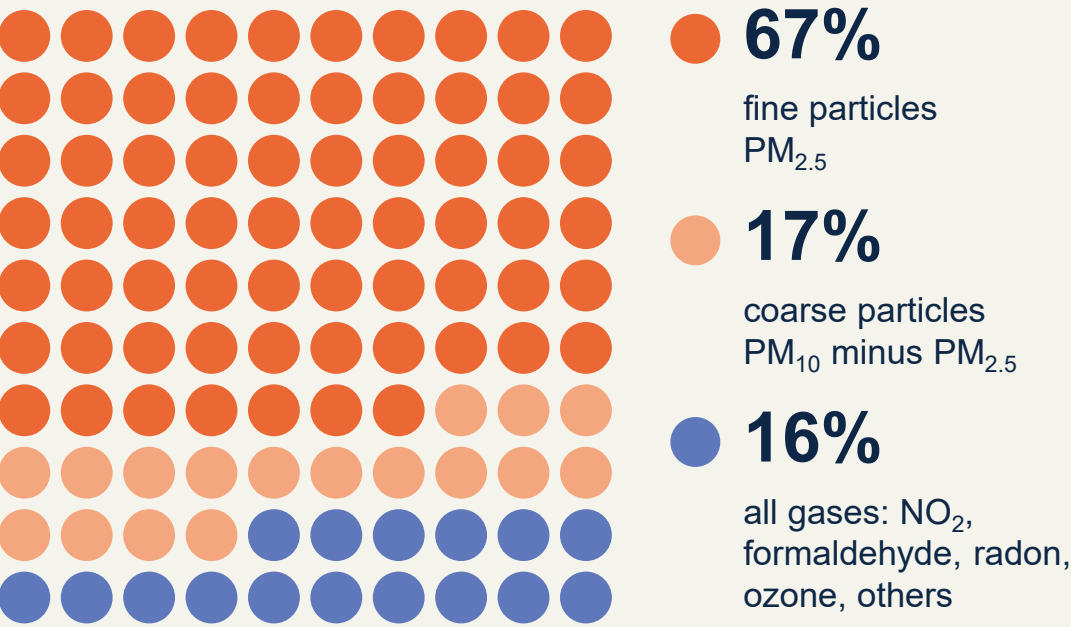
The formula gives 7 cfm per person in the apartment, 112 cfm per person in the custom home.

Too little air: the harm is mostly particles, not CO₂

HOW SMALL, TO SCALE



Share of the harm, in DALYs, from indoor air in homes



Harm is counted in DALYs, disability-adjusted life years: the healthy years lost to illness and early death

**Particles cause 84% of the harm from indoor air in homes.
A ventilation rate set only by CO₂ does not address most of the harm.**

Harm shares: [Morantes, Jones, Molina, Sherman, Environ. Sci. Technol. 2024](#), 58(1):242 to 257, page 251, rounded. Sizes: [U.S. EPA, Particulate Matter Basics](#): a hair is about 70 μm.
ASHRAE 62.2 Appendix D in passive buildings · PhiusCon 2026

Addendum A: filtration takes 20% off the fixed rate

4.1.4

The credit

20% off the total rate, Q_{tot} (Equation 4-8), on any day that meets the three conditions below

4.1.4.1

Every room

Filtered air supplied to or returned from every habitable room by a permanently installed fan

4.1.4.2

A PRF of 2.1

On the day's average FADR (Section 7.6): about 221 cfm all day through the filter in 1,500 ft²

4.1.4.3

Access and label

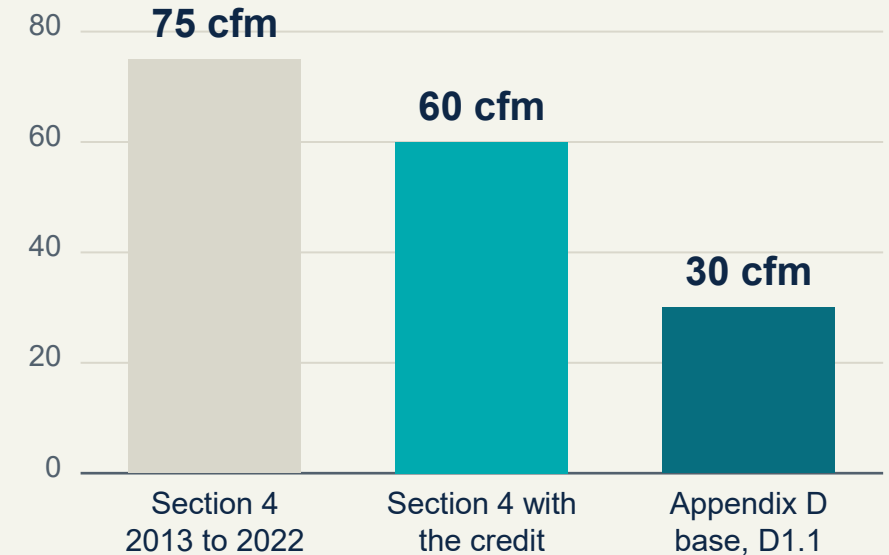
Filters reached from inside the house, bypass minimized, the filter rating shown at the access door

7.6.2

The filter

MERV 13, or an equal rating (50% at 1 μ m, AHRI 680, ISO 16890 ePM1 50%), or HEPA

The example home, 1,500 ft², three bedrooms, cfm

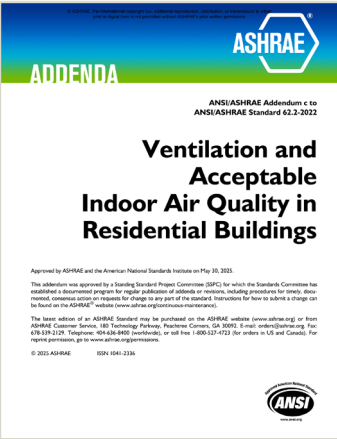


Appendix D takes no credit

D1.1 does not permit Section 4.1.4. It reuses Section 7.6 for the PM_{2.5} default: $12 \div \text{PRF}$ (D2.3).

**Filtration at a PRF of 2.1, all day, takes 20% off: 75 cfm becomes 60.
Appendix D's 30 cfm base takes no credit (D1.1).**

Addendum C adds Appendix D: a second way to set ventilation



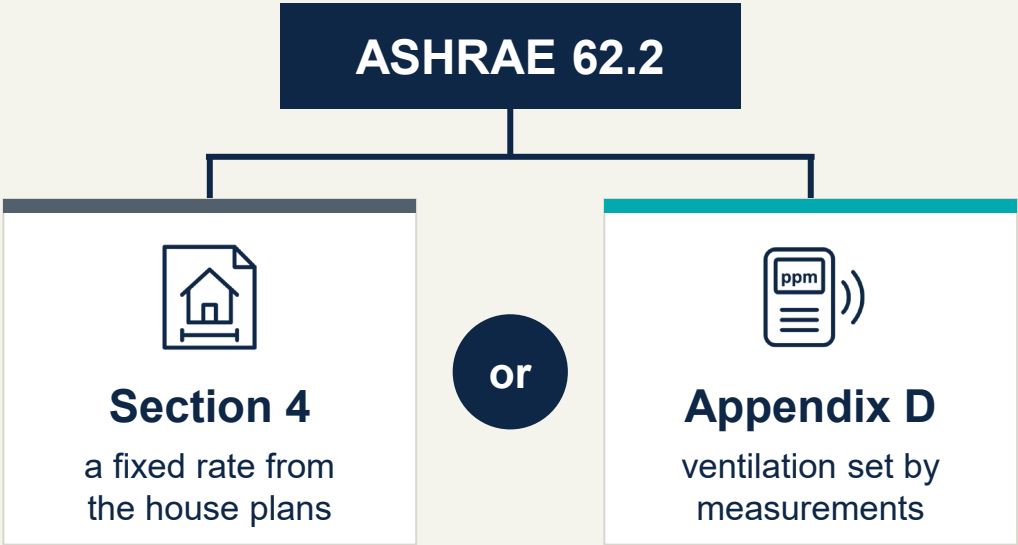
Addendum C to
ASHRAE 62.2-2022

**NORMATIVE APPENDIX D
INDOOR AIR QUALITY PROCEDURE**

The requirements of this appendix shall be applicable where selected by the designer as the compliance path for Section 4.

The dwelling unit systems shall meet the requirements for Sections D1 and D2. Where air cleaning efficiencies or contaminant measurements are part of the design, the appropriate Sections of D3 and D4 are also required.

Addendum C
the change, approved May 30th, 2025
Appendix D
the section it adds to ASHRAE 62.2



Commercial buildings have had ventilation set by measurement since 1981
ASHRAE 62.1's IAQ Procedure. ASHRAE 62.2, for homes, had none until Appendix D.

