

5. Ventilation

*Airtightness, thermal insulation, thermal bridges, condensation, **ventilation**, cost-in-use and windows*

ZEPHIR training session | Train-the-Trainers pilot programme (Day 3)

Dolni Rakovets (Bulgaria), 28 September to 2 October 2026

Dr. Phys. Francesco Nesi | ZEPHIR Passivhaus Italia



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"Let's build ecologically together"

SECTION 1

Ventilation fundamentals

How to address the comfort and determine the right ventilation rates

Why Ventilate?



Bring in fresh air:

- Dilutes pollutants such as CO₂, water vapor, VOCs
- Can help to improve humidity (in humid or dry climates)

Mechanical ventilation systems can:

- Filter the air
- Temper the air in heating & cooling seasons
- Provide humidification and dehumidification
- Reduce indoor humidity arising from clothes drying
- Reduce risk of mould and condensation (coupled with good thermal bridge detailing)
- Take advantage of heat recovery between the outgoing exhaust air and incoming fresh air

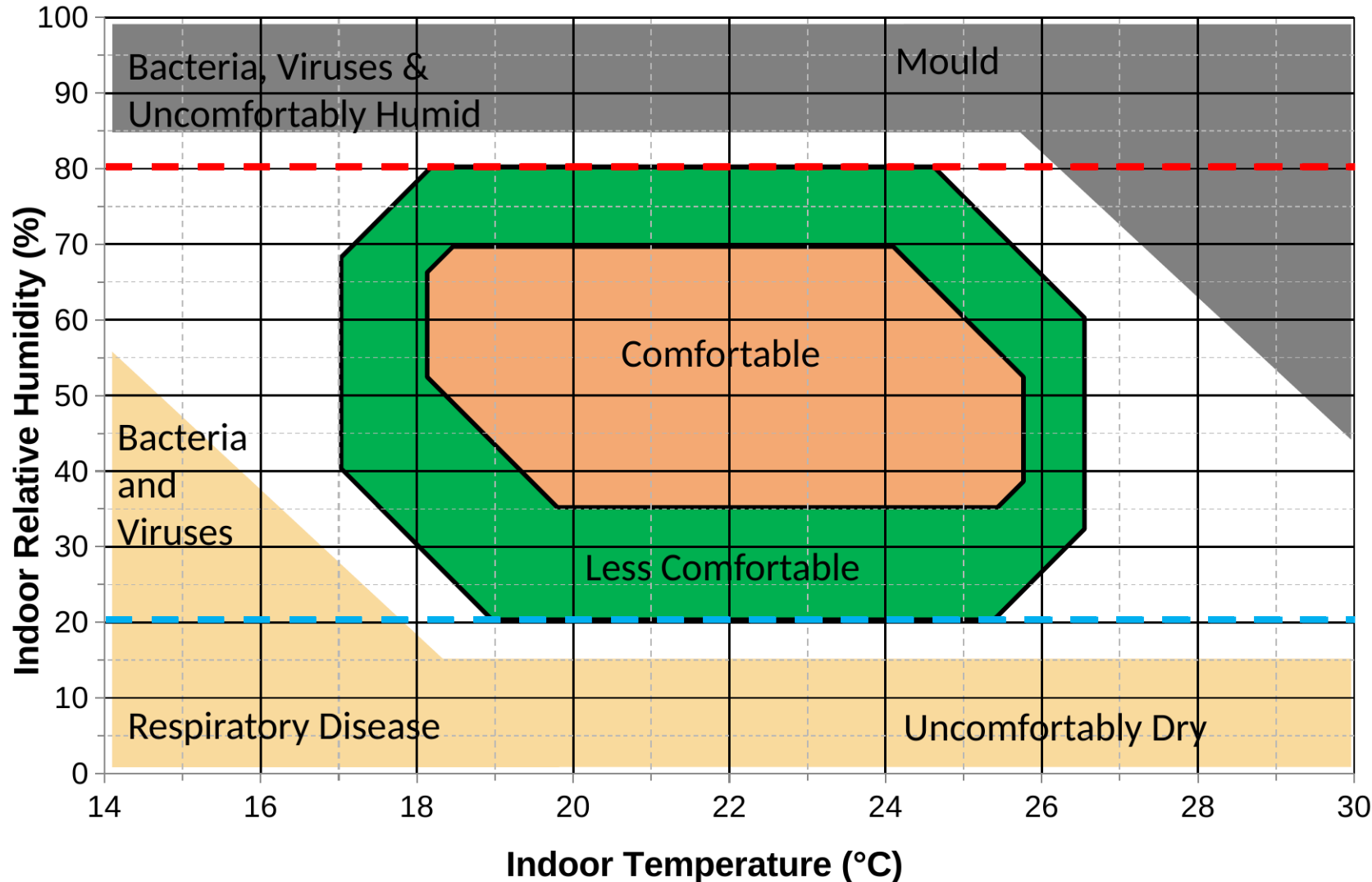


Pollutants in Indoor Air



Pollutant	Effects
Water vapor	None at moderate levels (30-60% RH). If lower, can be uncomfortable for skin dryness. If too high, can be uncomfortable but also lead to mould/mildew growth.
Carbon Dioxide (CO₂)	Not harmful until concentrations over 5,000 ppm, but as an indicator of air quality it is generally accepted that 1,000 ppm or less should be maintained. (Atmospheric concentration is approximately 400 ppm).
Dust, pollen	Numerous sources, often an allergen or irritant, can be harmful for repeated or continual exposure to high levels.
Volatile Organic Compounds (VOCs)	Various natural and artificial chemicals found in paint, adhesives, cleaning products, "new car smell," but also from plants and animals. Some are harmful after long-term exposure, others are harmless.
Carbon Monoxide (CO)	A product of combustion, this odourless toxic gas causes headaches around 100 ppm for many hours, above 800 ppm cause severe effects within 1 hour, over 1,600 ppm is fatal after 2 hours.
Radon	A natural but harmful product of the radioactive decay process of uranium, radon must be controlled at ground level with radon barrier and sub-slab exhaust system, if in regions with high levels.

Relative Humidity Comfort Zones



Relative humidity below approximately 30% can cause dryness of the skin and mucous membranes, possibly increasing the risk of infection, as well as dry out wood floors and furniture.

High humidity levels, 70 – 80 % and up, foster mold growth, dust mites, and is generally uncomfortable especially at high temperatures.

The target range for relative humidity indoors is thus 35 – 60%

Legal Ventilation Flow Rates & Passivhaus



Table B.6 — Design ventilation rates for sedentary, adults, non-adapted persons for diluting emissions (bio effluents) from people for different categories

Category	Expected Percentage Dissatisfied	Airflow per non-adapted person l/(s per person)
I	15	10
II	20	7
III	30	4
IV	40	2,5

B.3.1 Default design ventilation air flow rates

B.3.1.1 General

Due to health reasons the **total minimum airflow rate** during occupancy expressed as l/s per person should **never be below 4 l/s per person** (Table B.6) and the WHO Guideline values in B.7 is met. The default air flow rates given in this sub-clause B.3.1 are design ventilation air flow rates.

Table B.7 — Design ventilation rates for diluting emissions from different type of buildings

Category	Very low polluting building, LPB-1 l/(s m ²)	Low polluting building, LPB-2 l/(s m ²)	Non low-polluting building, LPB-3 l/(s m ²)
I	0,5	1,0	2,0
II	0,35	0,7	1,4
III	0,2	0,4	0,8
IV	0,15	0,3	0,6

For preventing the risk of overly dry air in winter, Passivhaus requires a supply air flow rate of about **8.3 l/(s per person)!**

For a single-person **office** of 10 m² in a low-polluting bldg., this accounts for additional 0.4 l/(s m²) * 10 m² = 4 l/s air flow rate for building and activity related emissions → 4 l/s for human emission + 4 l/s for bldg. related emissions = **8 l/s** total supply air flow rate

For a 4-persons **house** of 100 m² in a low-polluting bldg., this accounts for additional 0.4 l/(s m²) * 100 m² = 40 l/s air flow rate for building and activity related emissions → 4*4 l/s for human emission + 40 l/s for bldg. related emissions = **56 l/s** or **14 l/(s per person)** total supply air flow rate

Legal Ventilation Flow Rates & Passivhaus



Table B.13 — Design air flow rates by room and building type (qroom)

Number of main rooms in the dwelling	Design extract air flow rates in l/s				
	Kitchen	Bathroom or shower with or without toilets	Other wet room	Toilets	
				Single in dwelling	Multiple (2 or more in dwelling)
1	20	10	10	10	10
2	25	10	10	10	10
3	30	15	10	10	10
4	35	15	10	15	10
5 and more	40	15	10	15	10

Table B.14 — Categories for predefined **extract** air flow rates

Category	Airflow rates defined in Table B.13 multiplied by
I	1,4
II	1
III	0,7 ←
IV	0,5

NOTE In the tables only the category numbers are used without the IEQx symbol.

Category 4 applies only if there is an additional range hood in the kitchen.

Passivhaus reqs.

17.0

11.1

5.6

Legal minimum

14.0

7.0

7.0

If lower, Passive House rates can be adjusted to match minimums

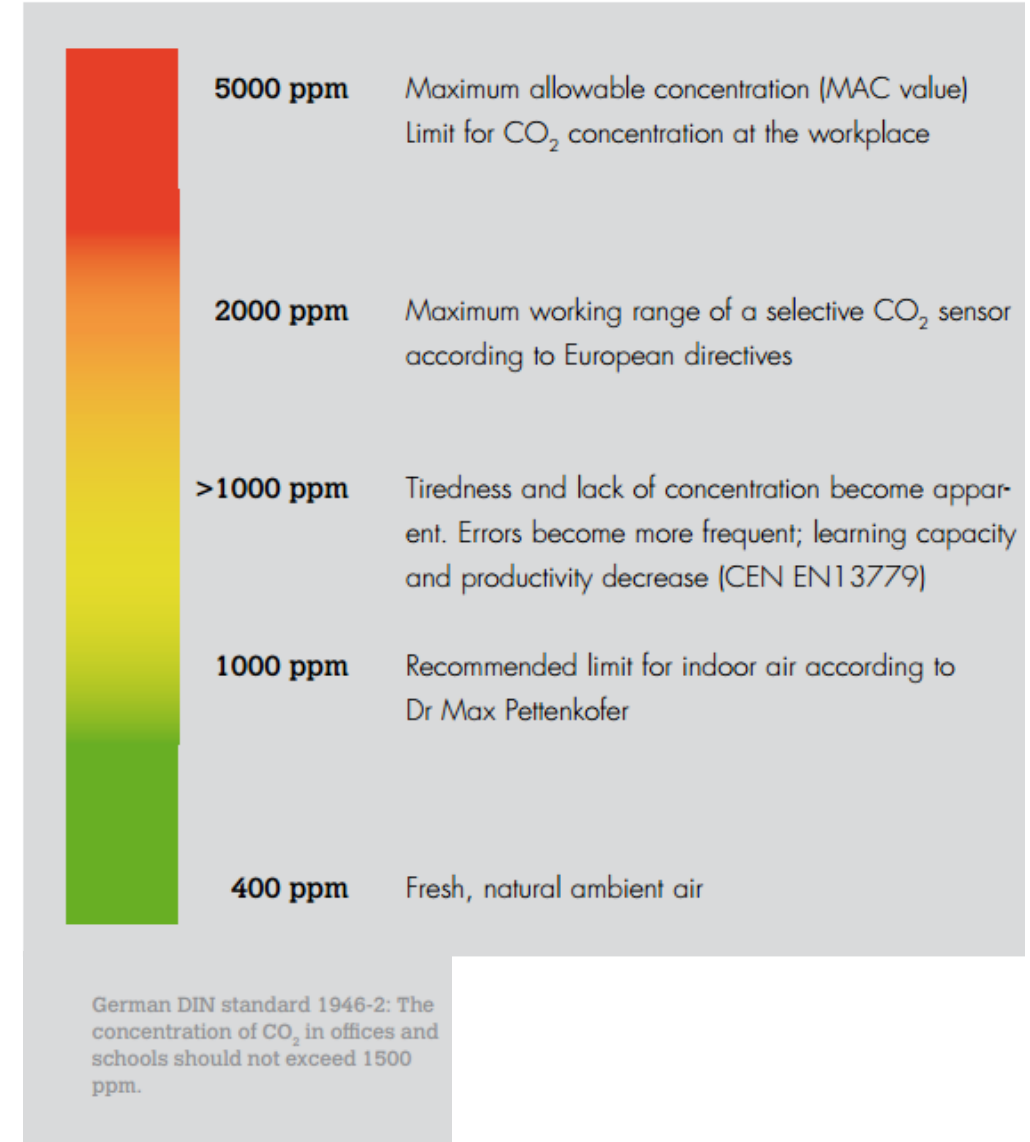
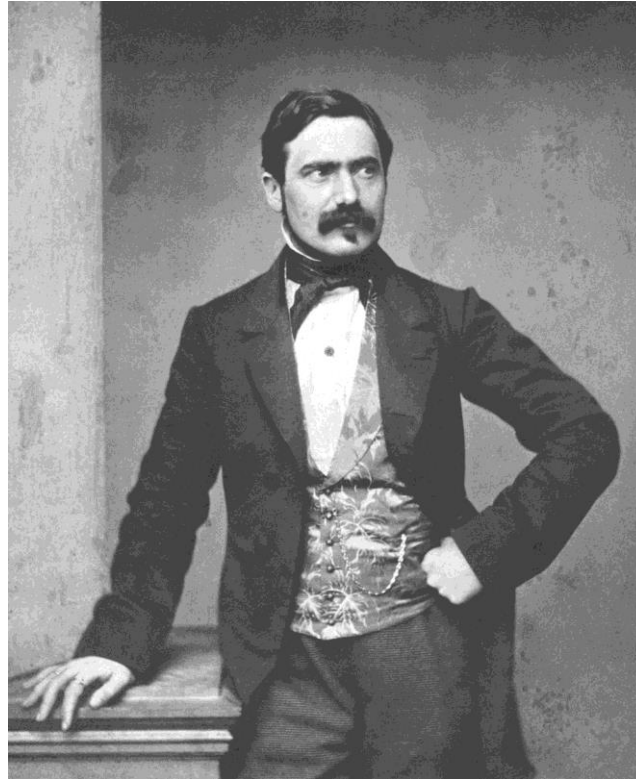
Ensure that MVHR supply ventilation rates comply with legal building code requirements, but in standard use keep low rates to prevent discomfort!

