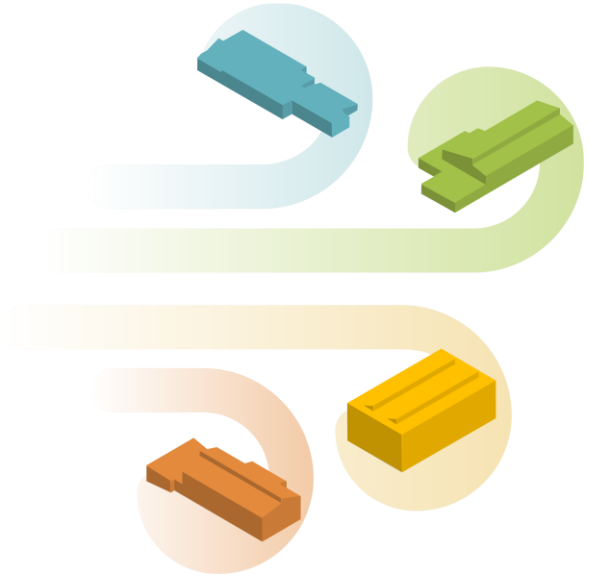

Indoor air quality in UK Passivhaus primary schools

Findings from PhD research on '*Total Performance of UK Passivhaus Primary Schools*' by Chryssa Thoua at **UCL** Institute for Environmental Design and Engineering with **Architype**.
Supervisors: Prof Anna Mavrogianni*, Prof Dejan Mumovic*,
Dr Manolis Bagkeris*, Mark Lumley

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This presentation

Context

Research objectives

Methods

Case studies: Four Passivhaus primary schools in England and in Wales

Main findings:

Performance of Passivhaus primary schools and **determinants** of performance

Implications of findings for **practice** and **policy**

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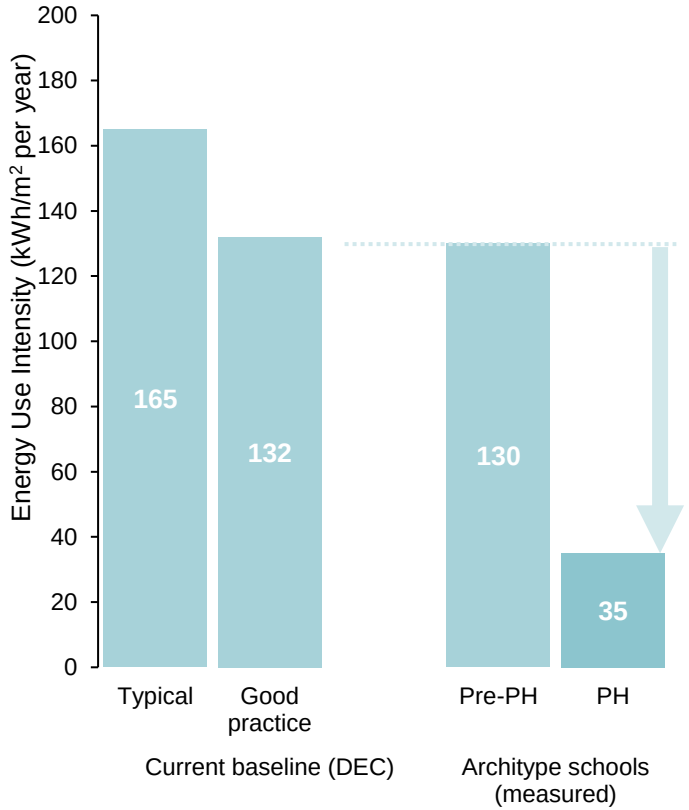
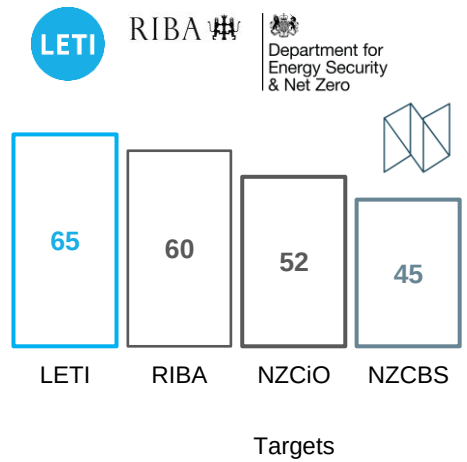
Context

Passivhaus can help achieve **Net Zero Carbon targets** in schools.

However, there is an **evidence gap** on indoor air quality and overheating risk for Passivhaus primary schools.



Primary schools



Current baseline (DEC database, Hong et al. 2014): typical (median) and good practice (25th percentile).

Pre-PH: 2010 St Luke's BREEAM Excellent Primary School, Architype.

PH:2018 Parc y Twyn Primary school, built to Passivhaus standard.

RIBA: RIBA's 2030 Climate Challenge target for schools

LETI: London Energy Transformation Initiative target for schools.

NZCiO: Net Zero Carbon in Operation (UK government, Department for Energy Security and Net Zero).

NZCBS: Net Zero Carbon Building Standard target for primary schools.