For the first time, ASHRAE 62.2 lets indoor air measurements set the ventilation rate in homes.

The Appendix D defaults, as Addendum C writes them

Condition	µg/m ³	CR points	100 limit
PM_{2.5} D2.3: 12 ÷ PRF, weight 10.3			
No recirculating filter, PRF 1	12	<div></div>	123.6
PRF 2: MERV 13, 200 cfm in 1,500 ft ²	6	<div></div> 61.8	
NO₂ D2.5, weight 1			
a) No combustion	10	<div></div> 10	
b) All combustion in the kitchen or vented	20	<div></div> 20	
c) Neither, with CO ₂ control (D1.2)	40	<div></div> 40	
Formaldehyde D2.4.1, weight 0.7			
TSCA Title VI certified wood	25	<div></div> 17.5	
Not certified	50	<div></div> 35	

D2.3 Alternative Concentration Determination for PM_{2.5}. Unless real-time measurement is being used, the concentration of PM_{2.5} in Equation D-1 shall be 12 µg/m³ divided by the particle reduction factor based on the daily average filtered air delivery rate, determined in accordance with Section 7.6.

D2.4 Alternative Concentration Determination for Formaldehyde. Unless real-time measurement is being used, the concentration of formaldehyde in Equation D-1 shall be determined by default values in accordance with Section D2.4.1 or a commissioning study in accordance with Section D2.4.2.

D2.4.1 The default value for a dwelling unit in which composite wood products covered by EPA TSCA Title VI are certified to TSCA Title VI shall be 25 µg/m³. Otherwise, the default value shall be 50 µg/m³.

D2.5 Alternative Concentration Determination for Nitrogen Dioxide. Unless real-time measurement is being used, the concentration of nitrogen dioxide in Equation D-1 shall be determined as follows:

- a. Where there is no combustion equipment in the dwelling unit, the concentration shall be set to 10 µg/m³.
- b. Where all the combustion equipment in the dwelling unit is either in the kitchen or vented, the concentration shall be set to 20 µg/m³.
- c. Where Sections D2.5.a and D2.5.b are not met and Section D.1.2 is being complied with, the concentration shall be set to 40 µg/m³.

Otherwise, Section D2.5 shall not be used.

Addendum C to ASHRAE 62.2-2022, Sections D2.3 to D2.5, reproduced for citation. D2.5 ends: otherwise, D2.5 shall not be used.

Any term measured in real time replaces its default (D2.2)
Or, for formaldehyde, a 24 h test after move-in (D2.4.2)

Every term has a default. With no filter, the PM_{2.5} default alone scores 124, over the limit of 100.

TSCA Title VI: the federal formaldehyde limit for composite wood

WHAT IT COVERS · 40 CFR PART 770

Products: hardwood plywood, particleboard, and MDF, as panels and inside cabinets, doors, trim, flooring, and furniture

Since: June 1st, 2018, for products made in or imported to the U.S.
Laminated products: March 22nd, 2024

Exempt: structural plywood, OSB, glulam, I-joists, structural composite lumber, and hardboard

THE LABEL

Panels: “TSCA Title VI certified,” with the producer, the lot number, and the certifier’s EPA number

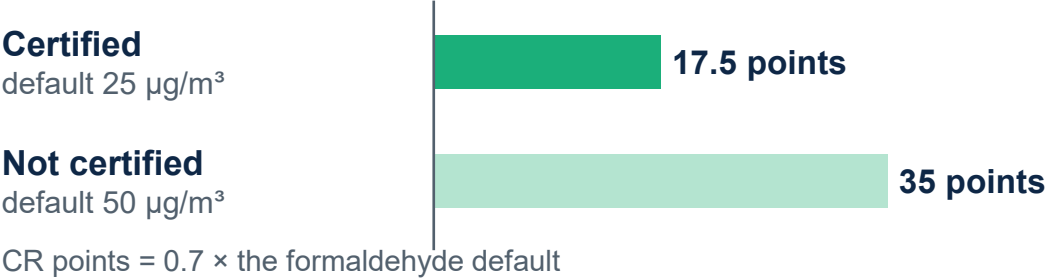
Finished goods: “TSCA Title VI compliant,” with the fabricator and the month and year made

The record: keep the labels, the invoices, or the submittals on file

THE LIMITS, PPM OF FORMALDEHYDE (ASTM E1333 CHAMBER)



WHAT IT IS WORTH IN THE CR · D2.4.1



Certified wood earns the 25 µg/m³ default, 17.5 CR points instead of 35.
Keep the labels and submittals on file.

Requirement 2: a CO₂ sensor replaces the bedroom count

D1. BIOEFFLUENT CONTROL SYSTEM

D1.2 CO₂ Controlled Ventilation System. A dwelling unit mechanical ventilation system shall be provided that complies with Section 4.2 or Section 4.4 and **that limits the carbon dioxide concentration to not more than 1600 ppm.**

If air mixing is provided that supplies air to most of the habitable spaces, the measurement is permitted to be at **a single central location** provided that the air handling system or equipment operates **at least 15 minutes per hour**; otherwise, the measurement shall be the maximum of those made within each room of the habitable space.

This section shall not be used in the presence of air cleaning technology that would remove carbon dioxide.

Addendum C to ASHRAE 62.2-2022, Appendix D, Section D1 (excerpt)

WHERE TO MEASURE



One central sensor, if the air handler mixes the house 15 min per hour



Otherwise, the highest room reading



TODAY · SECTION 4

7.5 cfm × (bedrooms + 1)

estimated from the house plans



APPENDIX D · D1.2

CO₂ at or below 1,600 ppm

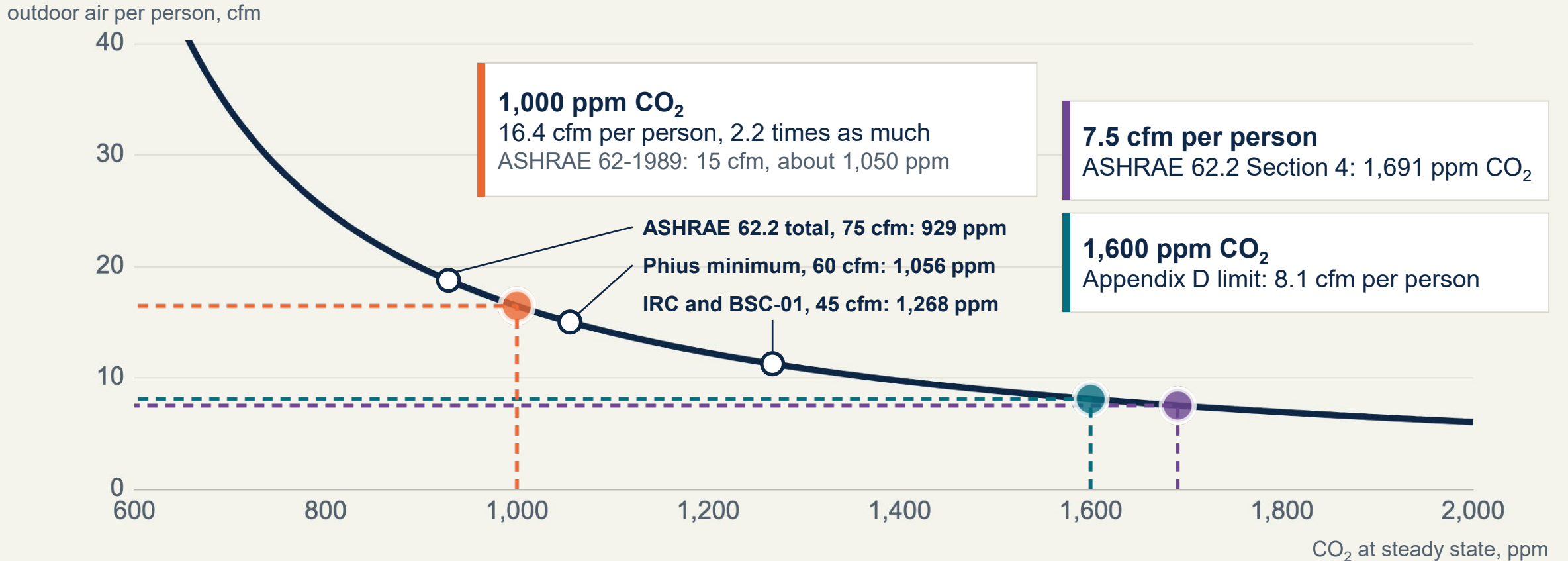
measured: who is actually there

**Section 4 estimates the number of people from the bedroom count.
Appendix D measures CO₂, which rises with the occupants who are actually home.**

Addendum C to ASHRAE 62.2-2022, Appendix D, Section D1.2. ASHRAE 62.2-2022 Section 4.1, Equation 4.1a.