CO₂ as Air Quality Indicator



Dr Max Joseph von Pettenkofer:
*“From these experiments the evidence arises, that air which due to respiration and perspiration of humans, contains more than **1 per mille carbonic acid**, is not comfortable to us. Therefore we have the right to declare all air as bad, which contains more than 1 per mille carbonic acid.”*

Source: Literarisch-Artistische Anstalt der J.G. Cotta'schen Buchhandlung, Munich, 1858



Sizing Air Flow Rates for Air Quality

			CO ₂ per Activity Level		
	EN 13779 Class	Max CO ₂ ppm*	Asleep (12 l/h CO ₂)	Typical (18 l/h CO ₂)	Working (23 l/h CO ₂)
Excellent indoor air quality	IDA 1	800	30 m ³ /h	45 m ³ /h	58 m ³ /h
Very Good indoor air quality	IDA 2	1000	20 m ³ /h	30 m³/h	38 m ³ /h
Good indoor air quality	IDA 3	1400	12 m ³ /h	18 m ³ /h	23 m ³ /h
Moderate indoor air quality	IDA 4	1600	10 m ³ /h	15 m ³ /h	19 m ³ /h

Recommended supply rate per person at 'boost':

- 30 m³/h or
- 8.3 litres/sec

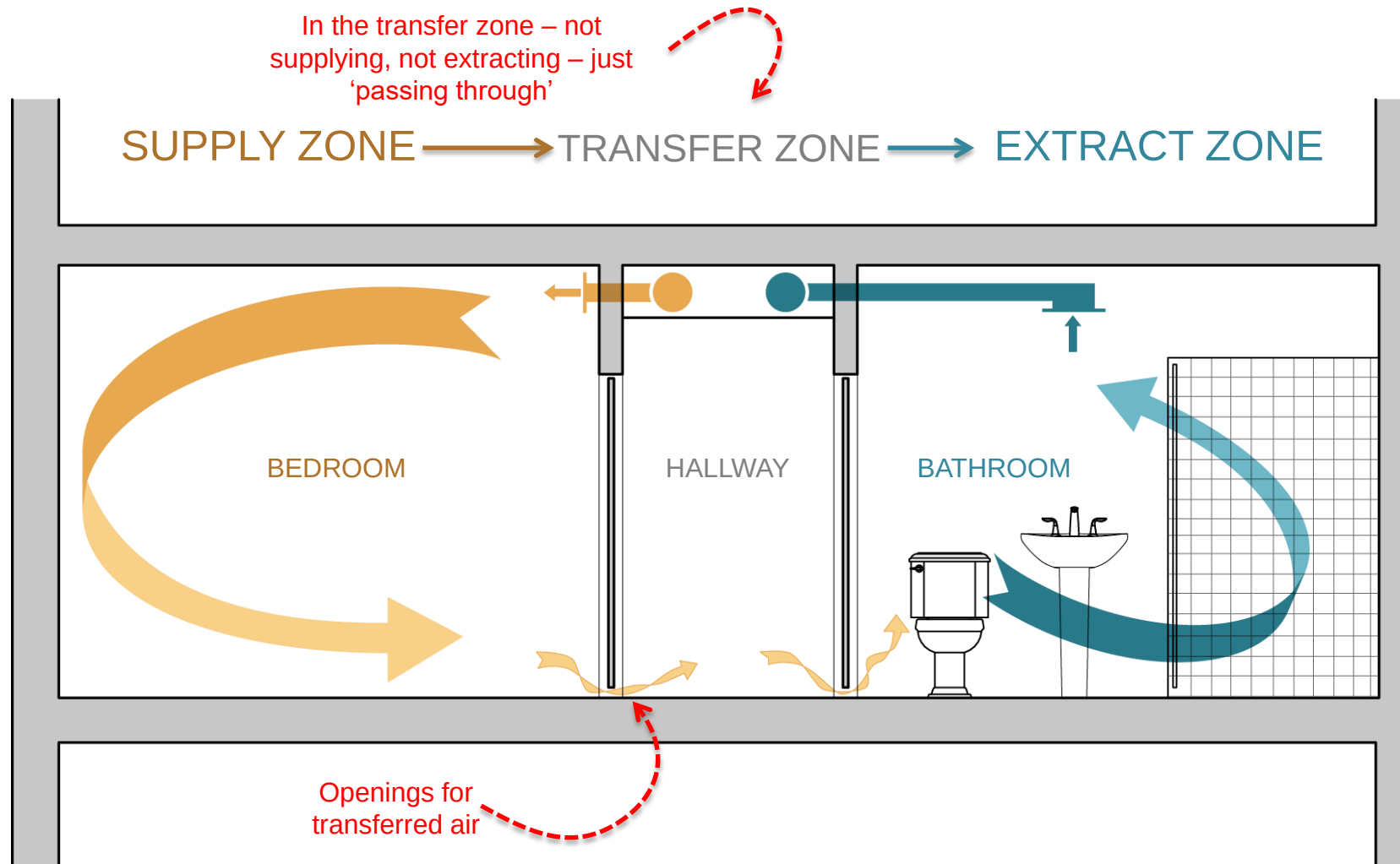
*EN 13779 actually specifies CO₂ concentrations as levels above outdoor concentrations. The values in this table have been adjusted to account for an outdoor concentration of 400 ppm.

Adapted from original prepared by Passive House Institute

Three Ventilation 'Zones'



The distribution of ventilation (fresh air supply and stale air extraction) should use as little ductwork as possible but still provide air flow through the entire building:



Determining Ventilation Capacity



Passivhaus uses **3 methods** to calculate the Ventilation Rate, then takes the highest of the 3 for the **Design Ventilation Rate**:

1. MIN. TOTAL SUPPLY @ 100% fan speed:

- 30 m³/h per person

'Boost'
speed

2. MIN. TOTAL EXTRACT @ 100% fan speed:

- Each WC, Storage, Laundry, etc: 20 m³/h
- Each Full Bath: 40 m³/h
- Each Kitchen: 60 m³/h

3. MIN. HYGENIC AIR CHANGE RATE @ 77% fan speed:

- 0.3 ACH*

'Normal'
speed

* = 0.39 ACH @ 100% fan speed

Determining Ventilation Rates: Equations

1. SUPPLY:

Flow Rate = number of people $\times$ 30 m³/h

2. EXTRACT:

Flow Rate = (Kitchens $\times$ 60 m³/h) + (Bathrooms $\times$ 40 m³/h)
+ (Laundry/Half-Baths/etc. $\times$ 20 m³/h)

3. HYGIENIC AIR-CHANGE-RATE:

Flow Rate = (0.3 ACH $\times$ V_v) $\div$ 0.77

V_v = the “ventilated
volume” of the building
= TFA $\times$ 2.5 m

Divide by 0.77 to adjust 0.3 hygienic air
changes per hour at ‘normal’ flow rate to full
speed to compare to the other calculations

Determining Ventilation Rates: Examples



For an apartment deep retrofit project for 3 people, 100 m² floor area with 1 kitchen, 1 full bathroom and 1 WC:

1. SUPPLY:

$$3 \text{ people} \times 30 \text{ m}^3/\text{h} = 90 \text{ m}^3/\text{h}$$

2. EXTRACT:

$$1 \times 60 \text{ m}^3/\text{h} \text{ (kitchen)} + 1 \times 40 \text{ m}^3/\text{h} \text{ (bathroom)} \\ + 1 \times 20 \text{ m}^3/\text{h} \text{ (WC)} = 120 \text{ m}^3/\text{h} \quad \text{Required maximum capacity}$$

3. HYGIENIC AIR-CHANGE-RATE:

$$0.3 \text{ h}^{-1} \times (100 \text{ m}^2 \times 2.5 \text{ m}) \div 0.77 = 87.7 \text{ m}^3/\text{h}$$

SECTION 2

Mechanical ventilation with heat recovery

Efficiency, heat recovery, control strategy, components

Mechanical Ventilation with Heat Recovery (MVHR)

The MVHR is the “lungs” of a highly efficient deep-retrofit ventilation system



Photo: Zehnder

MVHRs must be:

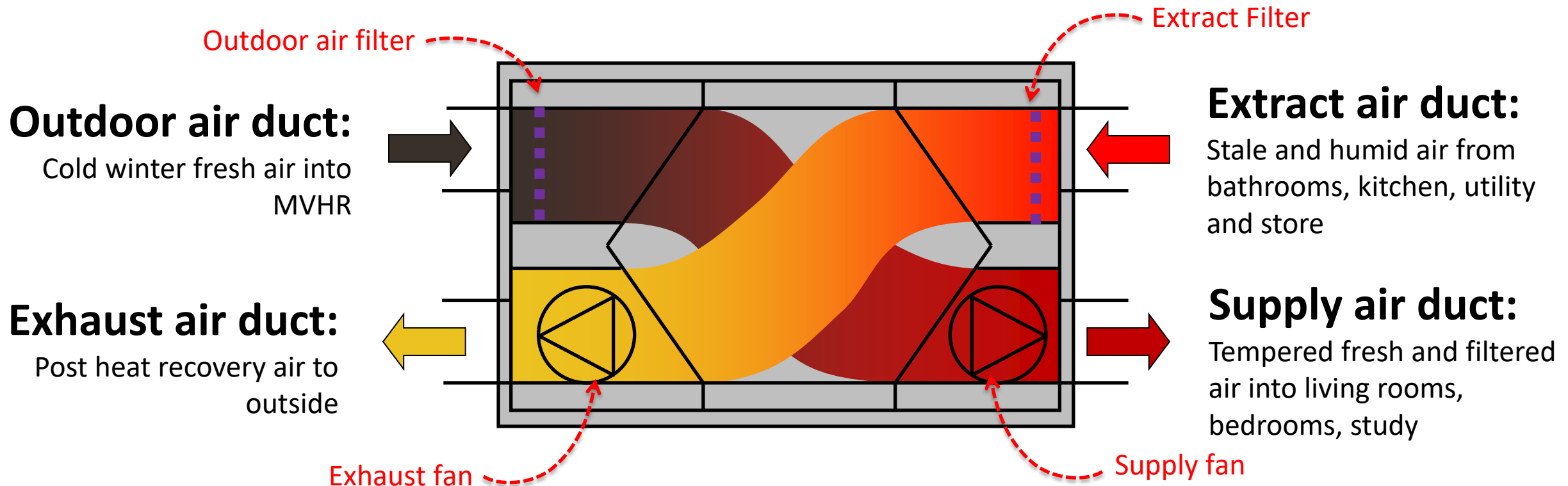
- Super-insulated
- Airtight
- Thermal bridge free
- Compact
- Quiet
- Energy efficient
- Suitably located

Heat Recovery: Heating Climate



Every MVHR system has 4 sections of ductwork, in 2 categories:

- **Fresh air:** outdoor intake into the unit, through the core, then supply air to the bedrooms, living rooms, offices, classrooms.
- **Stale air:** extract from the baths/kitchens, through the core, then exhausted to outside.