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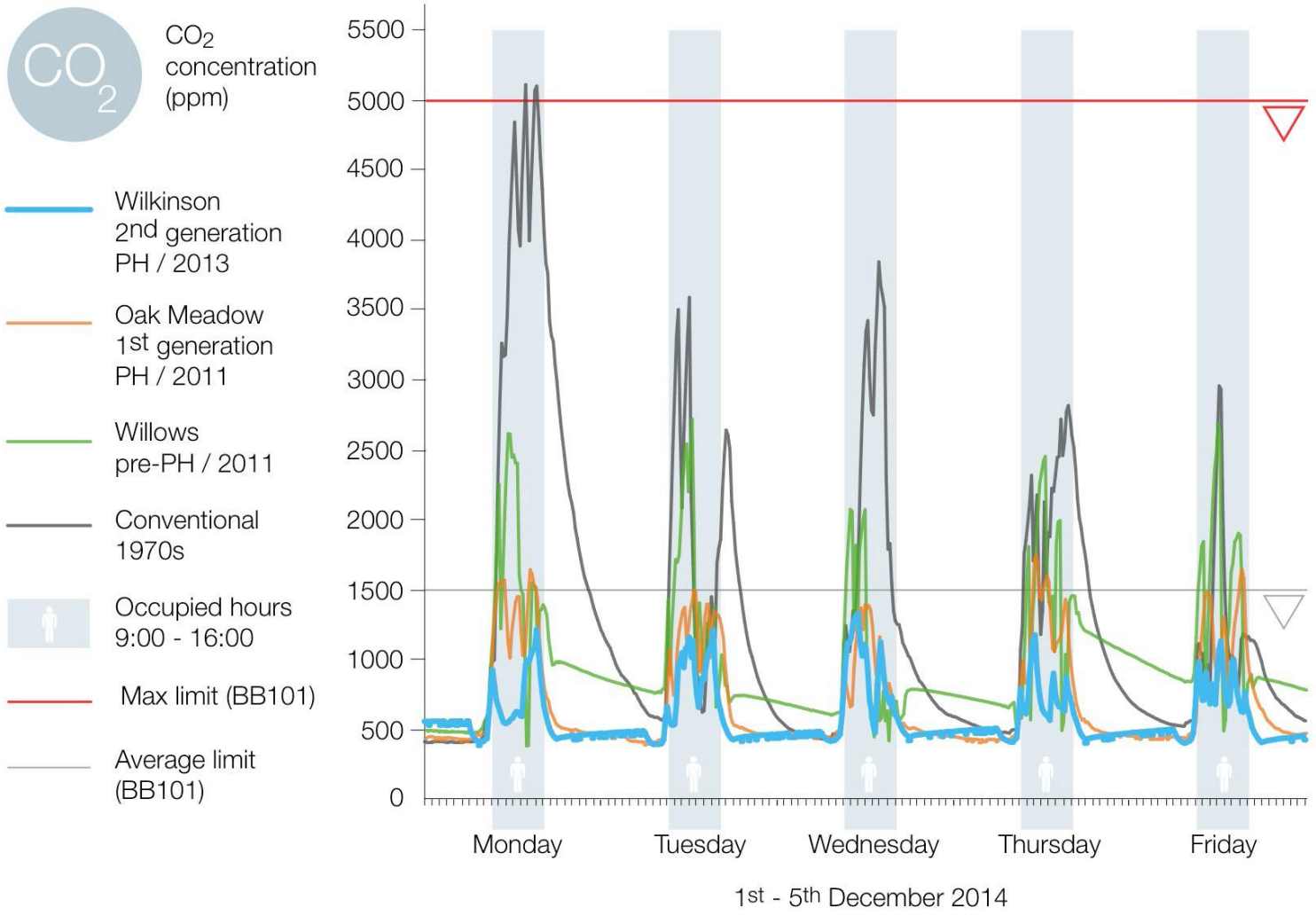
Context

Better ventilation and lower CO_2 levels



- Adequate ventilation in cold weather.
- Ventilation requirements can be met without compromises in thermal comfort.
- CO_2 levels (occupant generated indoor pollutant) remain below BB101 limits.

Data presented here were obtained from the ERDF funded KEEN research project with Coventry University and Architype.

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Research Objectives

1 To assess **in-use performance** of four UK Passivhaus case study schools in terms of:

- Thermal conditions and overheating risk
- Indoor air quality
- Ventilation rates
- Energy use

2 To identify the **determinants of performance** in the four Passivhaus case studies:

3 To evaluate the **effect of future climate** on:

4 To develop **evidence-based recommendations** for the design and operation of UK Passivhaus primary schools, for optimised performance, in terms of:

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Methods

A

Empirical data Collection

Four UK Passivhaus primary schools (2018-19)

Temperature, RH, over a year, Questionnaire surveys.

CO_2 over a year, occupancy and operation during seasonal focused investigation periods.

$PM_{2.5}$, PM_{10}, NO_2, $TVOC_{DR}$, over a year.

VOCs, $TVOC_{GC}$ during seasonal focused investigation periods.

Monthly electrical and fossil thermal energy use over a year.

B

Existing data Sets

SINPHONIE-UK (2011-12) monitoring of six primary schools in London.
Monitoring:
temperature, RH,
CO_2,
PM,
NO2
VOCs

Energy use intensity in primary schools in England and in Wales from the DEC database (Hong et al. 2014)

C

Qualitative emissions screening from building materials

The emissions from new samples of six flooring and ceiling products typically specified in schools were screened for qualitative emissions at the laboratory using two different sampling techniques.

D

Building dynamic thermal simulation modelling

A small Passivhaus school in London, calibrated to monitoring data.
Baseline: 2020s – high emissions
Future climate:
2080s – medium emissions

E

Statistical analysis of primary and secondary datasets

Determinants of:

Half-hourly mean indoor temperature in the heating and non-heating seasons

Daily mean indoor CO2 during occupied hours in the heating season (primary dataset)

Half-hourly mean PM2.5, PM10, NO2, during occupied hours in the heating and non-heating seasons (primary dataset)
$TVOC_{DR}$ at night-time in the heating season in Passivhaus schools,
Time-averaged formaldehyde concentrations in a combined dataset.

F

Synthesis of Findings

Synthesis of findings from the first three research objectives, in the context of literature review into a framework of improvement of performance of future UK Passivhaus schools.