ASHRAE 62.2 Appendix D in passive buildings · PhiusCon 2026

1,600 ppm of CO₂ is close to ASHRAE 62.2's 7.5 cfm per person

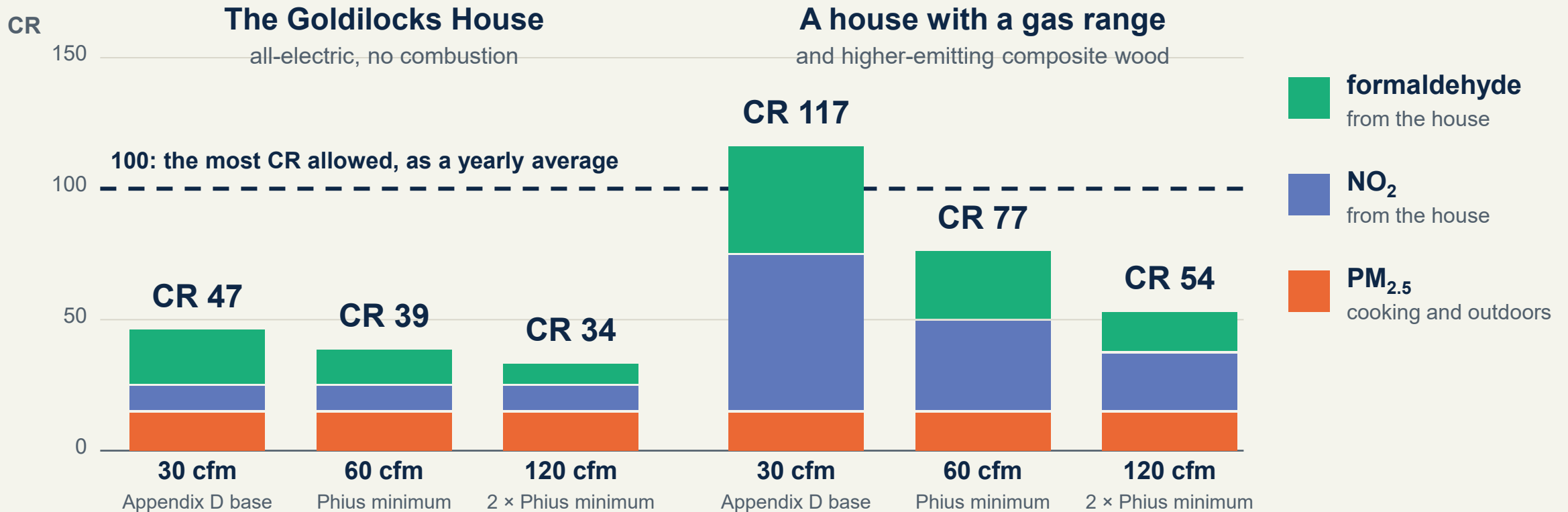


Holding 1,600 ppm of CO₂ takes 8.1 cfm per person, close to ASHRAE 62.2's 7.5 cfm per person.

Steady state: CO₂ = 420 ppm + G ÷ Q, G = 0.0045 L/s per seated adult ([Persily and de Jonge 2017](#), at 77 °F). ASHRAE 62-1989: 15 cfm per person, about 1,050 ppm. IRC: International Residential Code.

Does the house stay under CR 100 at three ventilation rates?

Bar height: CR, the yearly contaminant rating. Below each bar: the base ventilation airflow.

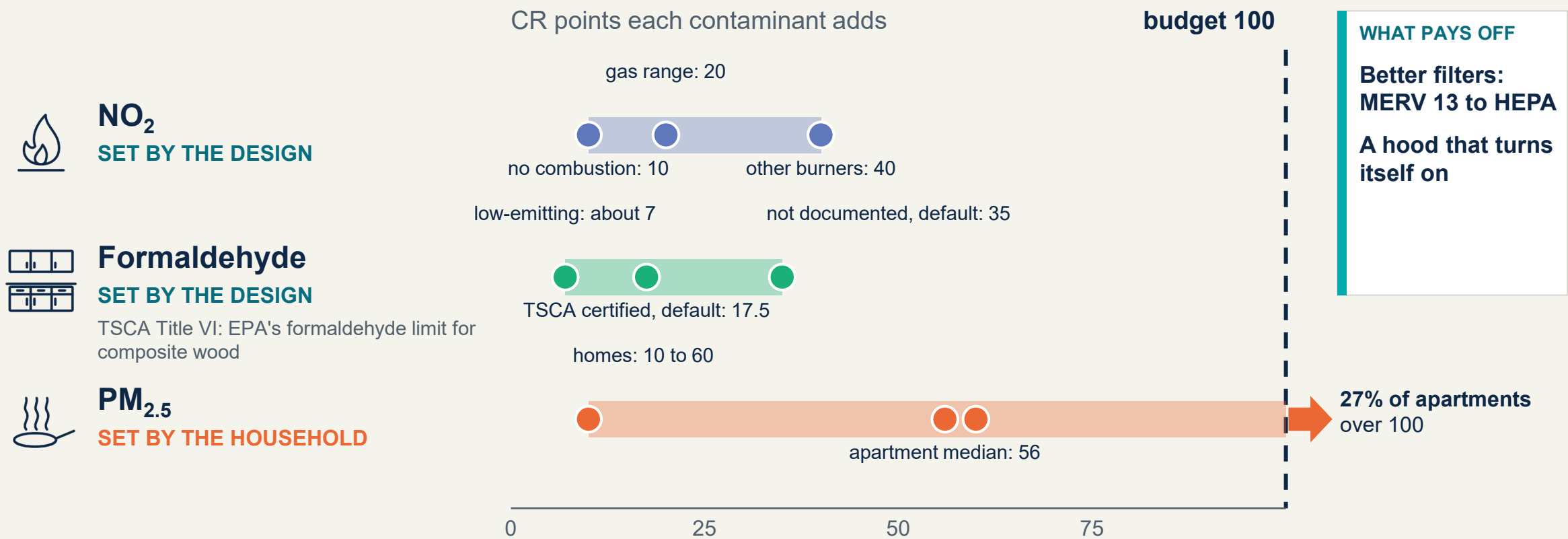


**More base airflow dilutes the house's own gases and lowers CR.
The particles barely change, so filtration and the hood matter more.**

Model: 12,750 ft³, PM_{2.5} held at 1.5 µg/m³ (measured 1.4). NO₂ 10 µg/m³ (D2.5a), or 10 + 1,500 ÷ airflow with a gas range. Formaldehyde 20 µg/m³ at 60 cfm, emission slowing as it rises ([Hult 2015](#)).

ASHRAE 62.2 Appendix D in passive buildings · PhiusCon 2026

Predict the gases from the house plans, measure the cooking



The design sets the gases through its materials and appliances. Filtration and a hood that turns itself on keep the $\text{PM}_{2.5}$ down.

Points = weight $\times$ $\mu\text{g}/\text{m}^3$ (Equation D-1). Low-emitting: NIST test house, $7.7 \mu\text{g}/\text{m}^3$ above outdoor ([Poppendieck 2015](#)), plus 1 to 5 outdoors ([Strum and Scheffe 2016](#)). $\text{PM}_{2.5}$: $10.3 \times$ summer average. ASHRAE 62.2 Appendix D in passive buildings · PhiusCon 2026

A lab badge for formaldehyde: \$117 a sample



Formaldehyde badge \$117 a sample

Passive DNPH badge, worn 24 to 72 h indoors
Lab: HPLC, the chemistry of EPA IP-6C
D3.1 names EPA IP-6, or equivalent



How it counts D2.4.2

Ventilate as designed for 24 h, doors and windows shut
Then badge the next 24 to 72 h in the living area
The reading replaces the 25 default in Equation D-1