Heat Recovery: Heating Climate

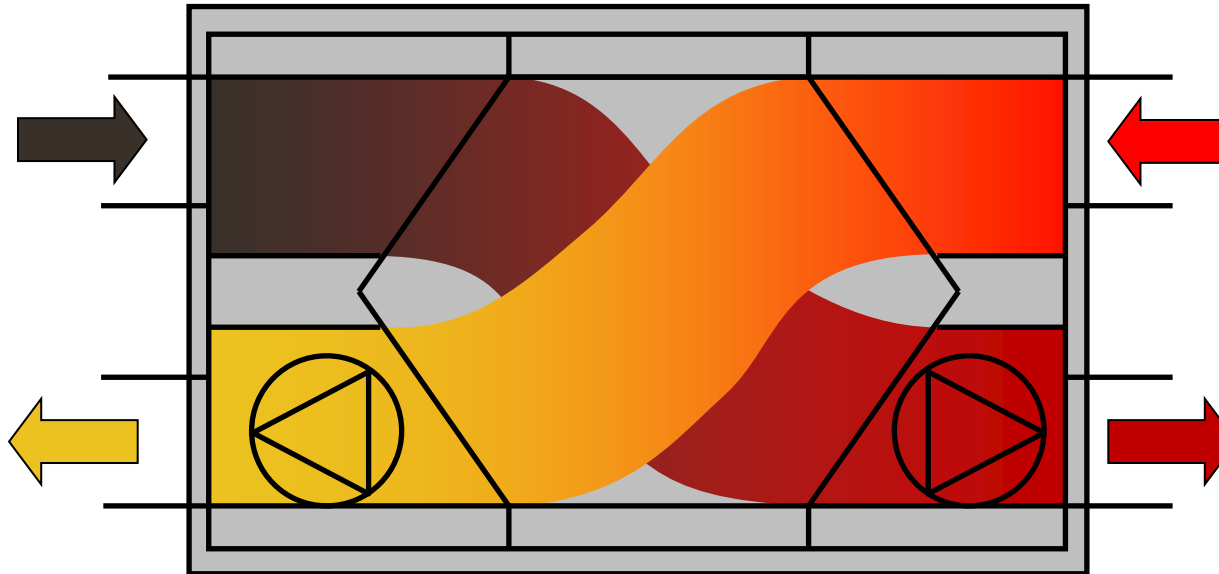


Air flow temperatures in a typical MVHR winter scenario:

Good quality MVHR's recovery approximately
90% of heat from the extract air stream

Outdoor air duct:
 $< 0^{\circ}\text{C}$

Exhaust air duct:
 $\sim 3-5^{\circ}\text{C}$



Extract air duct:
 $\sim 20^{\circ}\text{C}$

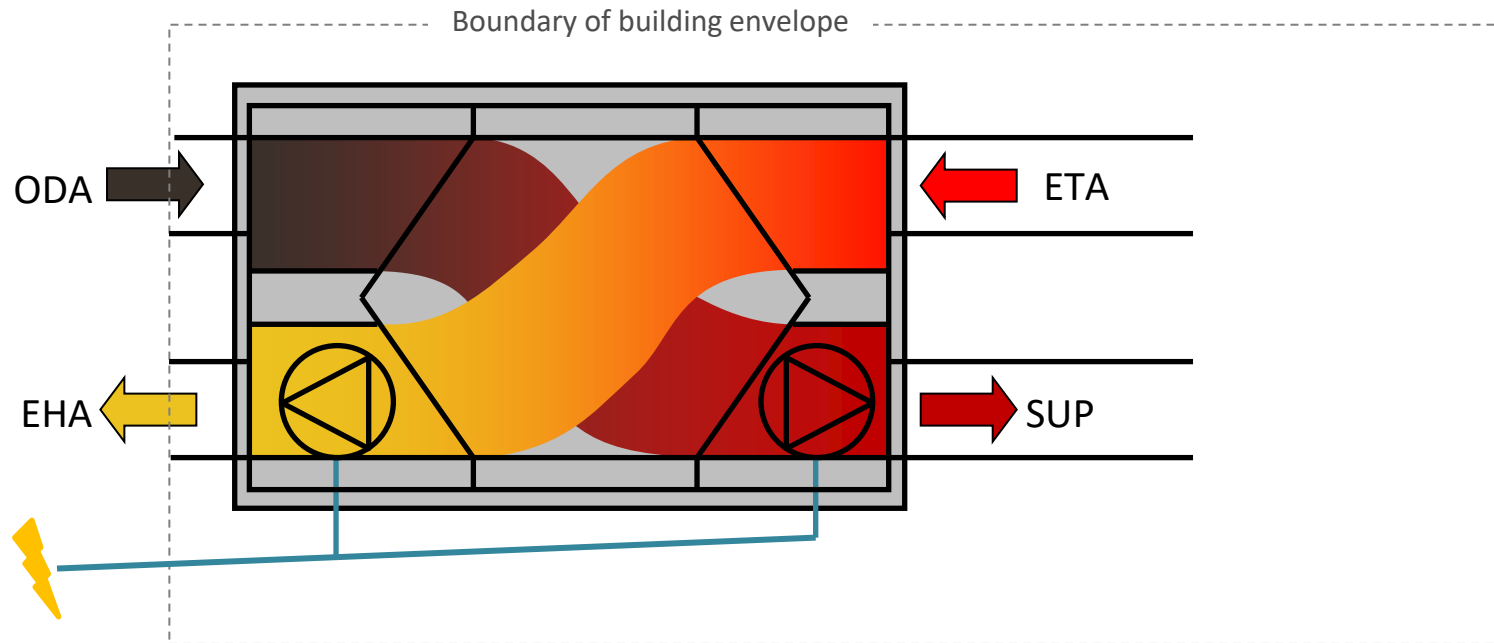
Supply air duct:
 $> 17^{\circ}\text{C}$

Example: “PH” HRV Thermal Efficiency Calculation



$$\eta_{HR} = \frac{(T_{ETA} - T_{EHA}) + \frac{P_{EL}}{(\dot{V} \times c_{air} \rho_{air})}}{(T_{ETA} - T_{ODA})}$$

Measures
'efficiency' gain
from heat of
fans in the
E/HRV box



Practice “PH” HRV Efficiency Calculation



$$\eta_{HR} = \frac{(T_{ETA} - T_{EHA}) + \frac{P_{EL}}{(\dot{V} \times c_{air} \rho_{air})}}{(T_{ETA} - T_{ODA})}$$

contributes
approx 5% of
the ‘efficiency’

Example:

$$\dot{V} = 120 \text{ m}^3/\text{h}$$

$$T_{SUP} = 18.3^\circ\text{C}$$

$$T_{ETA} = 20.0^\circ\text{C}$$

$$T_{ODA} = 0.0^\circ\text{C}$$

$$T_{EHA} = 4.0^\circ\text{C}$$

$$P_{el} = 37 \text{ W}$$

$$C_{air} = 0.33 \text{ Wh/m}^3\text{K}$$

(a constant)

$$\eta_{HR} = \frac{(20 - 4) \text{ K} + \frac{37\text{W}}{(120\text{m}^3/\text{h} \times 0.33 \text{ Wh/m}^3\text{K})}}{(20 - 0) \text{ K}}$$

$$\eta_{HR} = \mathbf{85\%}$$

Note:

The ‘industry’ method would suggest this machine is $\approx 92\%$ efficient!

$$\eta_{HR} = \frac{(T_{SUP} - T_{ODA})}{(T_{ETA} - T_{ODA})}$$

ERVs: Enthalpy Recovery Ventilators



Most manufacturers offer “enthalpy exchangers” which enable not just transfer of sensible heat but also latent energy, or water vapour.

This can help regulate indoor humidity, preventing overly dry air in very cold climates and excessively humid air in warm climates.

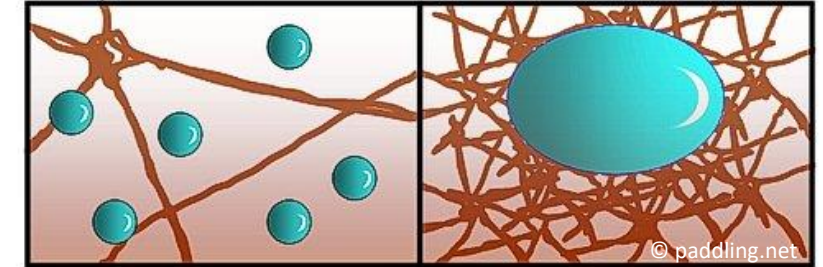


No transfer of liquid water

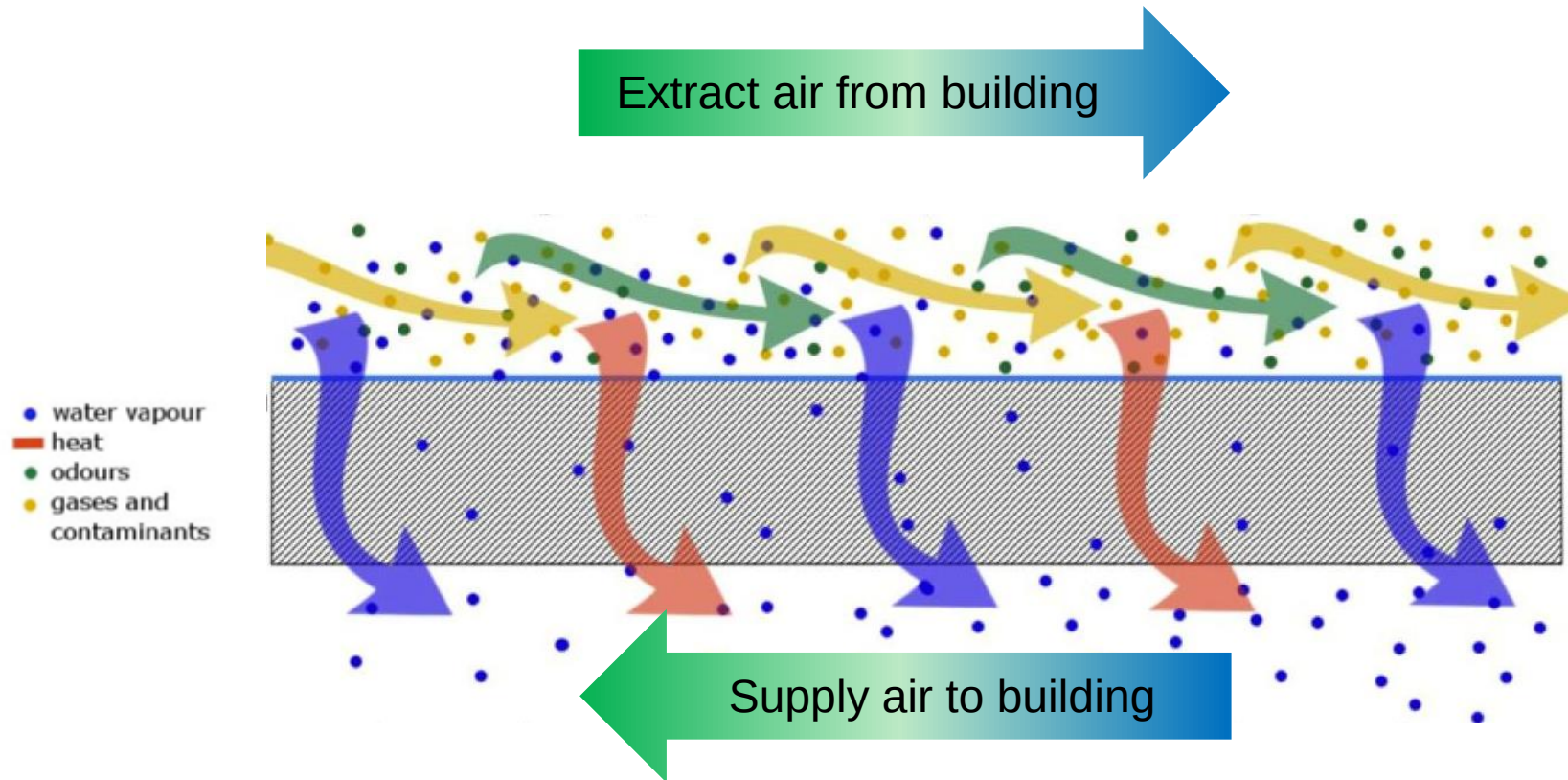


Transfer of water vapor

Micro pores (L) allow water vapor molecules to escape while preventing larger water drops (R) from passing through.