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Methods

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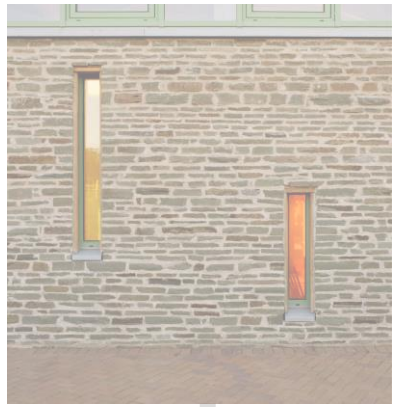
Selection of case study schools – Architype's portfolio



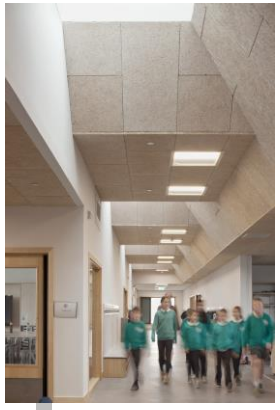
2009 The Willows POE through a KTP with Oxford Brookes University

2010 Staunton-on-Wye Endowed POE with TSB

2011 Bushbury Hill POE with Coventry University

2014 Wilkinson POE with Coventry University

2020 Welshpool Church in Wales Primary School POE



2023 Riverside primary school

2008 St Luke's POE through a KTP with Oxford Brookes University

2010 Bessemer Grange (2010) POE with TSB

2011 Oak Meadow POE with Coventry University

2015 Burry Port Community POE with UCL

2020 Hackbridge Passivhaus Plus Primary School POE

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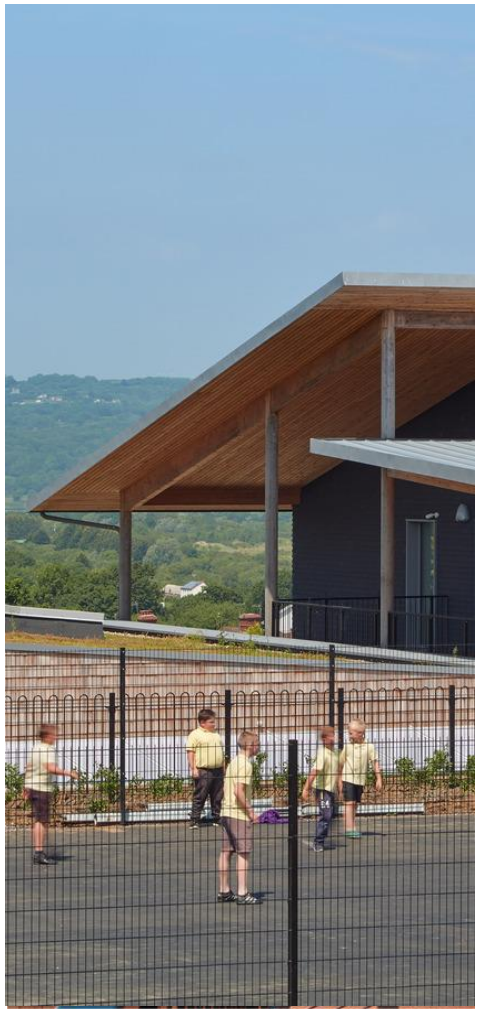
Schools



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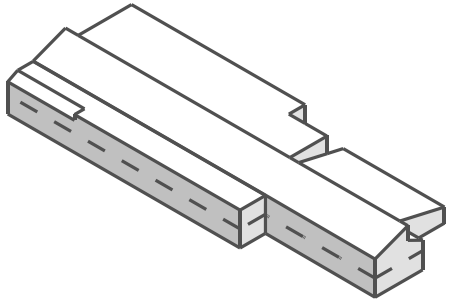
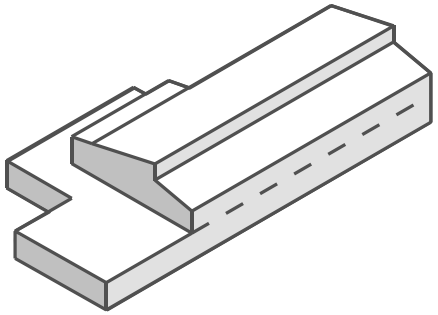
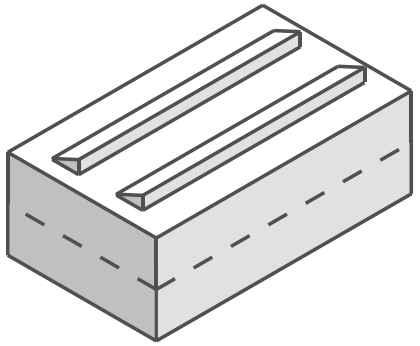
Schools