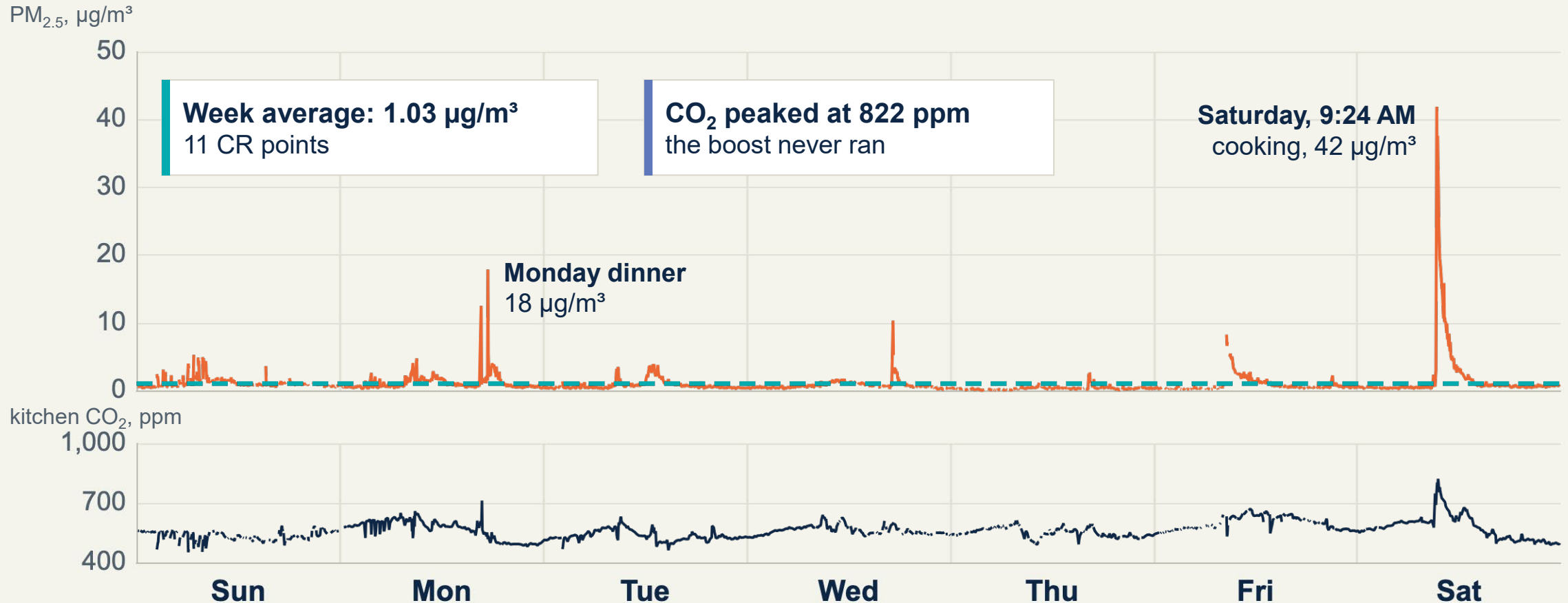
The lowest formaldehyde concentration the lab reports from one badge, against the Appendix D default, $\mu\text{g}/\text{m}^3$



A formaldehyde badge can replace the $25 \mu\text{g}/\text{m}^3$ default through D2.4.2.
 NO_2 has no badge path: Appendix D takes only real-time readings or its defaults.

SGS Galson fee, September 2026. Limit = lab minimum $\div$ air sampled: $0.1 \mu\text{g}$ at $13.56 \text{ mL}/\text{min}$ ([OSHA 1007](#)). Appendix D, D2.4.2, D2.5, and D3.1.

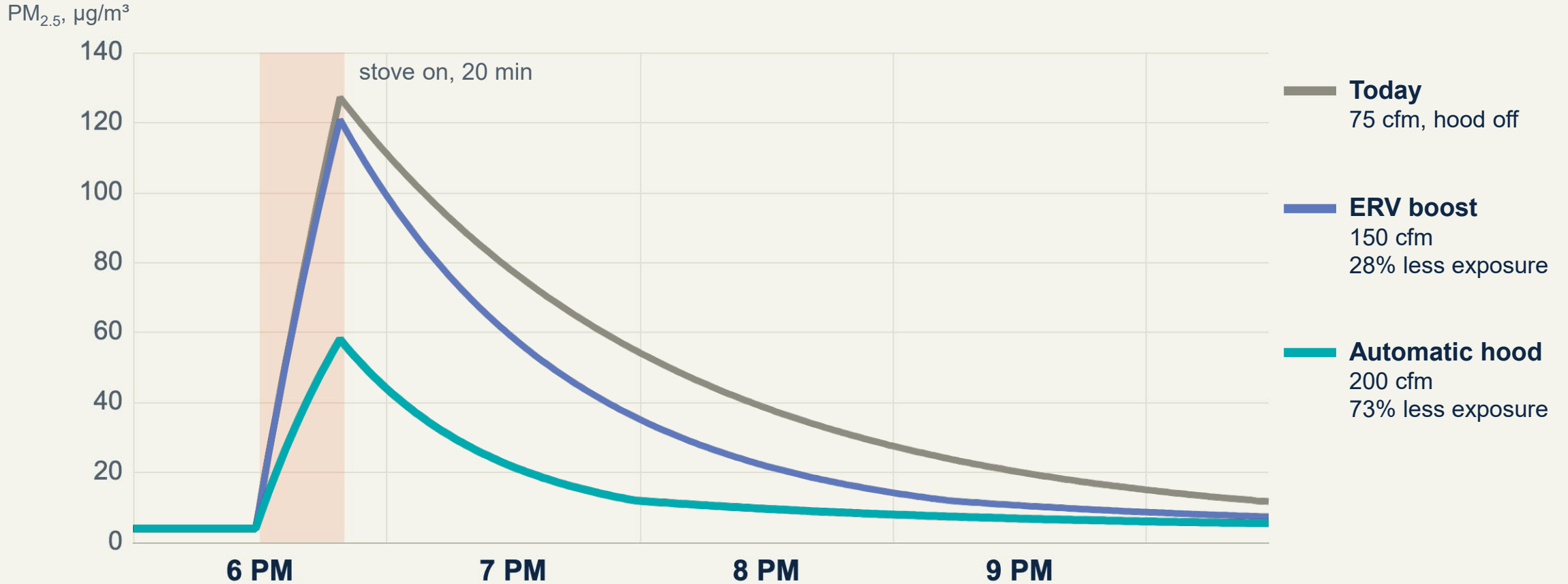
My kitchen: PM_{2.5} peaks at 42 µg/m³ and averages 1.0 µg/m³



**Cooking caused every PM_{2.5} peak, and CO₂ never reached a boost set point.
That is the case for a hood that turns itself on.**

Kitchen room sensor, my house, Sunday, July 5th, to Saturday, July 11th, 2026, 3-minute readings. PM_{2.5} part of CR = $10.3 \times 1.03 \text{ µg/m}^3 = 11$. Gases not yet measured.

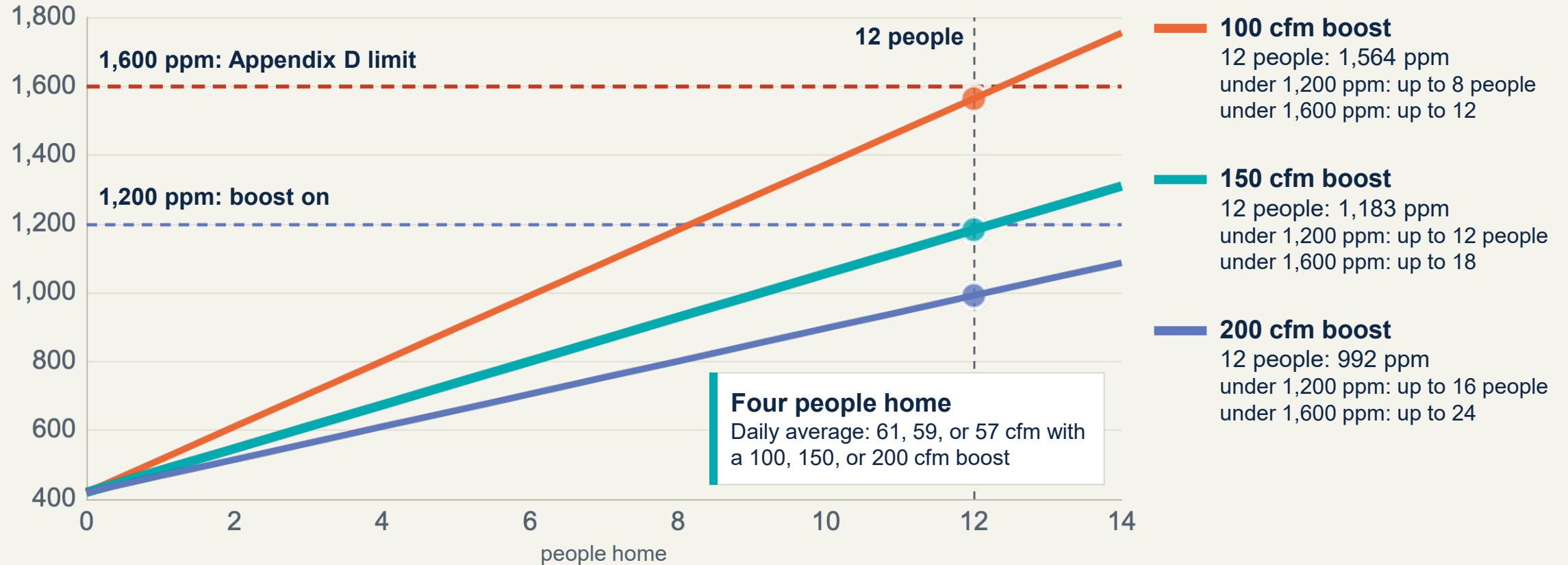
One dinner: a hood that turns itself on beats an ERV boost