ERVs - Membrane with Selective Transfer



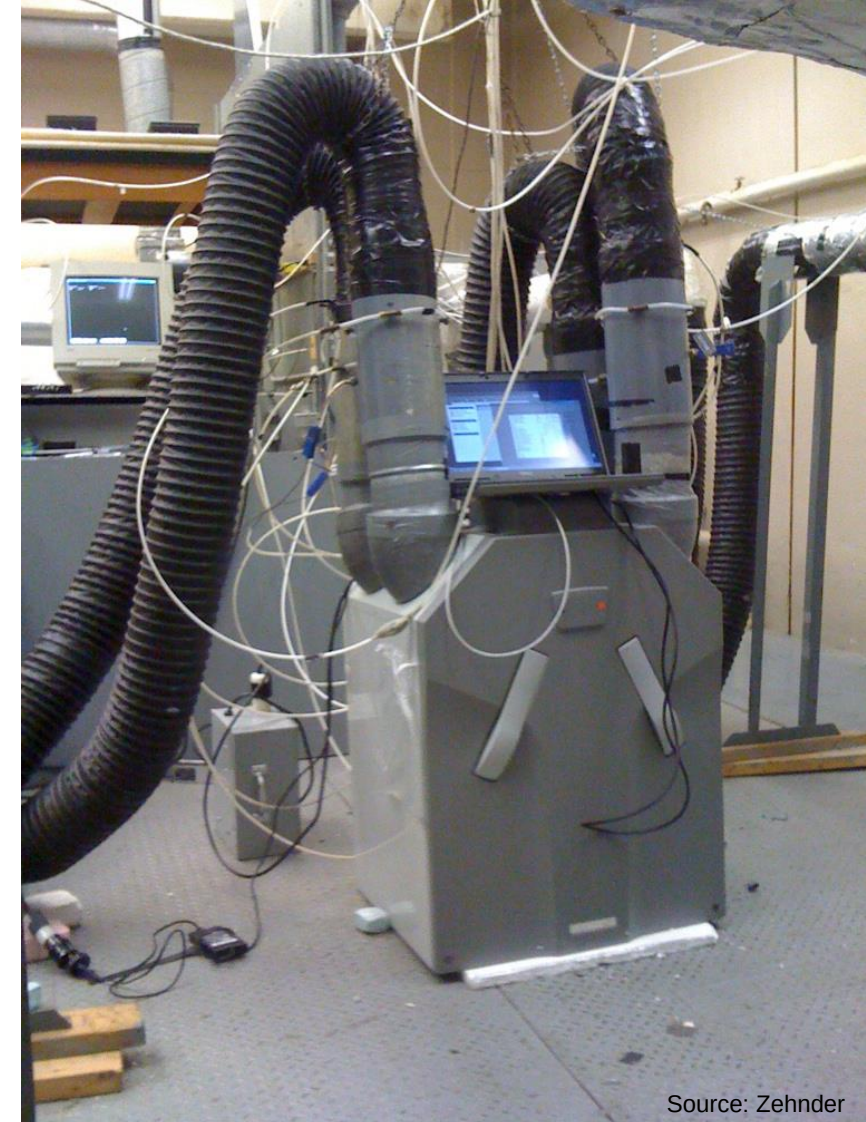
- Only transfer of heat and water vapour through the membrane
- No transfer of gases, contaminants or odours

Quality Criteria for MVHR Selection



The German Passive House Institute (PHI) provides a certification system for high quality MVHRs. Key assessment criteria used for certification are listed below.

- Determine upper and lower limits of operational **range** – **at least 3 controllable levels** must be possible (set-back (54%), normal (77%) and boost (100%))
- **Airtightness** testing (external and internal leakage) based on at least 4 testing pressures between 50 Pa and 300 Pa. Leakages $\leq 3\%$ at mid-flow range.
- **Heat recovery efficiency** according to PHI method, tested at 100 Pa, $\geq 75\%$ at outdoor temperatures of between -15°C and $+10^{\circ}\text{C}$.
- **Constant flow rate** fans, imbalance $< 10\%$.
- **Electrical consumption** for all fans and controls at upper limit of operational range $\leq 0.45 \text{ W}/(\text{m}^3/\text{h})$ (with frost protection disabled)



Source: Zehnder

Quality Criteria for MVHR Selection



- **Sound emission** at upper limit of operational range (≤ 35 dB(A) in installation room) including recommendation for silencers to achieve ≤ 25 dB(A) in living areas and ≤ 30 dB(A) in extract rooms
- **Frost protection shutdown for downstream hydraulic heater coils** (< 5 °C, example if exhaust fan fails)
- **Frost protection for heat exchanger** – must guarantee continued operation. Pre-heater must switch in at -3 °C or less (tested for 12 hours at -15 °C)
- **Comfort criterion** – minimum supply air temperature of 16.5 °C at external -10 °C
- Maximum **standby losses** (when in purely-stand mode) of 1W
- **Automatic restart** after power failure
- **Hygiene** – easy inspection and clearing of central apparatus and homeowner able to change filters
- **Filters**- outdoor air ducts must accommodate an F7 filter, G4 on extract air



Source: Zehnder

Certified MVHR Equipment



Database of Passive House Institute (PHI) certified MVHRs found here:

<https://database.passivehouse.com/en/components/>

Grouped according to following 3 types:

- Small: Capacity < 600m³/hour
- Large: Capacity > 600m³/hour
- Compact heat pumps



Ventilation Controls



At least **3 speeds**:

1. Setback:

At least 30% less than standard

2. Standard:

Outdoor air requirement according to standard occupancy

3. Boost:

At least 30% more than standard, usually activated by a separate switch, and timer-based so it returns to normal after defined period



Source: Zehnder

Note:

Be aware that heat recovery efficiency will decrease with increasing flow rates (less 'time' for the heat to exchange as air passes through the core)

Ventilation Controls



In addition to ventilation rates, most control systems will offer the following:

- **Summer Bypass**
Temperature-only or enthalpy (heat + humidity) based
- **Balancing / Commissioning**
Fine-tune fan speeds for exact air flow rates
- **Scheduled operation**
Example, filter change warning light
- **Error indicators**



Note:

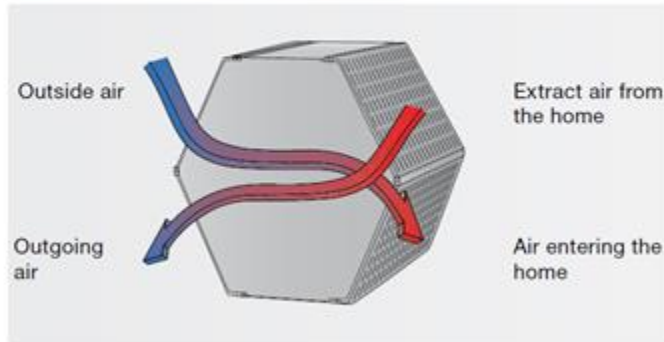
Balancing of system is normally achieved by adjusting (closing or opening slightly) supply and extract grills

“Summer Bypass” Mode in MVHR

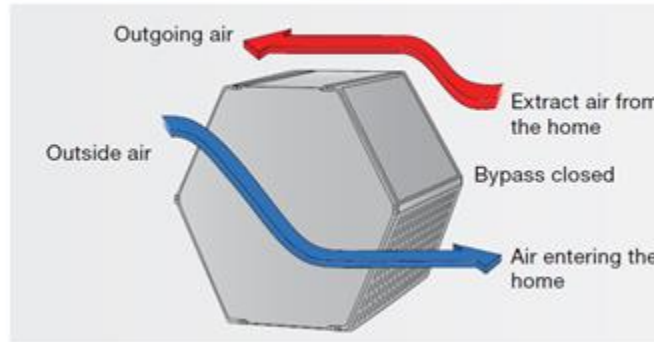


Used in the shoulder season when heat recovery is not required and when cool night air is delivered to the home providing ‘passive cooling’

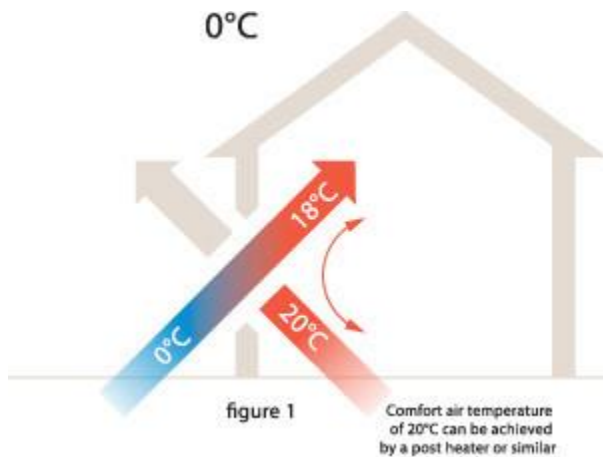
Heat Recovery Mode:



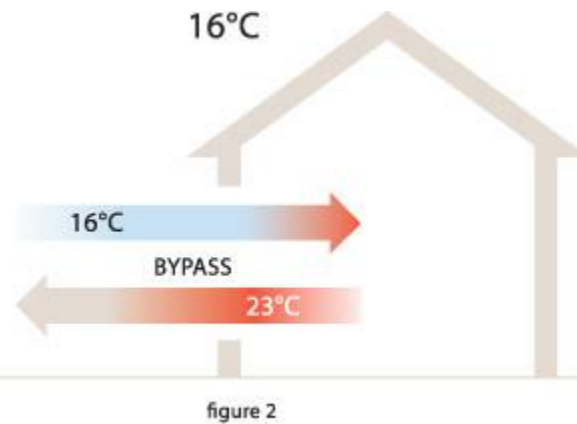
Summer By-pass Mode:



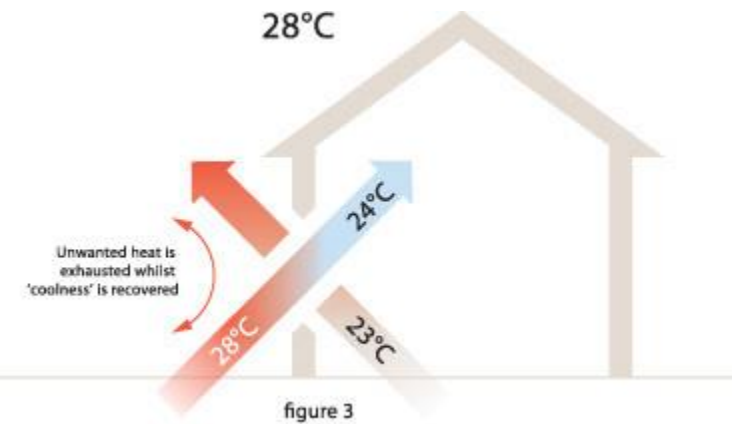
Dampers (flaps) in the MVHR change direction of airflow path to ‘bypass’ the heat exchanger



Normal heat recovery mode in winter to ‘heat’ cold outdoor air



Bypass mode used to ventilate with cool night air in summer



Normal heat recovery mode in hot weather to ‘cool’ hot outdoor air

Remote Ventilation Boost



- Boost ventilation option is desirable from bathrooms and kitchens
- Most manufacturers offer different levels of boost, sometimes set to a timer switch
- Smells of burned toast or excess fog from long teenager showers can be cleared quickly ;-)

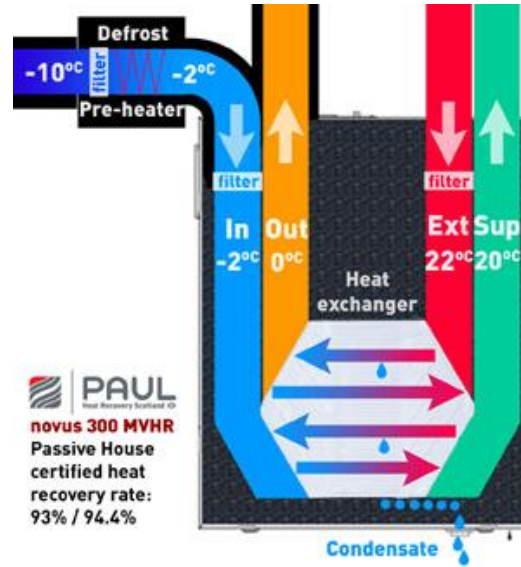


MVHR Frost Protection

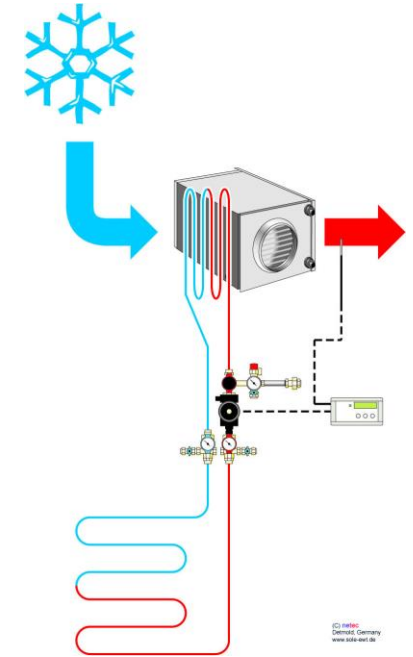
If the incoming air is cold enough (well below freezing), condensate from the exhaust air could freeze in the core and compromise indoor air quality.