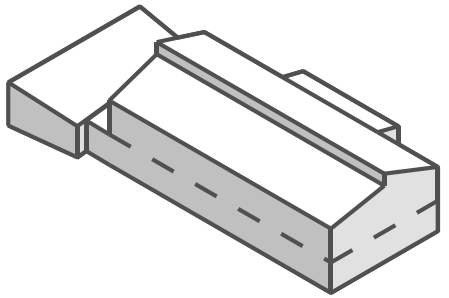
A



B

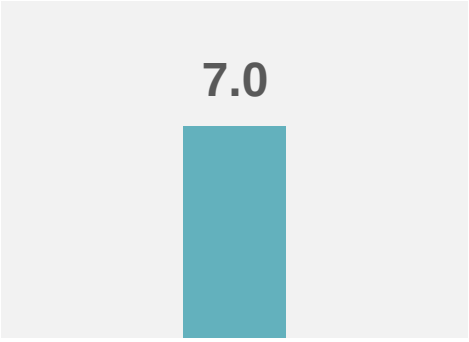


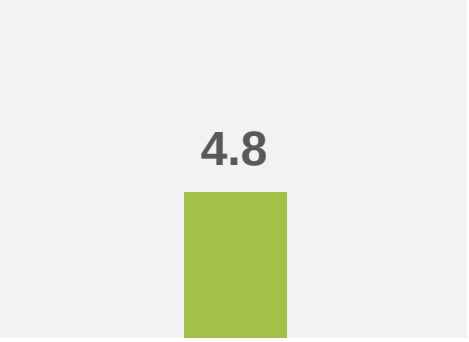
C

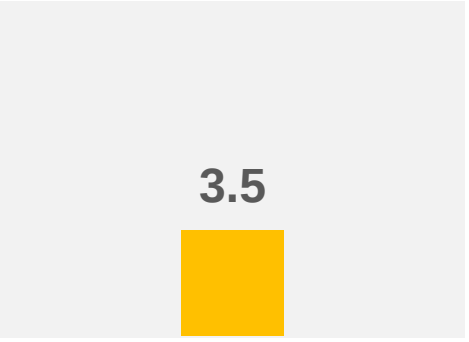


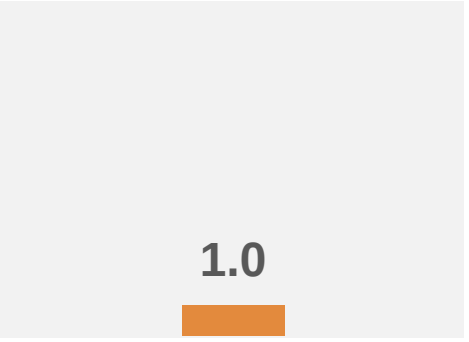
D

Age (years since completion at the mid-point of the monitoring period):









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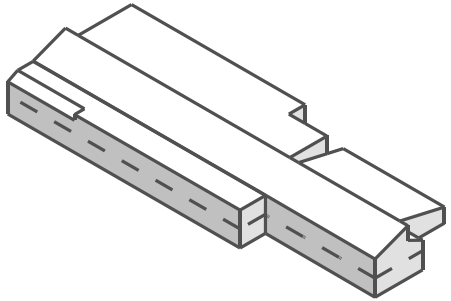
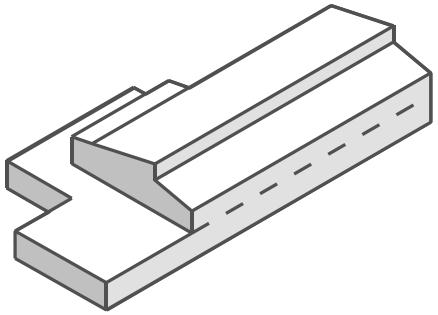
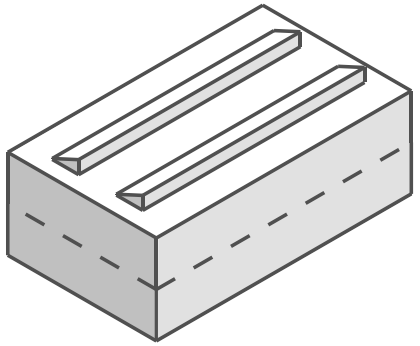
Schools



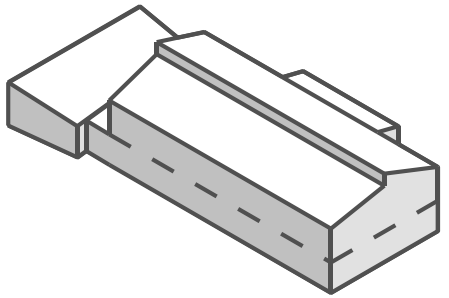
A



B



C



D

Size (influencing floor area and capacity in number of pupils):