**A hood that turns itself on when cooking cuts smoke exposure by 73 to 87%.
Boosting the ERV to 150 cfm cuts it by only 28%.**

Sizing the boost: its size only matters for a crowd

CO₂ with the boost running, ppm

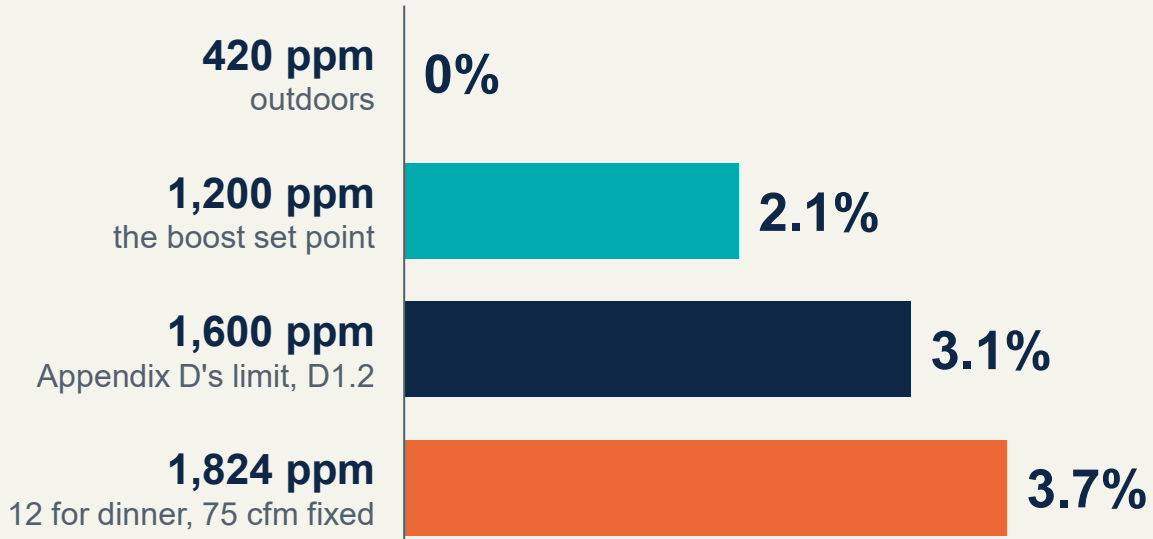


The boost size only matters for a crowd. A 150 cfm boost holds 12 people at 1,183 ppm of CO₂.

Model: steady state with the boost running, 12,750 ft³, 420 ppm outdoors, seated adults at 0.0045 L/s each ([Persily and de Jonge 2017](#)). Boost on at 1,200 ppm, off at 900. Base 30 cfm.

Why measure CO₂: the share of each breath already exhaled

Share of each breath that someone in the house already exhaled



$f = (\text{CO}_2 - 420 \text{ ppm}) \div 38,000 \text{ ppm}$, the CO₂ that breath adds
Rudnick and Milton 2003

WHAT CO₂ ITSELF DID, IN TESTS

Pure CO₂ at 1,000 ppm for 2.5 h: 6 of 9 decision scores lower than at 600 (Satish 2012, 22 people)
Office CO₂ at 945 and 1,400 ppm: scores 15% and 50% lower than at 550 (Allen 2016, 24 people)

SLEEP

Bedroom CO₂ 835 vs 2,395 ppm, a fan on above 900: better measured sleep and better next-day logical thinking (Strøm-Tejsen 2016, 16 people)

THE CAUTION

Reviews call the direct effect of CO₂ at indoor levels inconsistent (Du 2020, ASHRAE 2025).

Read CO₂ as the tracer for the occupants and what they give off.

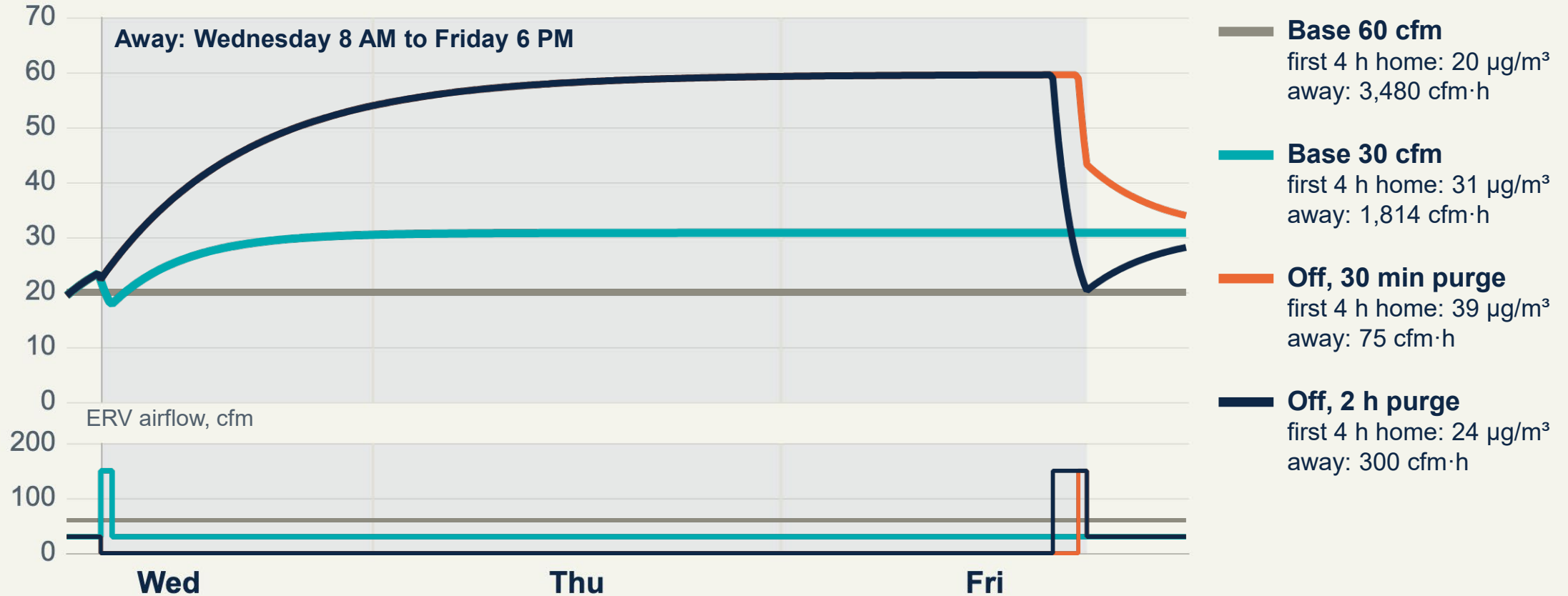
The rebreathed share is plain physics.

**At 1,600 ppm of CO₂, 3% of each breath was already exhaled by someone in the house.
CO₂ tracks the occupants.**

[Rudnick and Milton 2003](#), [Satish 2012](#), [Allen 2016](#), [Strøm-Tejsen 2016](#), [Du 2020](#), [ASHRAE position document on indoor carbon dioxide, 2025](#). Limits: Appendix D, D1.2 and D3.2.