Frost protection can be provided a number of ways through **pre-heating** the cold incoming fresh air when it drops below a certain temperature:

- Earth duct
- Electric preheat coil
- Ground brine or glycol loop to preheat coil
- Hot water coil from hot water tank or boiler to preheat coil



Intake tubes for earth tube pre-heaters



Brine heat-exchanger defroster

Source: netec www.sole-ewt.de

Air Intake & Exhaust Positioning & Protection



The outdoor air intake & exhaust air outlets should be positioned such that:

- **Intake air is clean & fresh** – not near parking areas or alleys, or exhausts from boilers, dryers, etc.
- **Exhaust is not too near windows** or other intakes (check local codes).
- Outdoor air intake should be located ≥ 3 m **above ground** where possible
- Intake and Exhaust external termination points should be **kept apart by ≥ 1.5 m**

Also, be sure to use louvers or vent caps that keep out wind-driven rain and rodents, but are not too restrictive, otherwise high pressure losses occur.



Separating Supply and Exhaust Ducts



- Important to separate ducts to avoid cross-contamination between supply and extract
- Locating on the roof hides the ducts from ground level
- Ensure easy access is possible for periodic checking

Grill on Fresh Air Intake

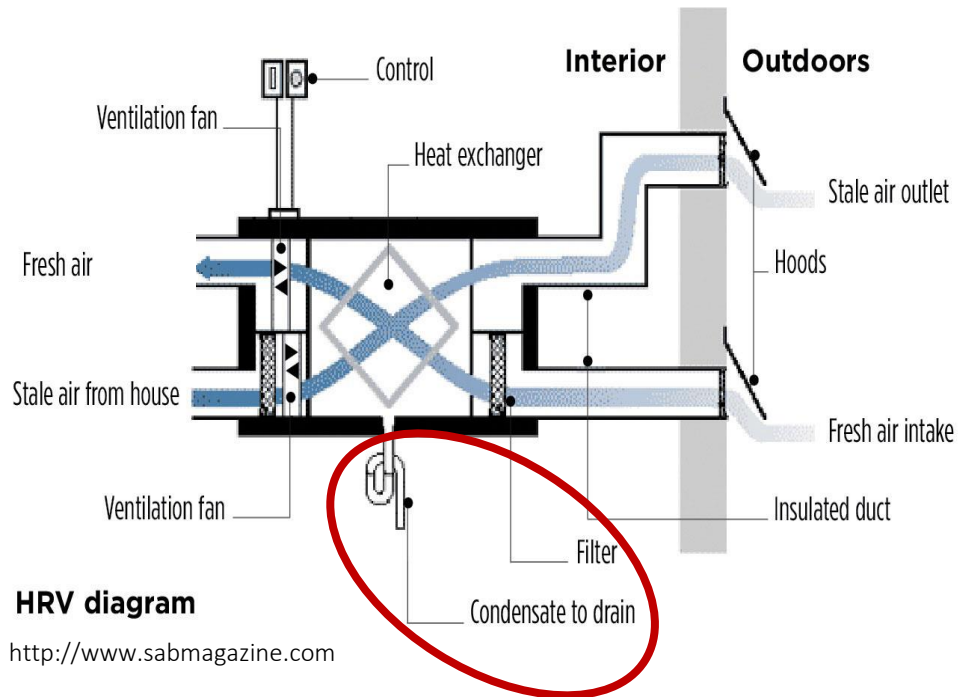


Do not use a very fine mesh on the fresh air intake as it will clog over time and create pressure drop



© Passive House Academy

MVHR Condensate Drain



- Condensate will be produced in winter (less with an ERV) and must be drained away
- Drain must have P-trap to prevent gases returning from waste water network
- Need to plan where to run condensate drain



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MVHR Filters



MVHR must filter have filters, for two reasons:

1. The heat exchange core must be protected from dust, from both the outdoors and indoors
2. To provide cleaner air for the occupants (dust, pollen, pollutants...).

Therefore there are filters on the intake air side of the MVHR core as well as the extract air side:

- **Outdoor intake:** F7 / F8 / F9
- **Extract return:** G4



Left: outdoor air filter
Right: exhaust air filter

Filters Must be Changed Regularly!



Clogged MVHR filter

- Homeowner must be advised that filters have to be changed regularly.
- This could be as often as every six months depending on outdoor environment (but generally at least once per year)



Clogged vacuum filter



Clogged car filter



Clogged coffee filter

Ductwork should be sized to allow for smooth, efficient airflow, but not so large that it wastes space or materials.

Higher air speed:

- more friction: higher fan power requirement
- risk of noise
- smaller ducts

Lower air speeds:

- lower friction: lower fan power requirement
- minimal risk of noise
- larger ducts

Target airspeed is 2 m/s for efficiency and acoustic reasons

- For ducts connected directly to rooms in the building the air speed should be **≤ 2 m/s**.
- For main trunk branches this can increase to a maximum of **3 m/s**.
- Fully engineered duct systems use more detailed methods, but for relatively short, simple duct systems, the target air speed rule-of-thumb method works well.

Example - Calculating the Duct Diameter



$$\text{Duct Diameter [m]} = 2 * \sqrt{\dot{V} [\text{m}^3/\text{h}] / (\text{velocity [m/s]} * \pi * 3600)}$$

Example, what duct size is required for a volumetric flow rate of 150 m³/h?

$$\text{Diameter} = 2 * \sqrt{150 / (2 * 3.14 * 3600)}$$

$$\text{Diameter} = 2 * \sqrt{0.0066348}$$

$$\text{Diameter} = 2 * 0.0814 = 0.163 \text{ m} = 163 \text{ mm}$$

Dealing with Clothes Dryers



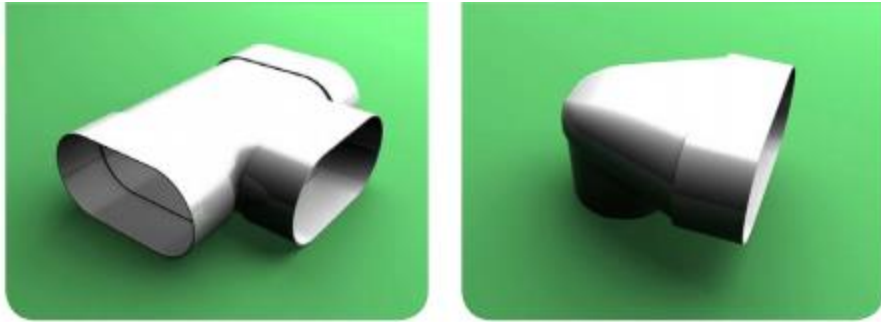
Condenser Dryer

- Condenses damp air from clothes into water
- Requires no vent to outside
- Perfect for Passive House

Vented Dryer

- Draws air from room, heated and blown through clothes
- Moisture laden air has to be exhausted to outside
- Needs ducting, damper and air-sealing

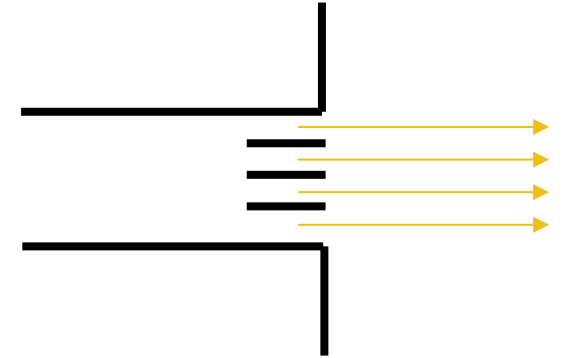
Duct Pressure Losses



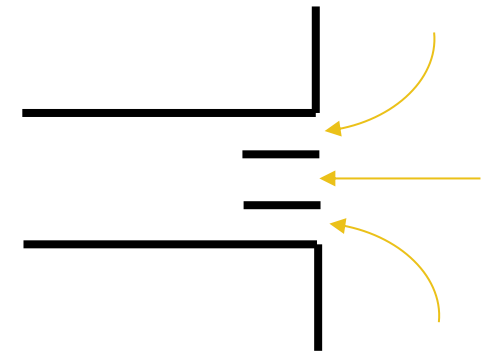
Every duct fitting (turn, transition, etc) adds friction to the system as well. Fitting losses are quantified by their equivalent length:

- At 3 m/s, a 90° elbow is equivalent to 1.8 m of straight duct.
- At 3 m/s, a 45° elbow is equivalent to 0.9 m of straight duct
- The lower the air speed, the lower the equivalent length for any fitting

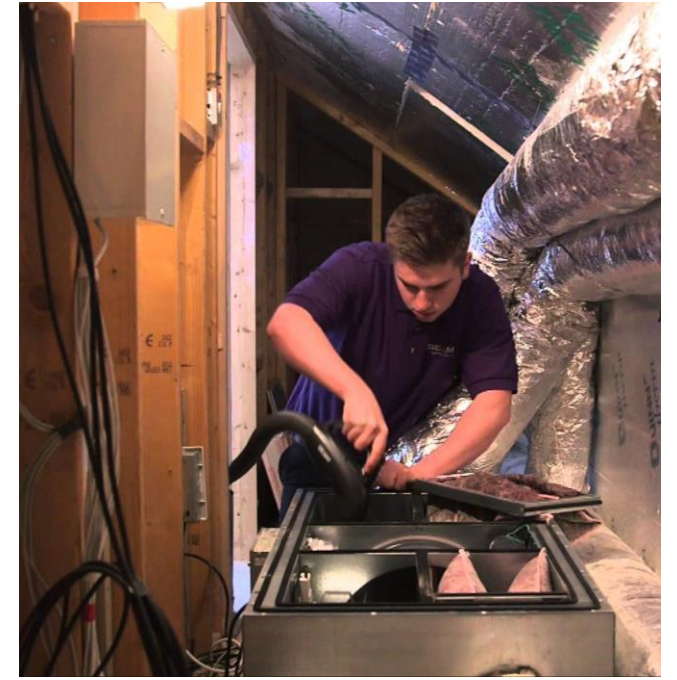
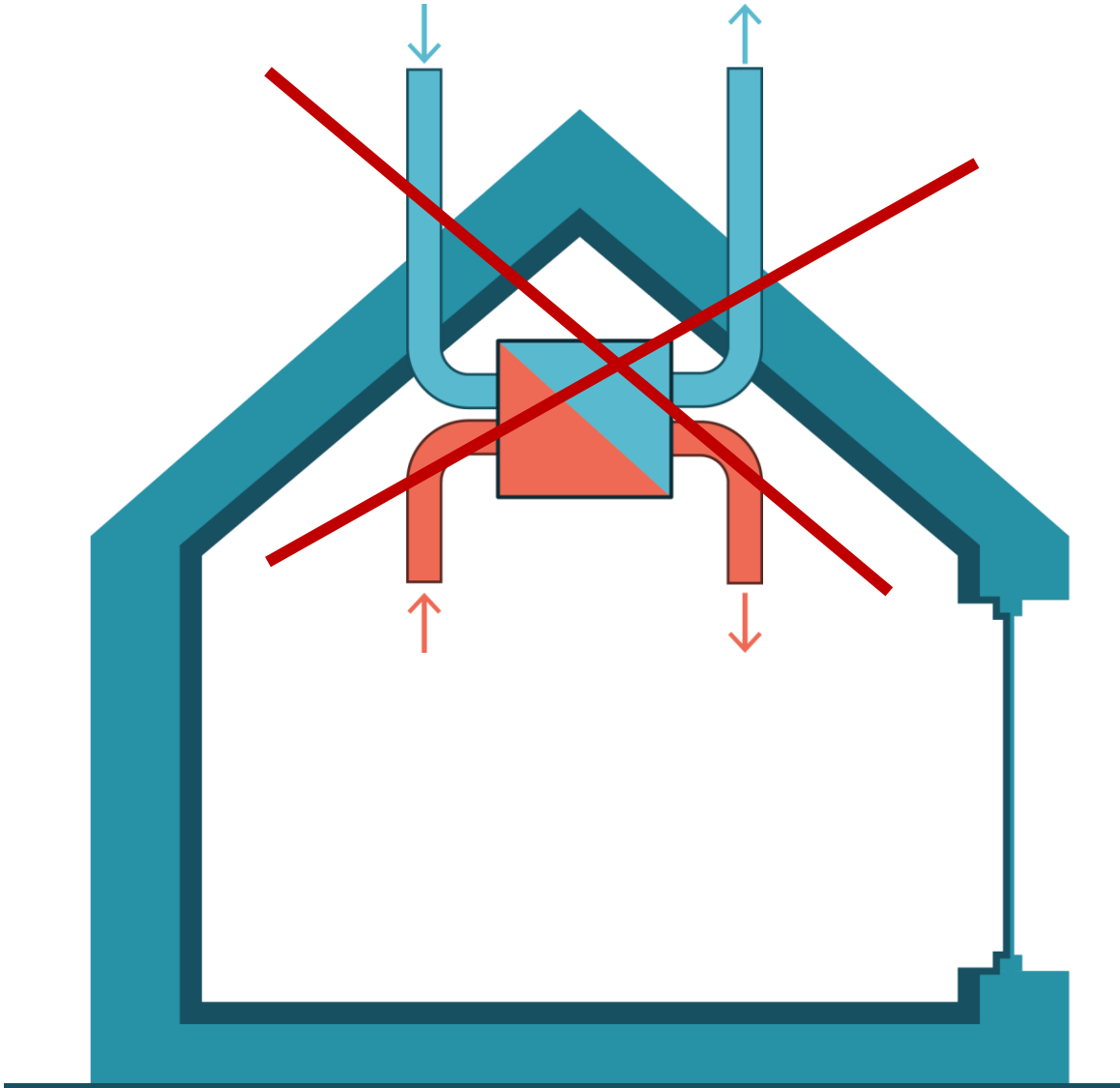
Supply registers/grilles are relied on, to some extent, to provide a certain air flow pattern in the space they serve – thus some constriction may be needed to create that pattern.