A	B	C	D
2	2	1	1
form entry	form entry	form entry	form entry

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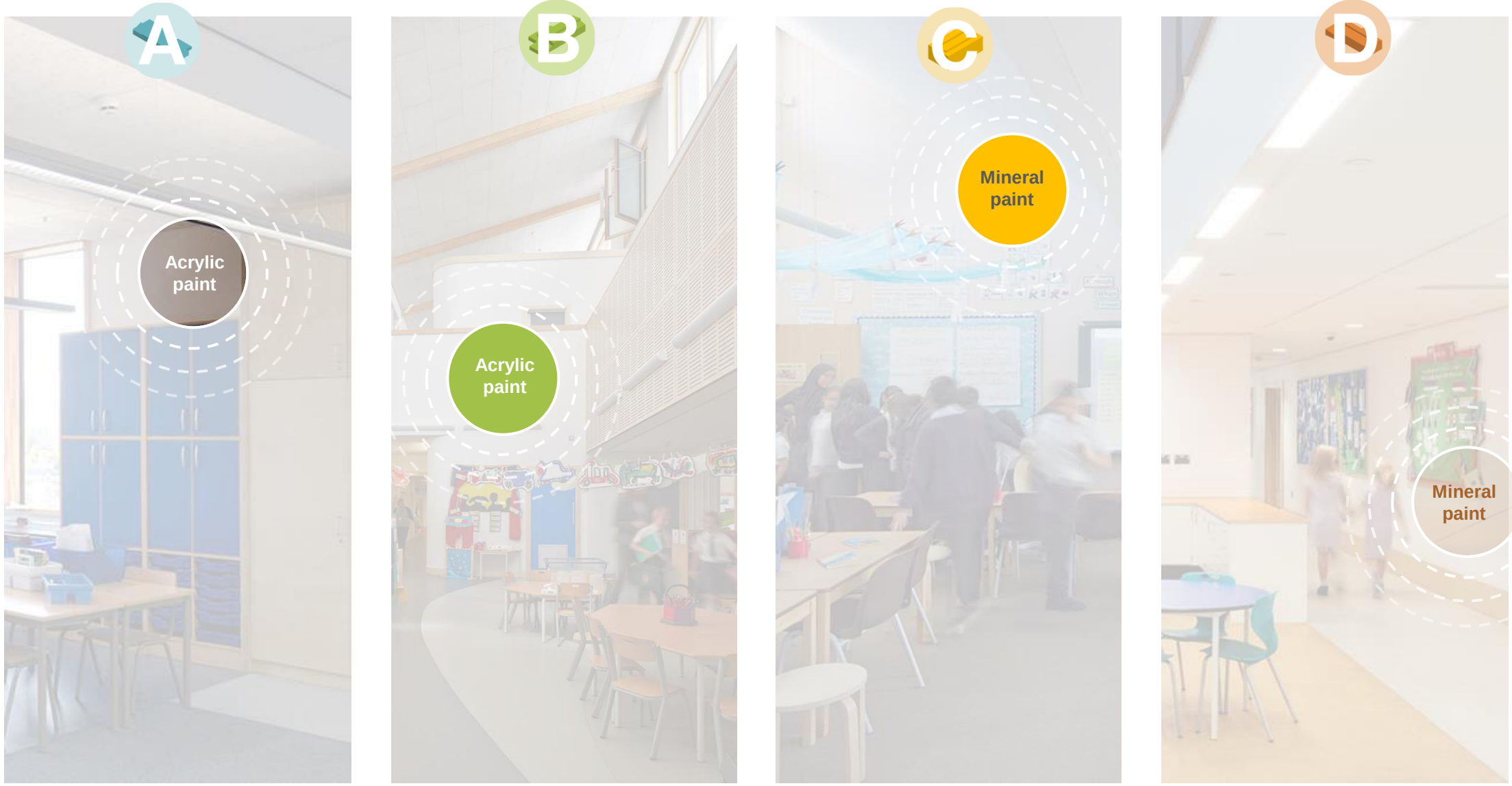
Materials – wall paint



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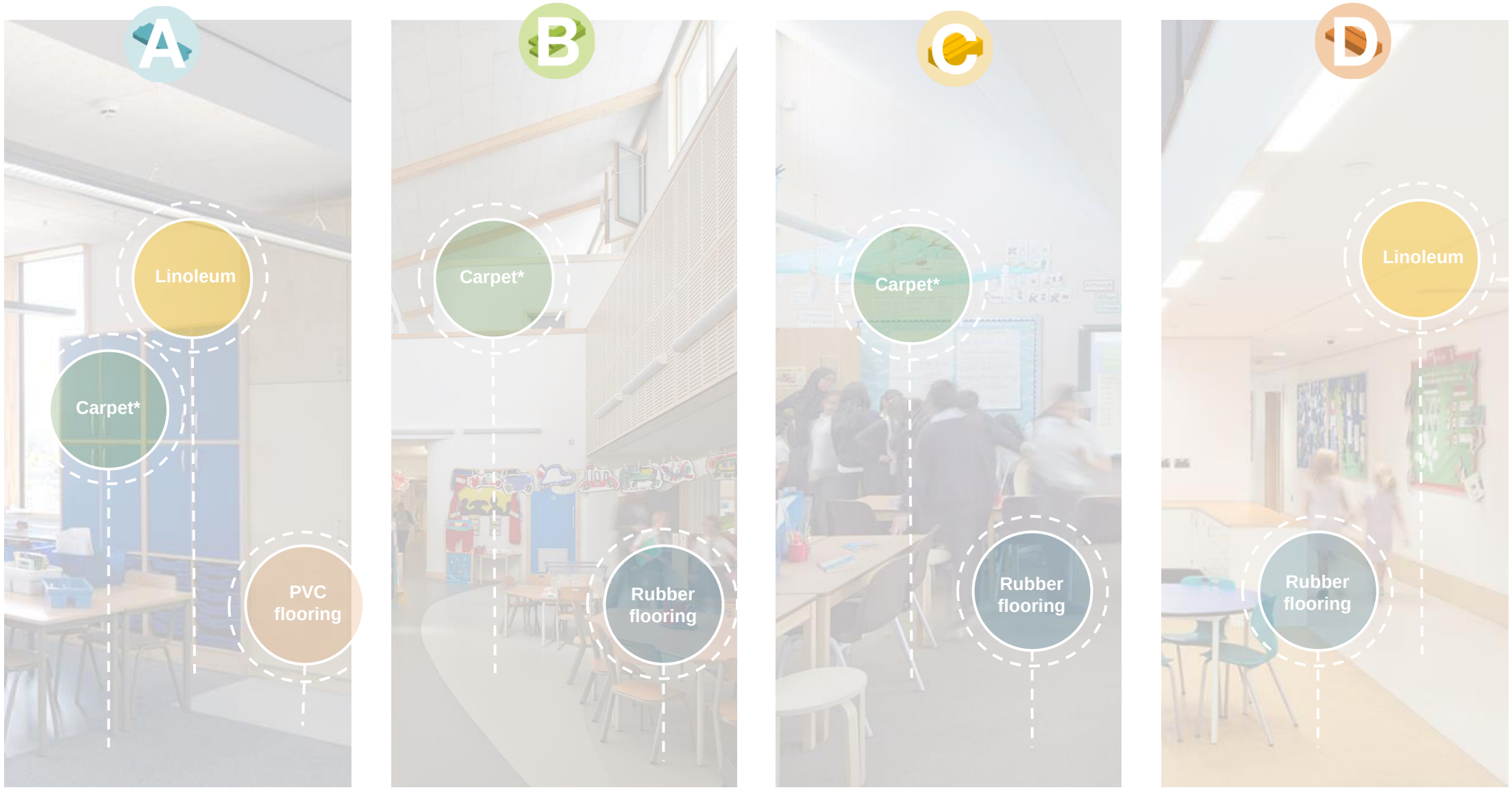
Materials – classroom flooring