What if a geo-fence turns the ERV off while you are away?

formaldehyde, $\mu\text{g}/\text{m}^3$

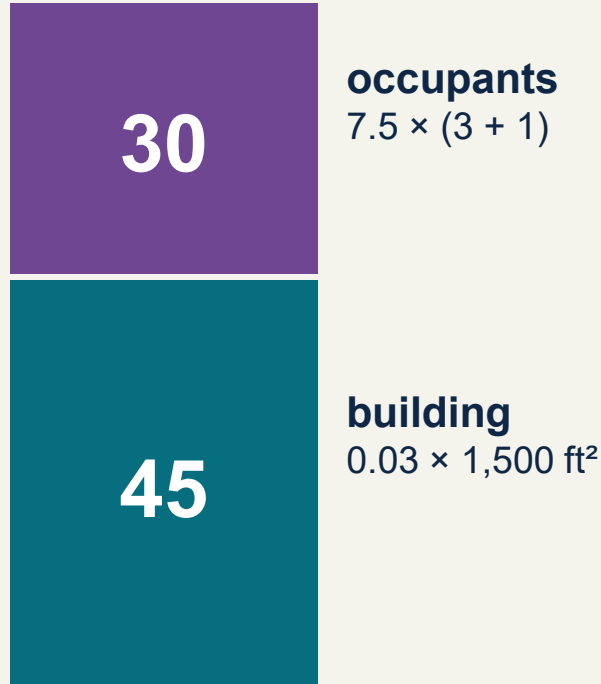


**A 2-hour purge at 150 cfm before the family comes home clears 76% of the buildup.
A 30-minute purge clears only 30%.**

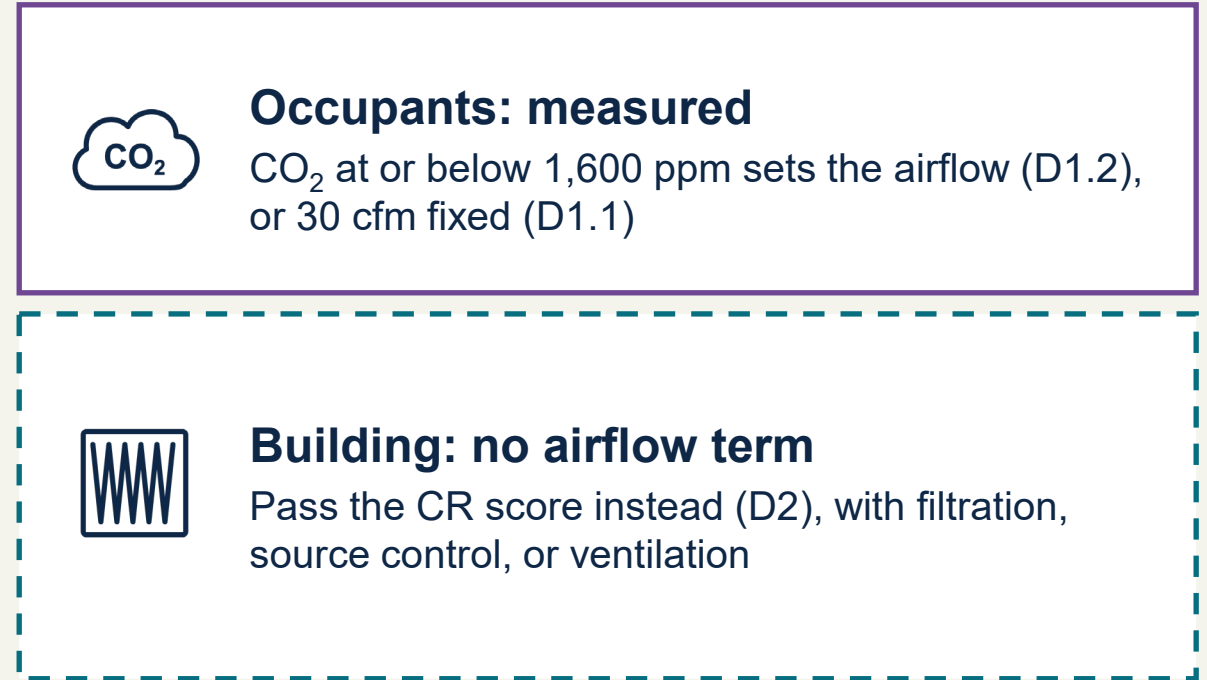
Model: 12,750 ft³, formaldehyde 20 $\mu\text{g}/\text{m}^3$ at 60 cfm, emission slowing as it rises ([Hult et al. 2015](#)), 5 cfm infiltration with the ERV off, purge at 150 cfm, CO₂ control after the return.

Appendix D replaces the building's 45 cfm with a test

ASHRAE 62.2 Section 4: 75 cfm



Appendix D



**60% of this house's 75 cfm is the floor-area term for the building.
Appendix D replaces it with the contaminant rating, CR.**

ASHRAE 62.2-2022 Equation 4.1a: $0.03 \text{ cfm/ft}^2 \times 1,500 \text{ ft}^2 = 45 \text{ cfm}$, $7.5 \text{ cfm} \times 4 = 30 \text{ cfm}$. [Addendum C to ASHRAE 62.2-2022](#), Appendix D, D1.1 (floor area of zero), D1.2, and D2.

Where the ventilation camps stand, for this house

1,500 ft², 3 bedrooms, 4 people
12,750 ft³, continuous rate

cfm	0	15	30	45	60	75	90
ACH	0	0.07	0.14	0.21	0.28	0.35	0.42

occupants: 7.5 cfm × 4

International codes (IRC, IMC)
the ASHRAE 62.2-2010 fan rate, less 30% if balanced
BSC-01 (Lstiburek)
the 2010 rate × 0.75 to 1.25 by system

ASHRAE 62.2, 2013 to 2025
0.03 cfm/ft² + 7.5 per person

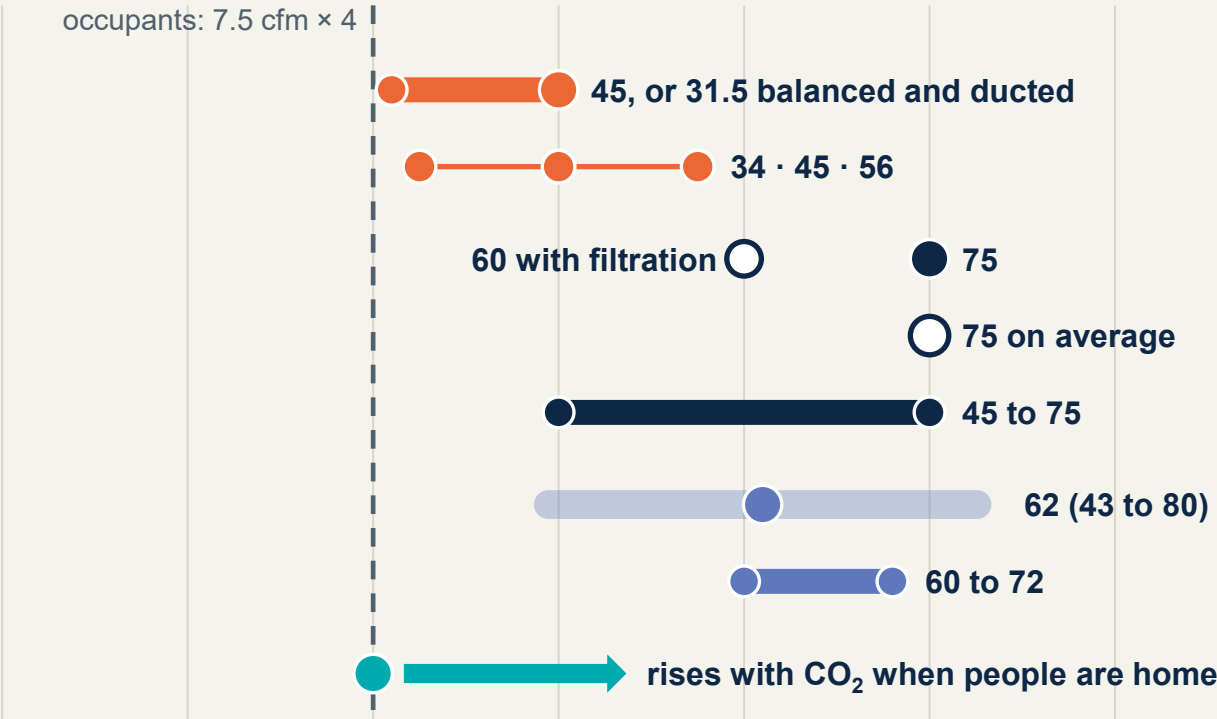
LBNL smart ventilation
ASHRAE 62.2's exposure, shifted in time

DOE Building America, NREL
ENERGY STAR, ZERH: ASHRAE 62.2-2010 or later

Passive House Institute
0.30 ACH, 20 m³/h per person, user ±30%

Phius
15 cfm per person, 18 recommended

ASHRAE 62.2 Appendix D
CO₂ ≤ 1,600 ppm or 7.5 per person, CR ≤ 100



LESS AIR, OWNER CONTROL
more air dries winters and wets summers

THE ASHRAE 62.2 TARGET
a building term for what the materials give off

PASSIVE BUILDING
enough for the occupants, no more: dry winters

MEASURED
the gases set the base

The camps disagree on how much air the building itself needs, and no health study has settled it.