Extracts (returns), however, cannot produce any significant pattern to the airflow being drawn in, thus there's no reason to have any substantial pressure loss at a return/extract point.



Where to Locate the MVHR?



Possibly not in the attic!

- Homeowner will be less inclined to check the MVHR and change the filters if it is placed in the attic
- Attic might be outside of thermal envelope, resulting in significant heat losses
- Position the MVHR somewhere visually and physically accessible

Correctly Locating the MVHR



- MVHR located adjacent to exterior wall ensuring minimal length of cold air ducts
- Positioned at comfortable height for changing filters
- Plenty of room for condensate drain to bottom (yet to be fitted)
- Could have left more room to right hand side for internal finishes

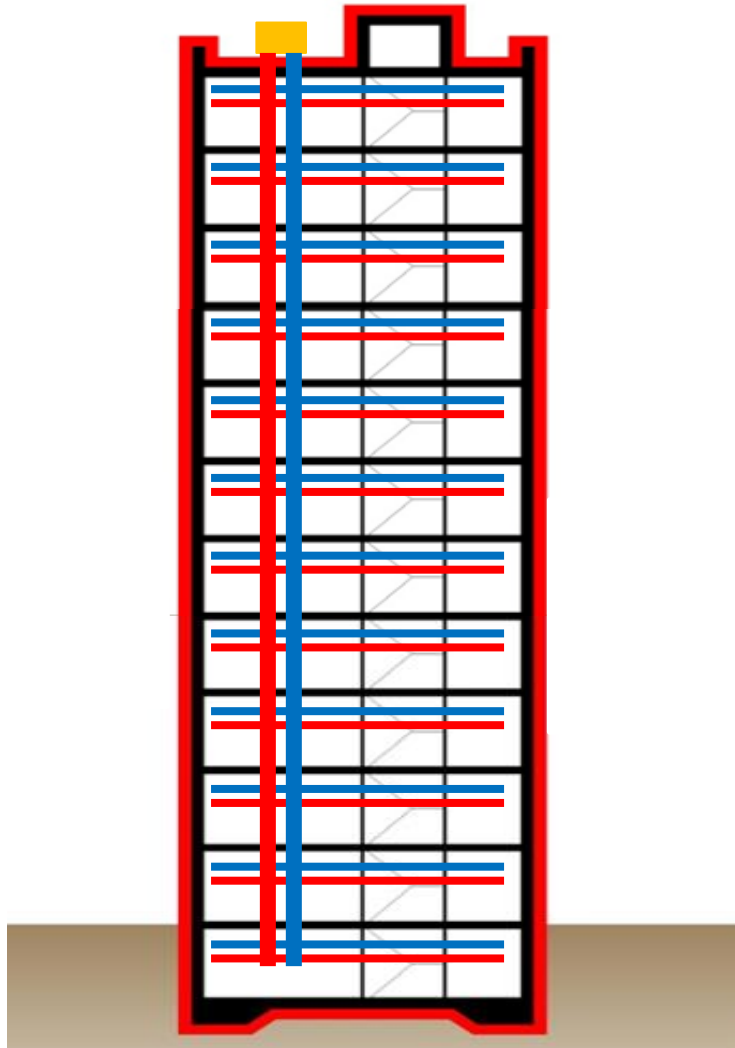


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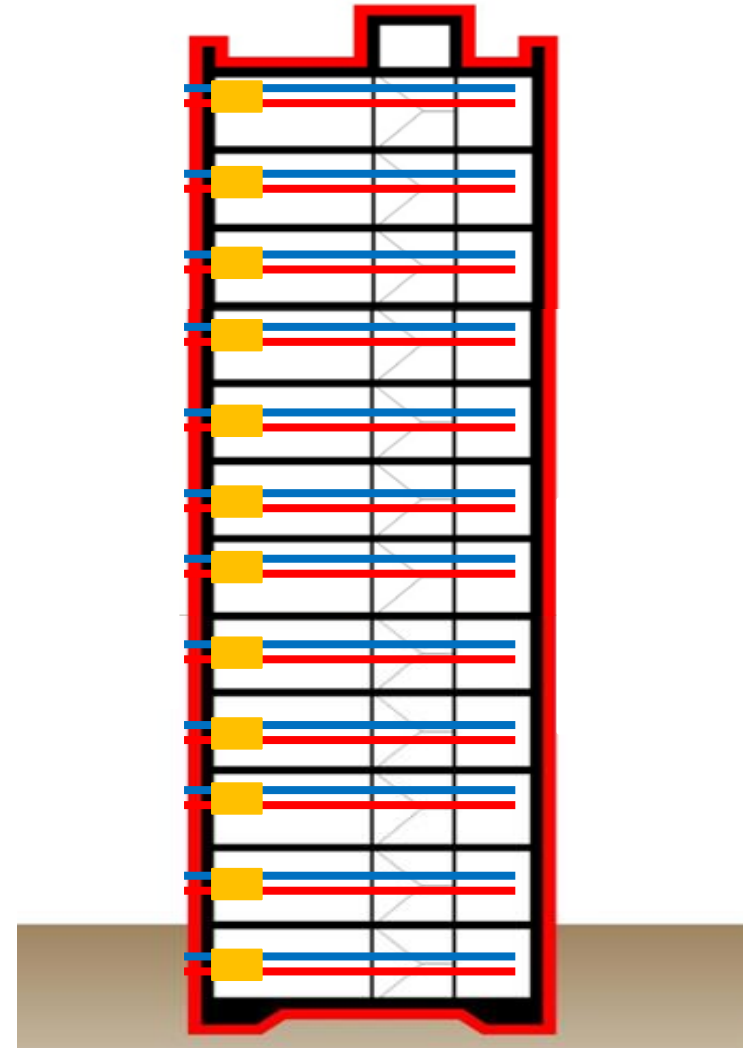
Ventilation distribution strategy



Centralised



Decentralised



Pros & Cons of Centralised & Decentralised

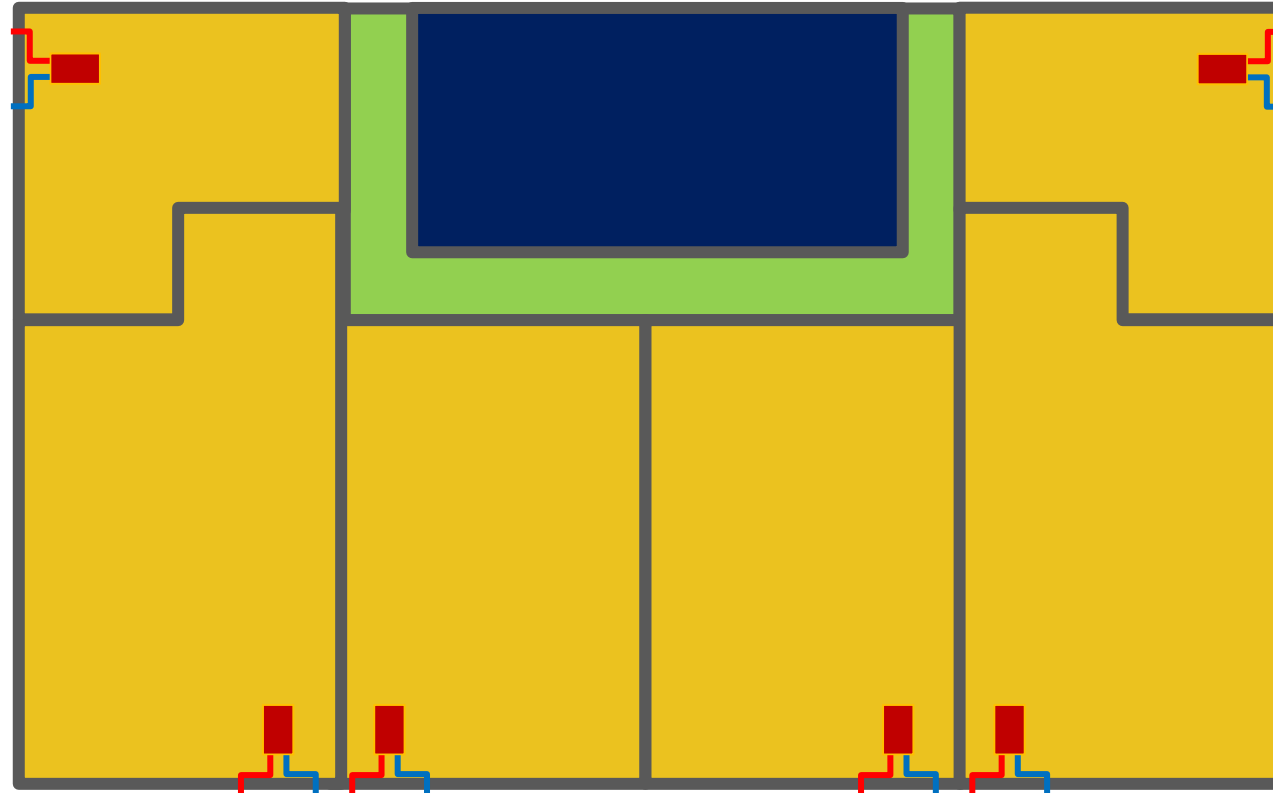


Comparison Factors	Centralised (one unit for all apartments)	Decentralised (one per apartment)
Filter changing	Remotely by building management	Access to each apartment
Risk of homeowner shutting off the MVHR	Impossible	Potentially possible
Fire separation	Fire smoke dampers needed	N/R
Service risers	Required for full height of building, occupying space	N/R
Space occupied by MVHR unit in individual apartments	N/R	Depends on unit selected
Penetrations of airtight envelope	2 for each unit	Possibly multiple
Aesthetic penetrations of walls for ventilation grills	None visible (on roof deck)	Possibly multiple
Ease of gaining access to clean external ventilation grills	Easy (via access on roof)	Difficult / costly
Insulation of ducts to minimize thermal bridging	Very few	Possibly multiple pairs of ducts
Dropped ceilings in apartments	Not generally required	Possibly required for cold ducts
Ease of control of flow rates by individual apartment owners	Challenging	Easy
Risk of noise from MVHR unit	Very low	Low to moderate
Condensate drain	1 drain needed for overall system	Drain needed in each apartment
Primary energy required	Lower	Higher

Optimal location for the decentralized units



Decentralised – place near external wall

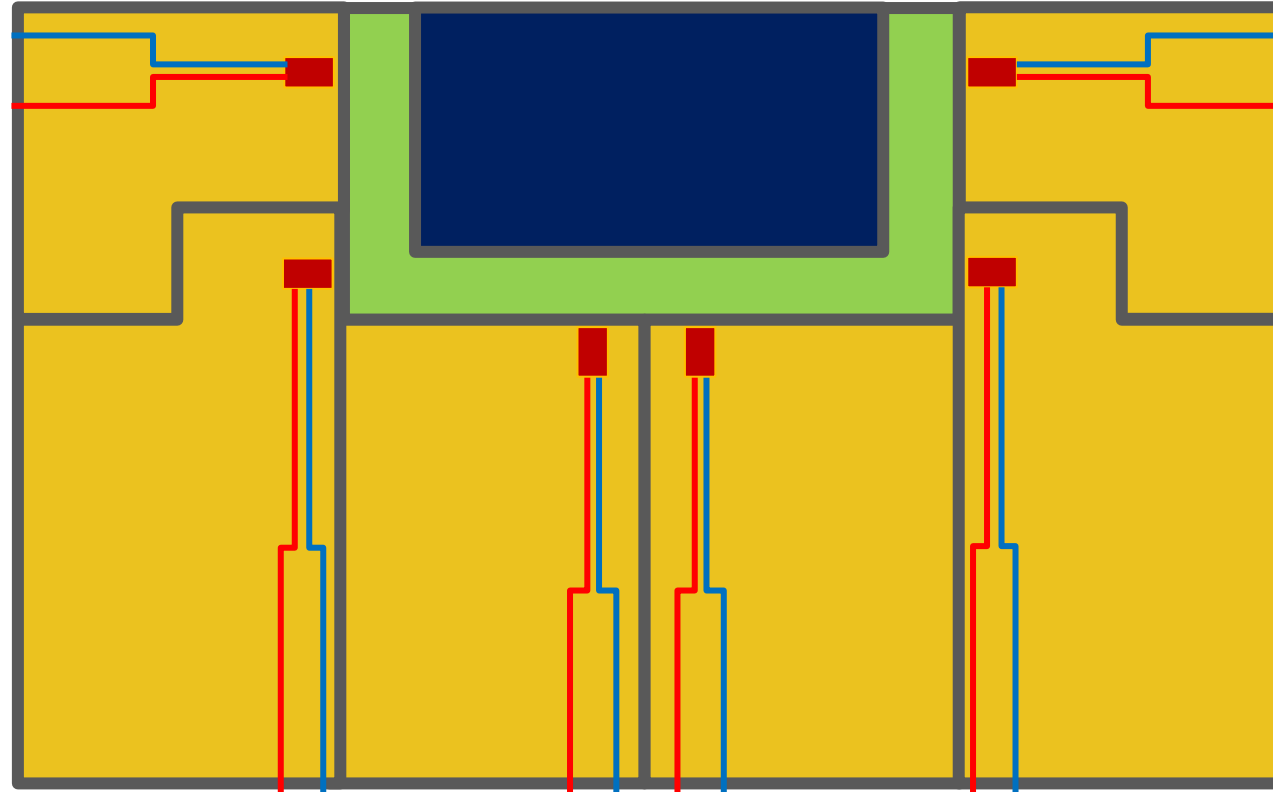


Ideal from energy efficiency perspective, but who will change the filters? Probably not the residents!