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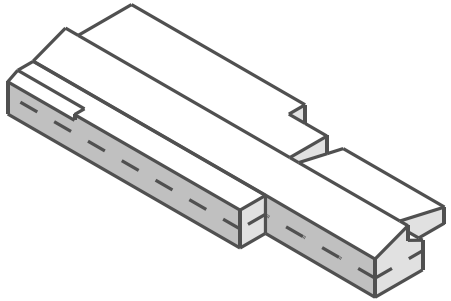
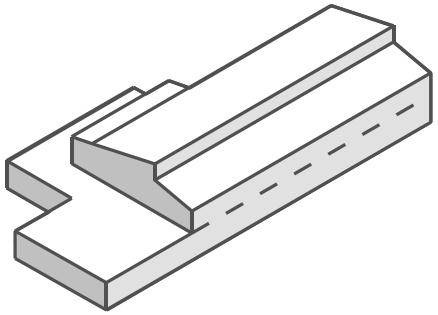
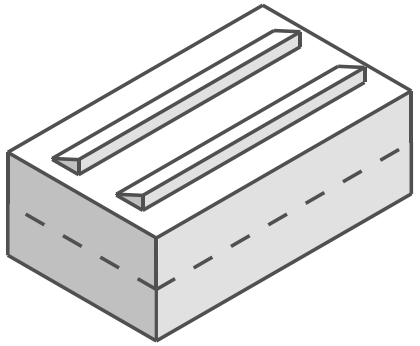
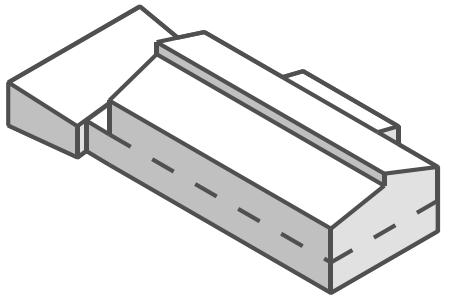
Schools









Ventilation strategy in the non-heating season:

Temperature dependent control

Average **6.5*** L/s per person

Mechanical extract

* Peak (two modes)

Constant mechanical ventilation rates

At **6.8** L/s per person

Balanced supply and extract

Constant mechanical ventilation rates

At **8.0** L/s per person

Balanced supply and extract

Constant mechanical ventilation rates

At **5.0** L/s per person

Balanced supply and extract

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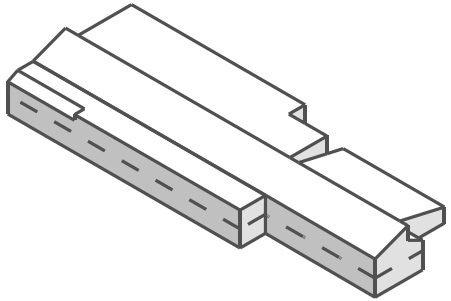
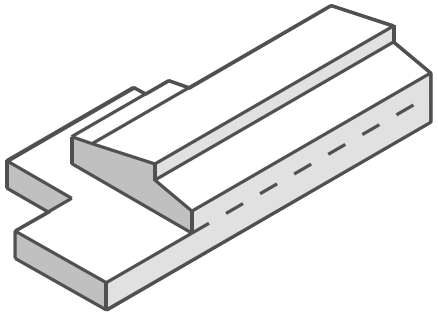
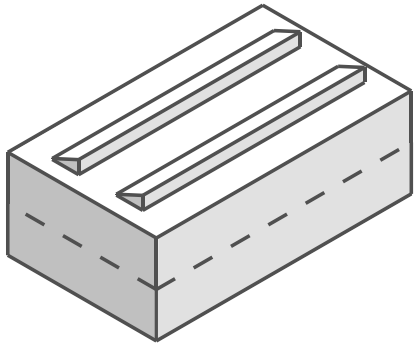
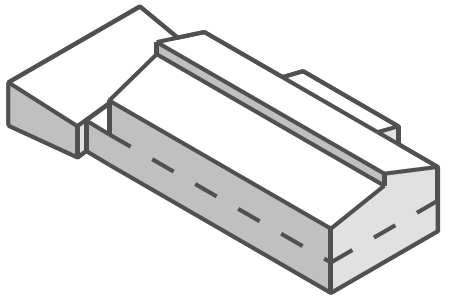
Schools









Ventilation strategy in the heating season:

Temperature dependent control of mechanical ventilation rates

Average **3.9** L/s per person

Demand control: **CO_2 dictated** mechanical ventilation rates

Average **4.2** L/s per person

Constant mechanical ventilation rates

At **8.0** L/s per person

Constant mechanical ventilation rates

At **5.0** L/s per person

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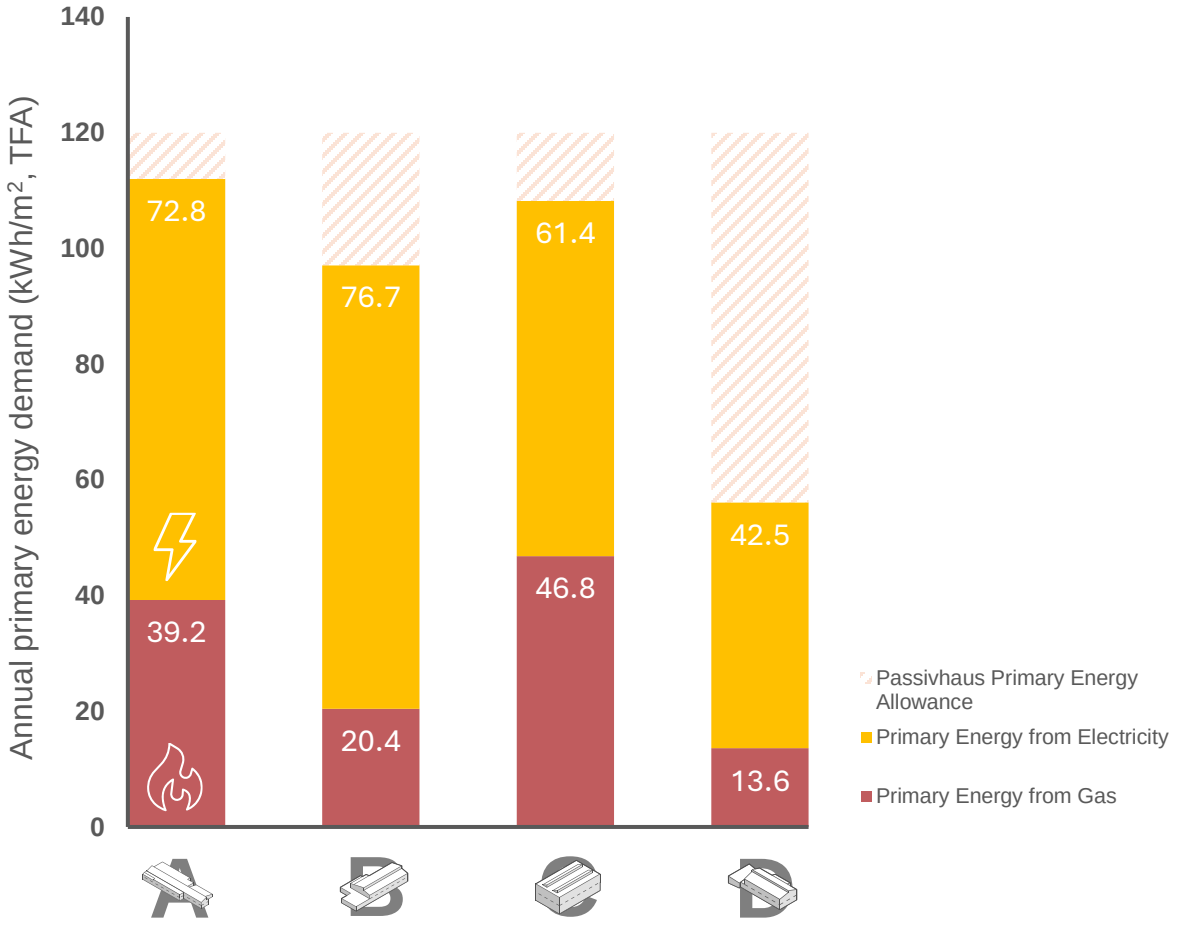
Main findings – Energy performance in four Passivhaus schools



Fossil thermal is normalised to UK's HDDs. All values are GIFA floor area normalized.
*from: https://assets.publishing.service.gov.uk/media/658040c583ba38000de1b741/GDB_Annex_2H-Energy-A-C14.pdf

Primary Energy demand requirements are met by all Passivhaus schools.

Variation of electrical energy use explained by school size: floor area and number of children.

Fossil thermal energy use variation due to some schools using fossil thermal for both space heating and domestic hot water/cooking.

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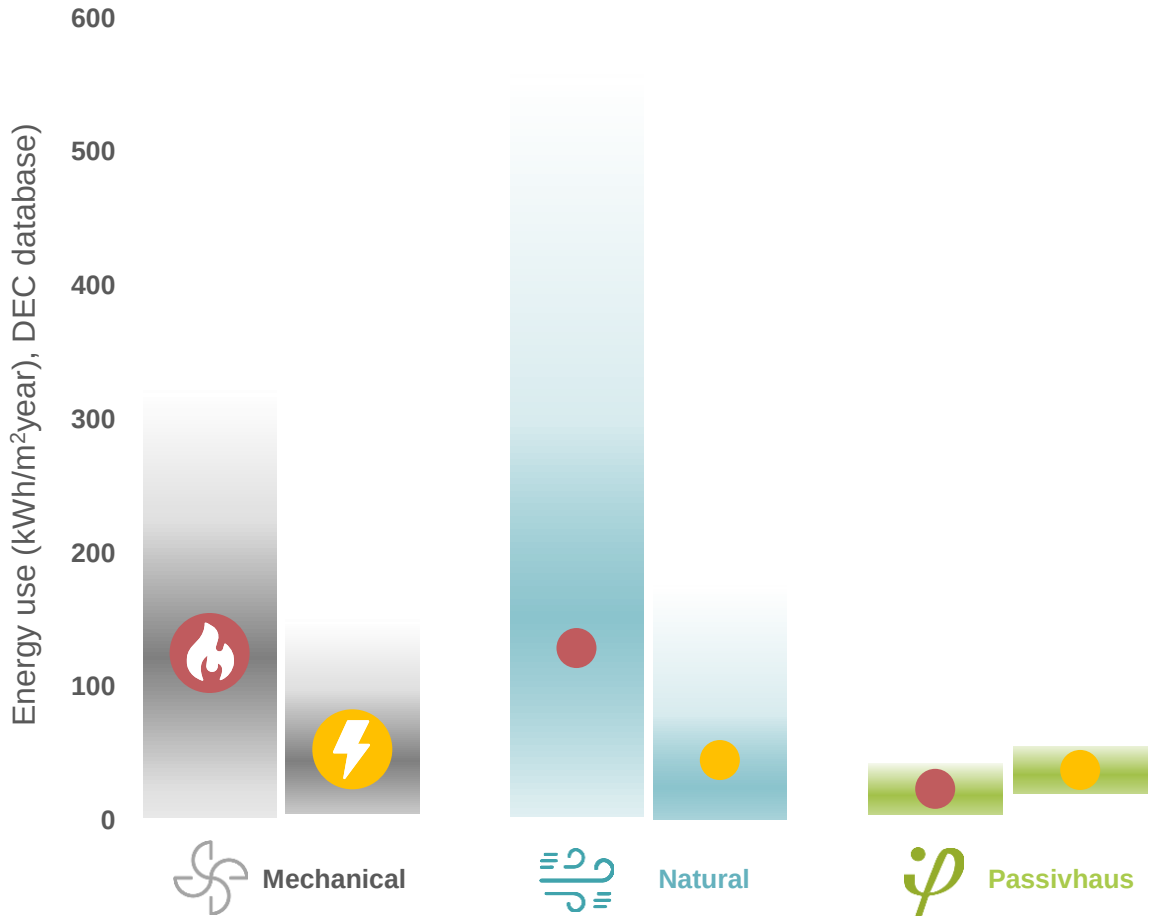
Main findings – Energy performance: Passivhaus vs. Baseline