A HEPA air cleaner lowers PM_{2.5} where more air cannot

Steady PM_{2.5} in the house, µg/m³



IN THE ROOM, NOT ON THE ERV

The HEPA unit recirculates room air. The ERV's filter only sees outdoor air.

With HEPA running, more ERV air raises PM_{2.5}: the filtered outdoor air is dirtier than the room.

IN ASHRAE 62.2

Section 4: a PRF of 2.1 or more cuts the fixed rate 20%, from 75 to 60 cfm

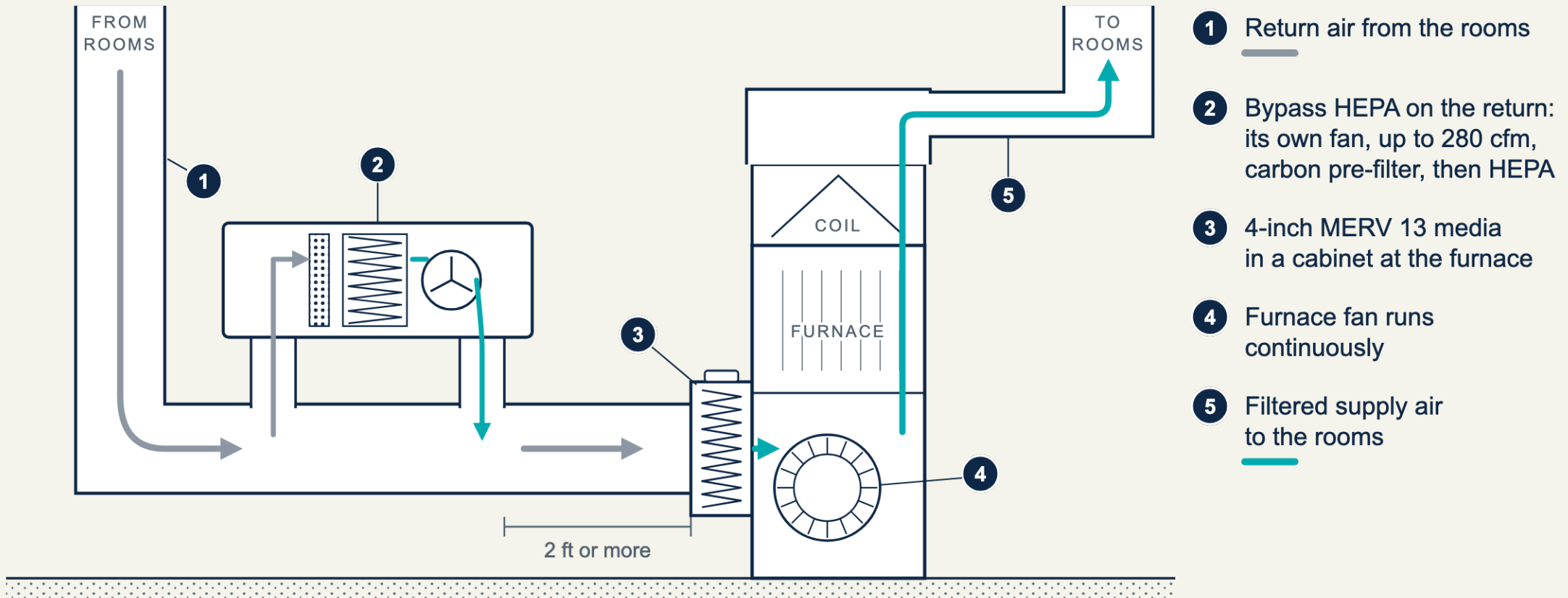
Appendix D: no credit on the base (D1.1), but the filter counts in the PM_{2.5} part

**Five times the outdoor air only lowers PM_{2.5} from 4.0 to 3.2 µg/m³.
A HEPA air cleaner lowers it to 1.3 µg/m³.**

Model: 12,750 ft³, outdoor PM_{2.5} 7 µg/m³, ERV filter 60%, deposition 0.4 per h, indoor sources set for 4.0 µg/m³ at 60 cfm. ASHRAE 62.2-2022 Addendum A, Sections 4.1.4 and 7.6. [Singer et al. 2017](#).

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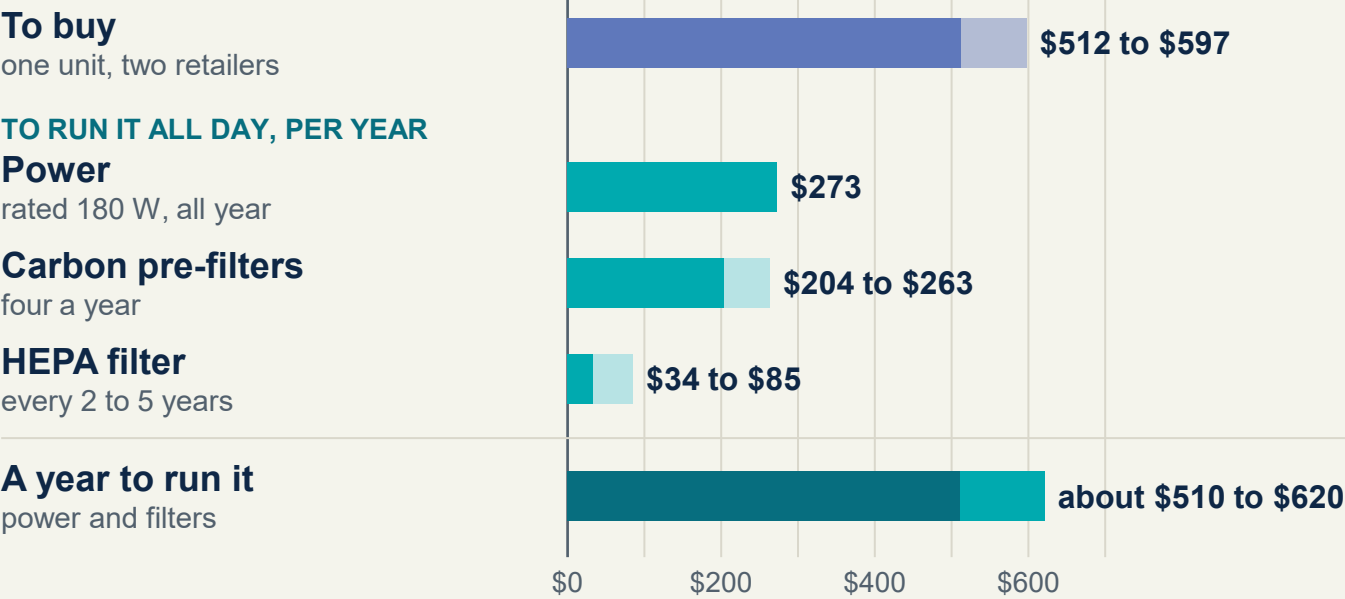
At the furnace: a 4-inch MERV 13 filter and a bypass HEPA



**The MERV 13 filter cleans all the air the furnace fan moves.
The bypass HEPA cleans a share of it to HEPA grade.**

What a bypass HEPA costs to buy and to run

One unit on the market, September 30th, 2026, \$



Installation and the furnace fan's own power are extra. Rated watts are the nameplate: measure the real draw.

THE UNIT PRICED HERE

Airflow 280 cfm free air, 241 cfm at 0.4 in. w.c.