Optimal location for the decentralized units



Decentralized – place near corridor



Can possibly change filters from hatch in corridor, but cold air ducts are very long – thermal bridge

SECTION 3

A case study

How to address the best solution for ventilation with the aid of BIM

Deep Retrofit Ventilation Case Study



Original condition



Mid-Way through deep retrofit



External wall detail with ventilation duct

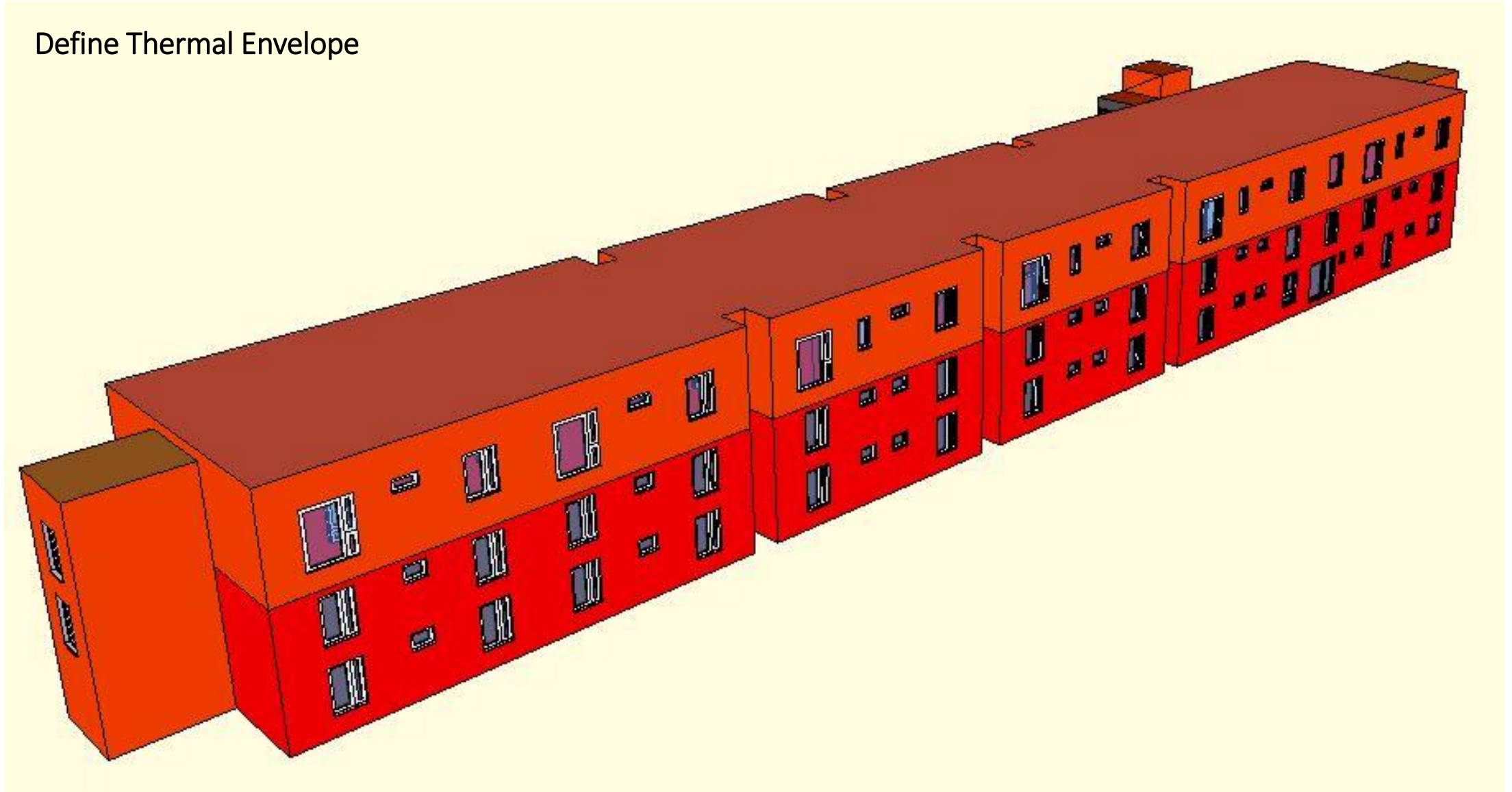


Near completion

Deep Retrofit Ventilation Case Study



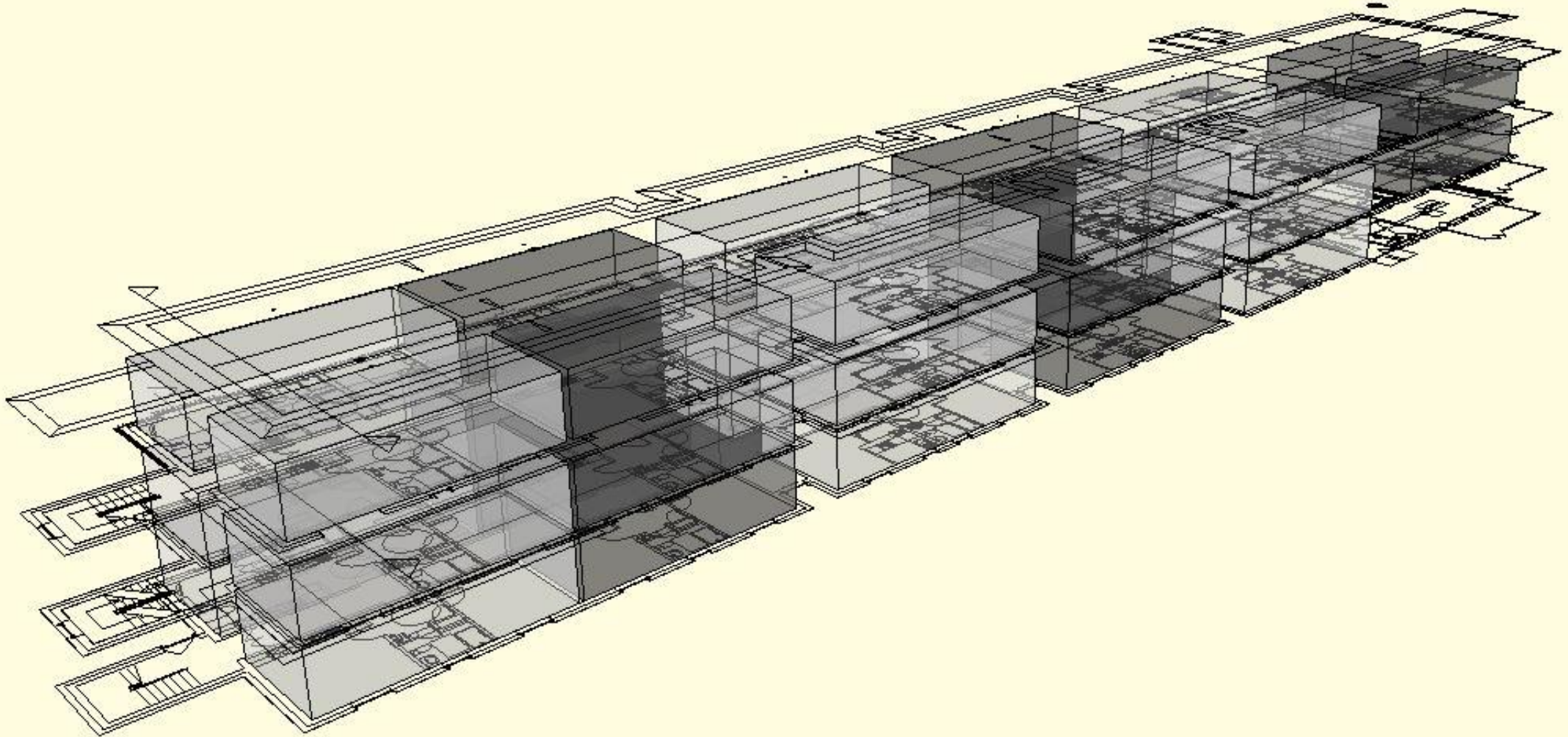
Define Thermal Envelope



Deep Retrofit Ventilation Case Study



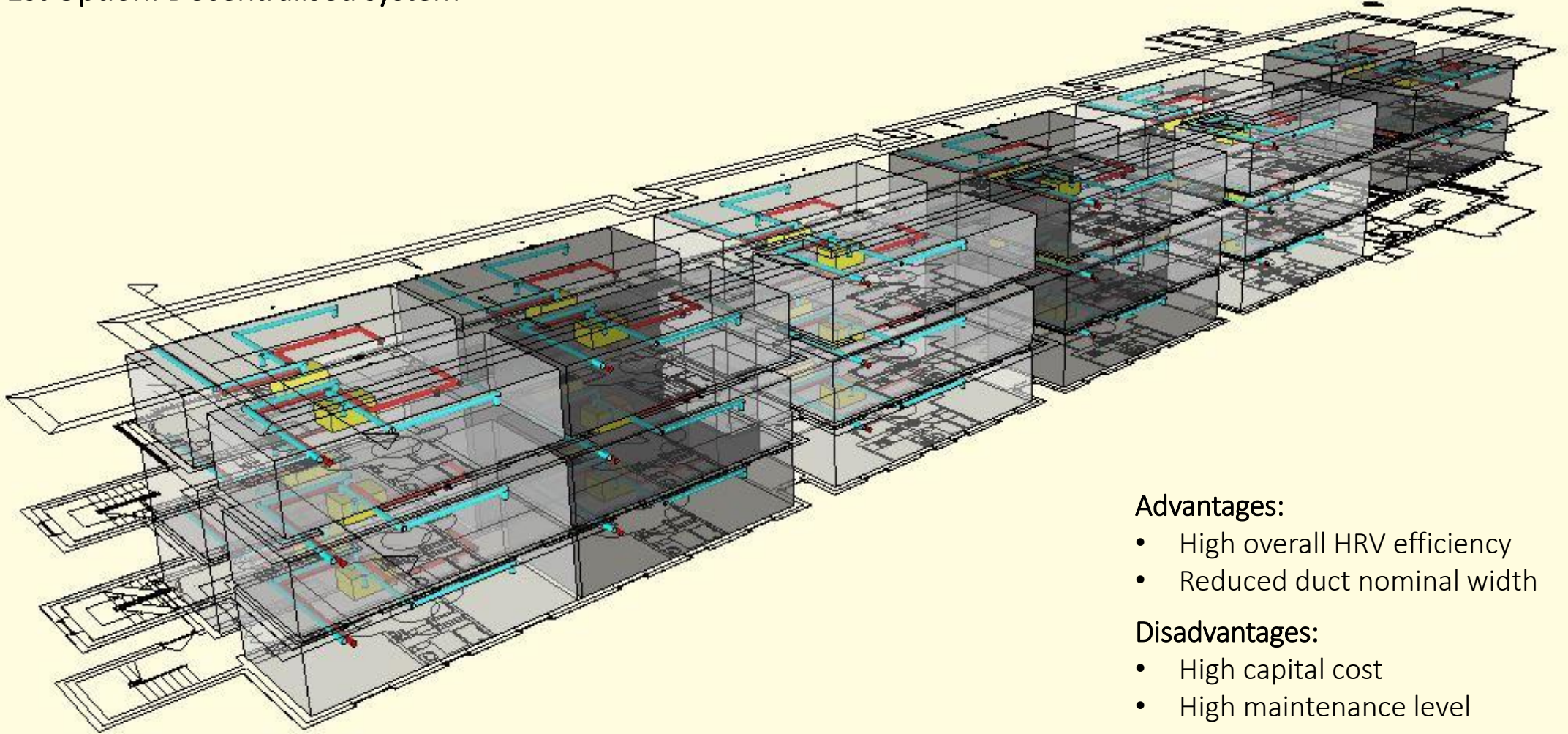
Create 3D Schematics



Deep Retrofit Ventilation Case Study



1st Option: Decentralised system



Advantages:

- High overall HRV efficiency
- Reduced duct nominal width

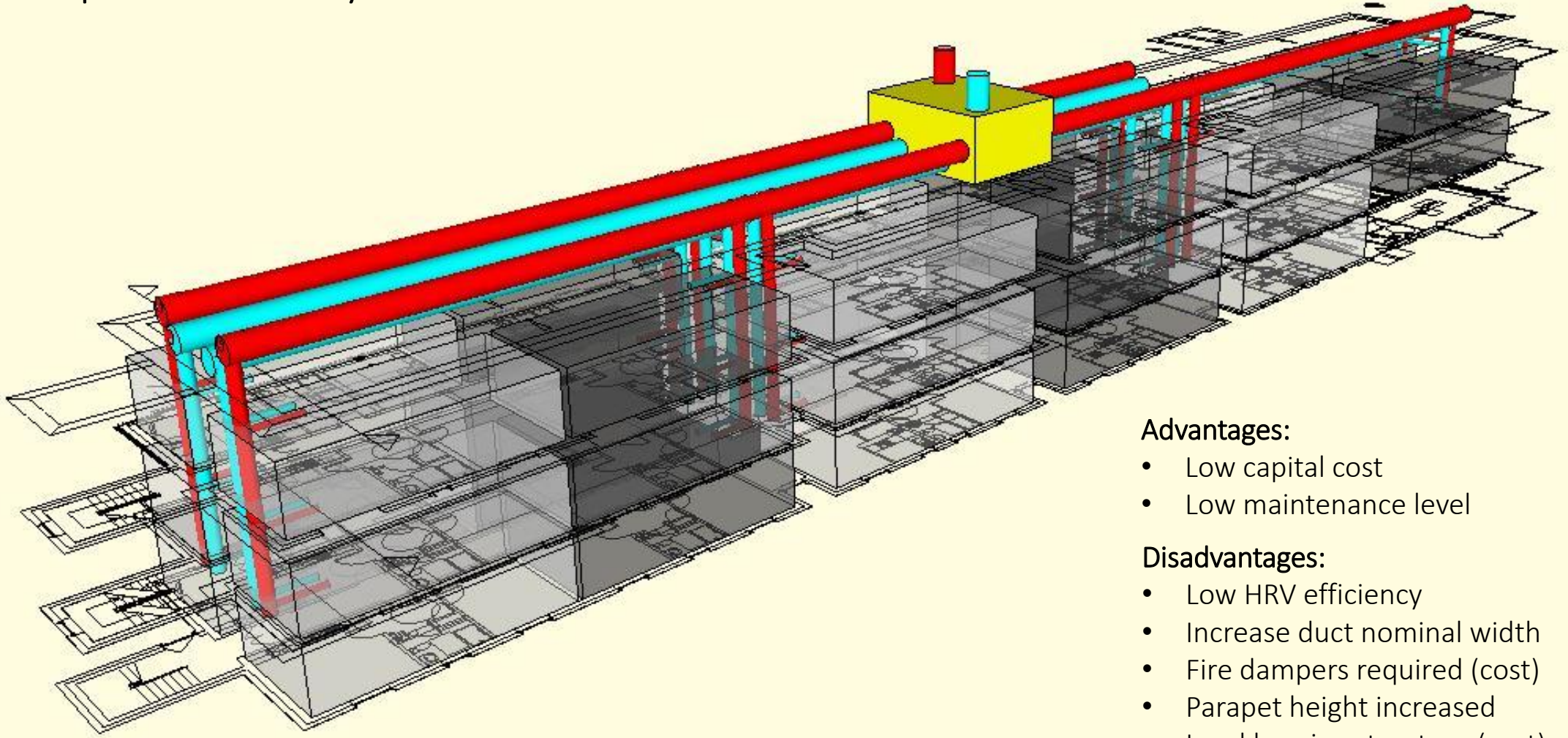
Disadvantages:

- High capital cost
- High maintenance level

Deep Retrofit Ventilation Case Study



2nd Option: Centralised system



Advantages:

- Low capital cost
- Low maintenance level

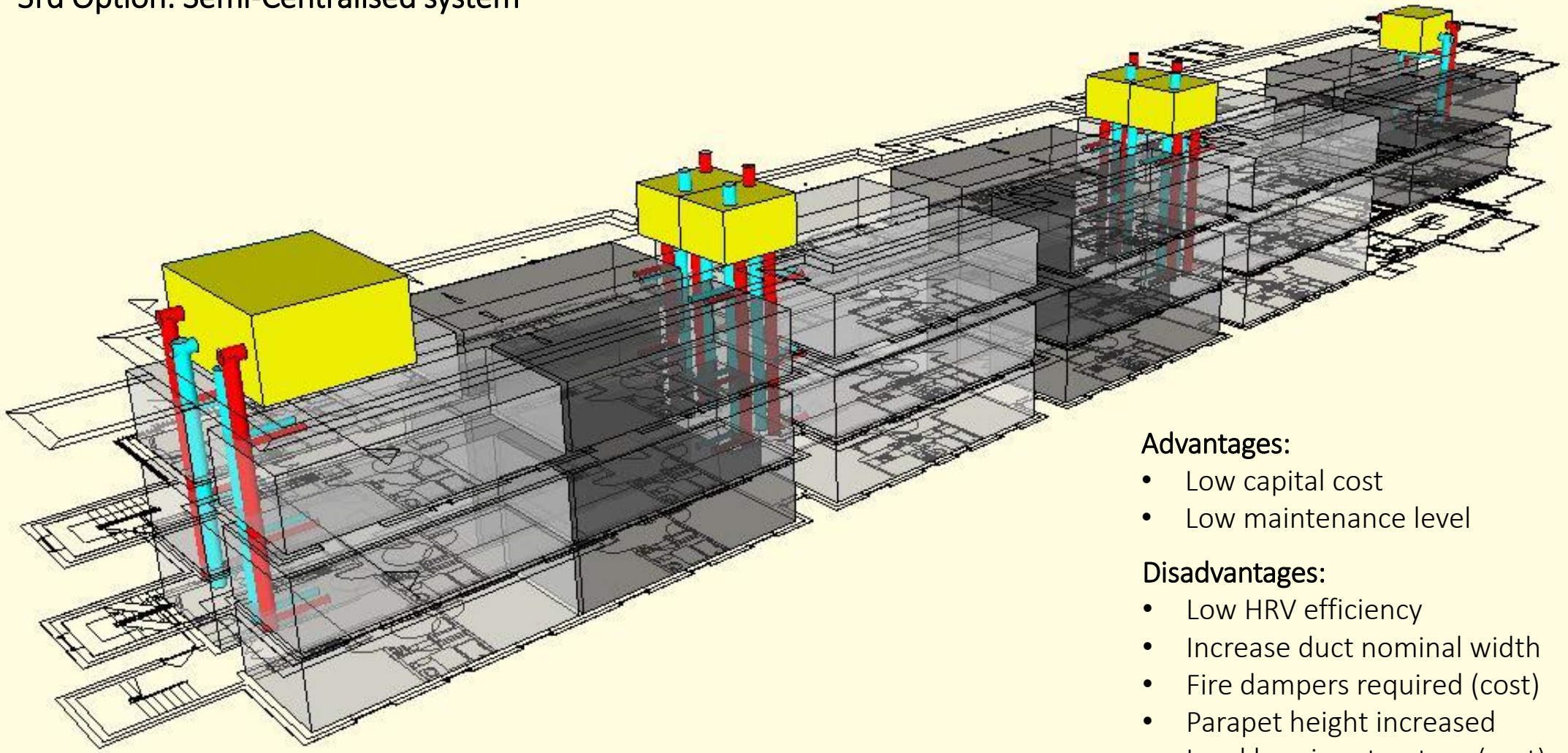
Disadvantages:

- Low HRV efficiency
- Increase duct nominal width
- Fire dampers required (cost)
- Parapet height increased
- Load bearing structure (cost)

Deep Retrofit Ventilation Case Study



3rd Option: Semi-Centralised system



Advantages:

- Low capital cost
- Low maintenance level

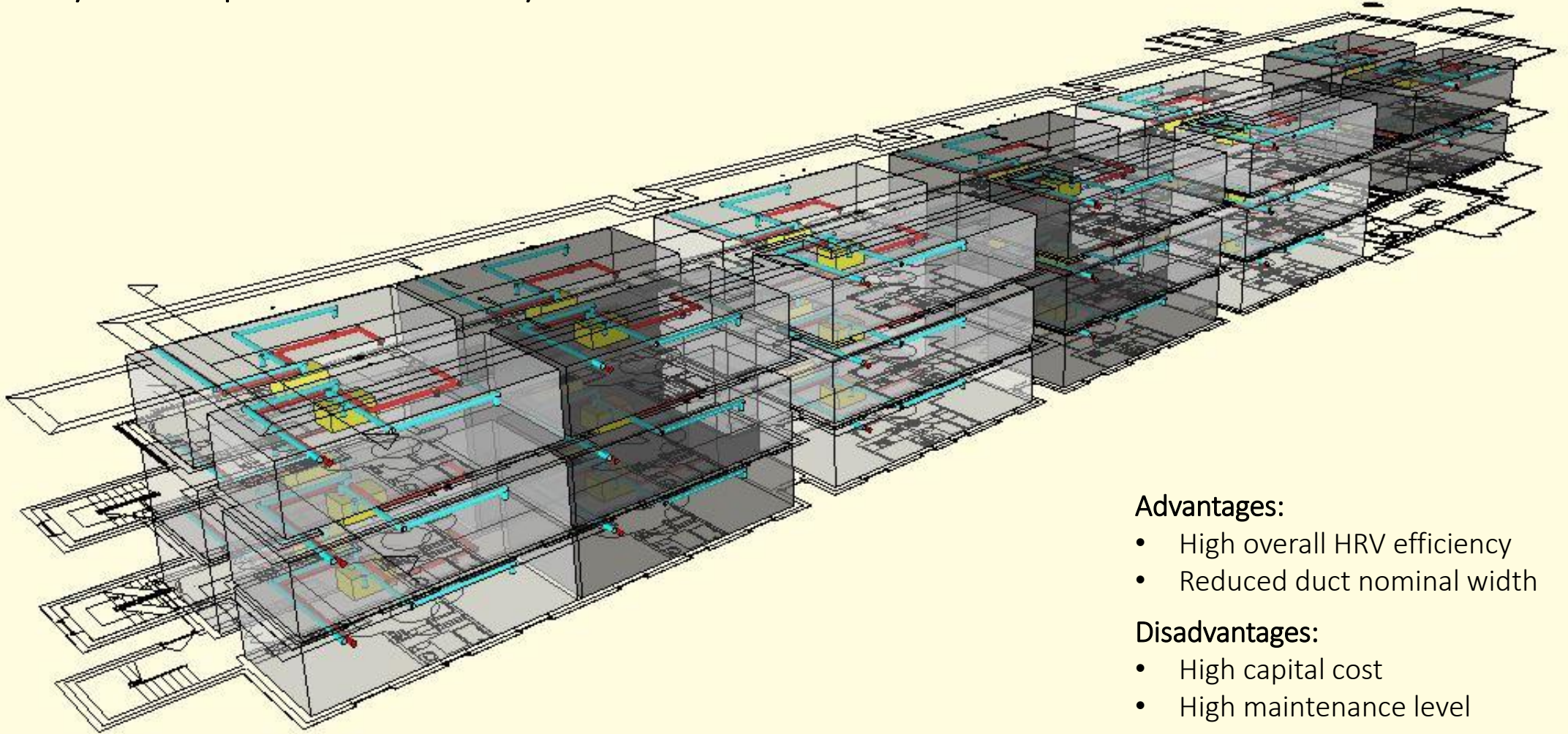
Disadvantages:

- Low HRV efficiency
- Increase duct nominal width
- Fire dampers required (cost)
- Parapet height increased
- Load bearing structure (cost)

Deep Retrofit Ventilation Case Study



Finally chosen Option: Decentralised system



Advantages:

- High overall HRV efficiency
- Reduced duct nominal width

Disadvantages:

- High capital cost
- High maintenance level

Thank you.

Every detail shown here is a detail you will teach a craftsman.

State the problem, give the principle, show the wrong and the right example,
let them practise by hand, test it, document it.

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