Filters carbon pre-filter, then HEPA, 99.97% at 0.3 µm

Power 120 V, rated 180 W, on with the furnace fan

Fit on the return duct, 8-inch collars, return to return

RUN ALL DAY, 240 CFM IN 1,500 FT²

PRF 2.2

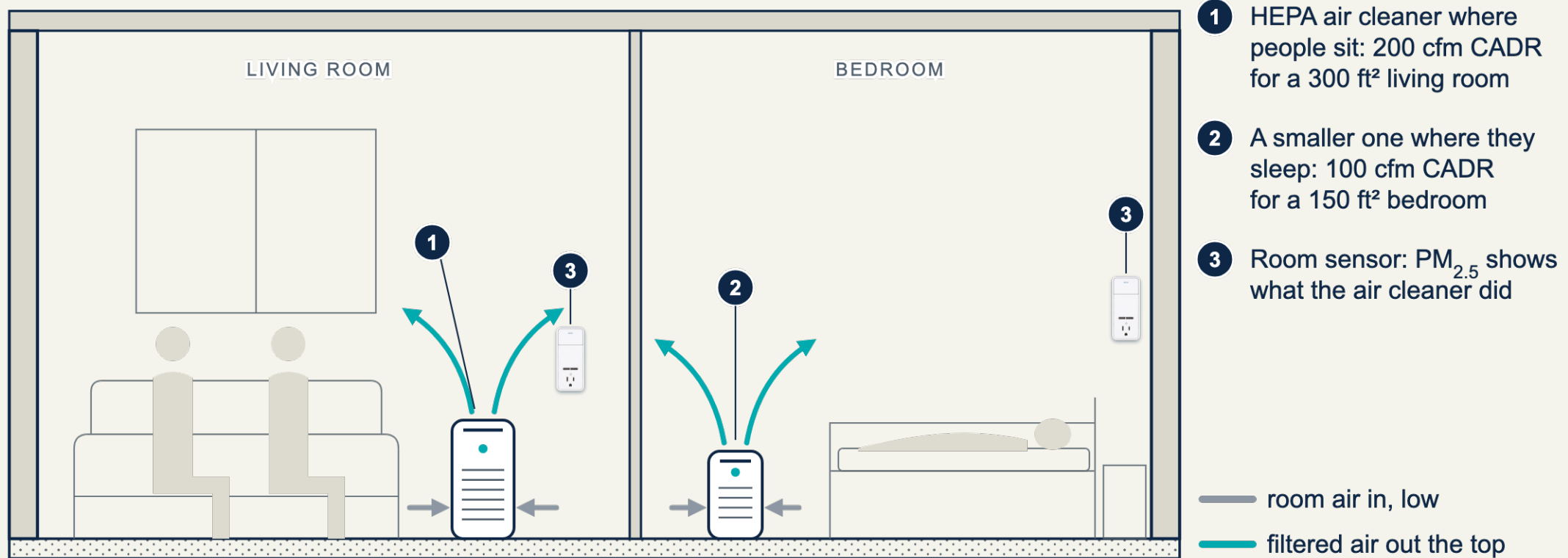
PM_{2.5} default $12 \div 2.2 = 5.5 \mu\text{g}/\text{m}^3$

CR 84 on the low gas defaults, 94 with a gas range

**Run all day with the furnace fan, the unit earns a PRF of 2.2.
Power and filters: about \$510 to \$620 a year.**

One unit's specification sheet, 2020. Prices: two online retailers, September 30th, 2026. PRF = $1 + 8.8 \times 0.85 \times 240 \div 1,500$ (Section 7.6). Power: 17.30 ¢/kWh, [EIA 2025](#).

Small HEPA air cleaners in the rooms where people live



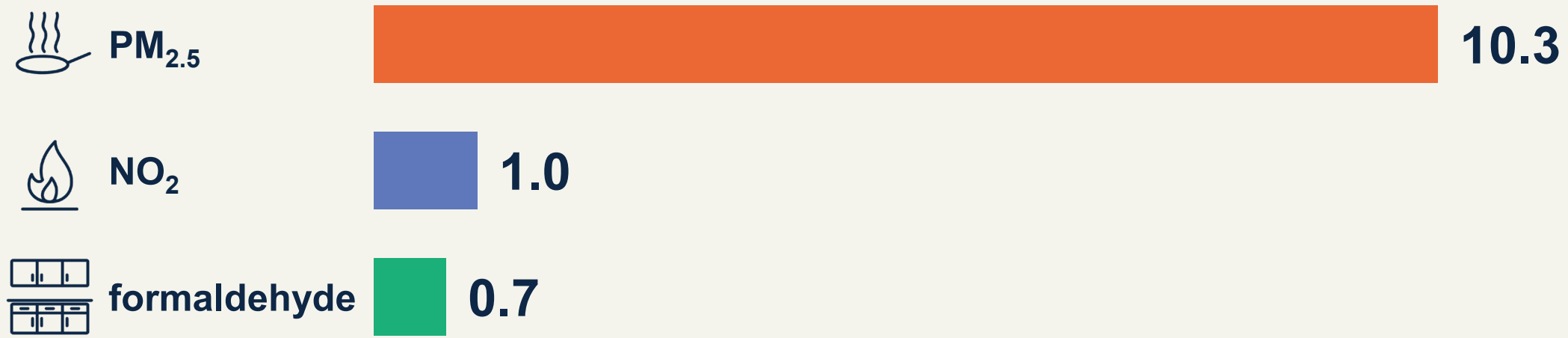
Put the air cleaner where people sit and sleep, and let the room sensor show what it did.

Illustrative section, not to scale. Sizing: AHAM guidance, smoke CADR in cfm at least 2/3 of the room's floor area in ft², for rooms with 8 ft ceilings.

ASHRAE 62.2 Appendix D in passive buildings · PhiusCon 2026

Microgram for microgram, particles score 10 times NO₂

Points added to the CR score by 1 µg/m³ of each contaminant



WHERE THE RATIOS COME FROM

Harm per microgram, from Morantes, Sherman, and colleagues (2024)

WHERE THE SCALE COMES FROM

Set so a median home meeting ASHRAE 62.2's rate just meets the budget of 100

One µg/m³ of cooking smoke adds as much to CR as 10 µg/m³ of NO₂ or 15 µg/m³ of formaldehyde.

References for the appendix and notes

1. ASHRAE. Addendum A to ANSI/ASHRAE Standard 62.2-2022 (filtration credit, Sections 4.1.4 and 7.6), February 29th, 2024. Addendum R to ANSI/ASHRAE Standard 62.2-2010 (infiltration credit), June 23rd, 2012. [Addendum A](#) · [ashrae.org](#)
2. ANSI/ASHRAE Standard 62.1-2022, Ventilation and Acceptable Indoor Air Quality, Section 6.3, Indoor Air Quality Procedure. [ashrae.org, read-only](#)
3. Persily A. Challenges in developing ventilation and indoor air quality standards: the story of ASHRAE Standard 62. Build Environ 2015, 91:61–69. [doi:10.1016/j.buildenv.2015.02.026](#)
4. Building Science Corporation. BSC Standard 01-2015, Ventilation for New Low-Rise Residential Buildings. July 20th, 2015. [buildingscience.com](#)
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Glossary

ACH air changes per hour: $\text{cfm} \times 60 \div \text{the house volume in ft}^3$

ACH50 air changes per hour at 50 Pa in a blower-door test

Addendum A the 2024 change to ASHRAE 62.2-2022 that sets the filtration credit

Addendum C the 2025 change to ASHRAE 62.2-2022 that adds Appendix D

Appendix D ASHRAE 62.2's Indoor Air Quality Procedure: D1 for the occupants, D2 for the house

ASHRAE American Society of Heating, Refrigerating and Air-Conditioning Engineers

ASHRAE 62.1 the commercial ventilation standard

ASHRAE 62.2 the ventilation standard for homes

CADR clean air delivery rate: the cfm of particle-free air an air cleaner delivers

cfm cubic feet per minute of airflow

cfm50 airflow through the envelope at 50 Pa in a blower-door test

CO₂ carbon dioxide, exhaled by people: it tracks how many are home

CR contaminant rating: $10.3 \times \text{PM}_{2.5} + 1.0 \times \text{NO}_2 + 0.7 \times \text{formaldehyde}$, in $\mu\text{g}/\text{m}^3$. The yearly average must be 100 or less

D1, D2 Appendix D's two requirements. D1, the occupants: CO₂ at or below 1,600 ppm. D2, the house: CR at or below 100

DALY disability-adjusted life year: one year of healthy life lost to illness, disability, or early death

DNPH dinitrophenylhydrazine: the coating in a formaldehyde badge that traps it for the lab

ERV energy recovery ventilator: balanced supply and exhaust that recovers heat and water vapor

FADR filtration air delivery rate: $0.85 \times \text{the cfm through the filter} \div \text{floor area}$

Harm the health burden of a contaminant, counted in DALYs. Not an acronym

HEPA high-efficiency particulate air filter: 99.97% of 0.3 μm particles

HPLC high-performance liquid chromatography: the lab analysis of a formaldehyde badge

IMC International Mechanical Code

in. w.c. inches of water column: the static pressure a fan works against

IRC International Residential Code

LBNL Lawrence Berkeley National Laboratory

MDF medium-density fiberboard, one of the three composite woods TSCA Title VI covers

MERV minimum efficiency reporting value, ASHRAE 52.2's filter rating, 1 to 16

NO₂ nitrogen dioxide, from gas burners and traffic

Passive badge a clip-on air sampler with no pump: opened for a set time, then mailed to a lab

PM_{2.5} particles 2.5 μm and smaller, from cooking, smoke, and outdoor air

PNNL Pacific Northwest National Laboratory

PRF particle reduction factor: how many times a filter divides indoor PM_{2.5}, $1 + 8.8 \times \text{FADR}$

Section 4 ASHRAE 62.2's fixed rate from the house plans: $0.03 \text{ cfm}/\text{ft}^2 + 7.5 \text{ cfm} \times (\text{bedrooms} + 1)$

TSCA Title VI EPA's formaldehyde emission limits for composite wood