Comparison of monitoring data to DEC data for primary schools in England shows:

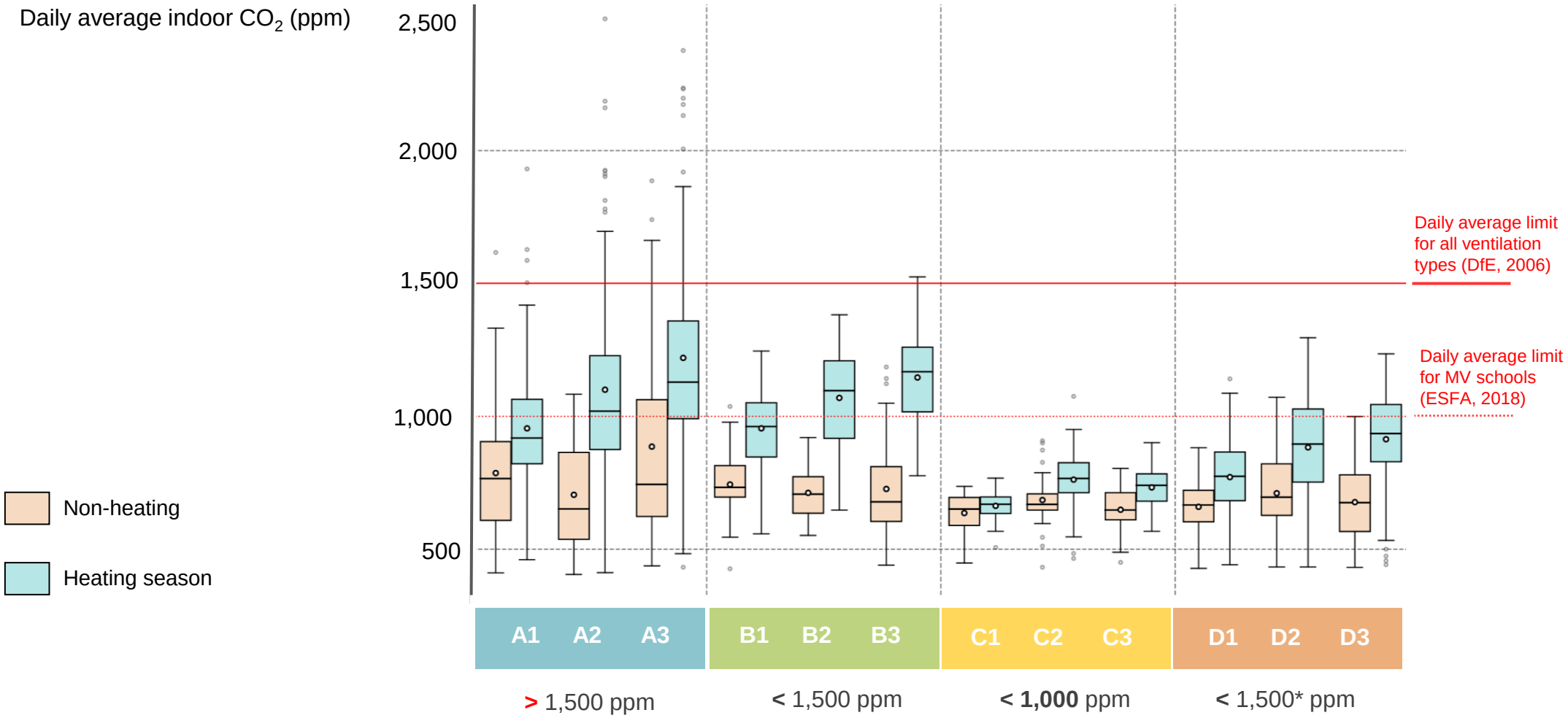
Significantly lower fossil thermal energy use compared to primary schools

Electrical energy use differences between Passivhaus and mechanically ventilated primary school buildings were not significant.

*Sample sizes are as follows: mechanical (n=224), natural (n=8675), Passivhaus (n=4)

* DEC Database, Hong et al. (2014)

Main findings – indoor CO_2



* School D classrooms occupied below capacity during monitoring year. MV: Mechanically ventilated

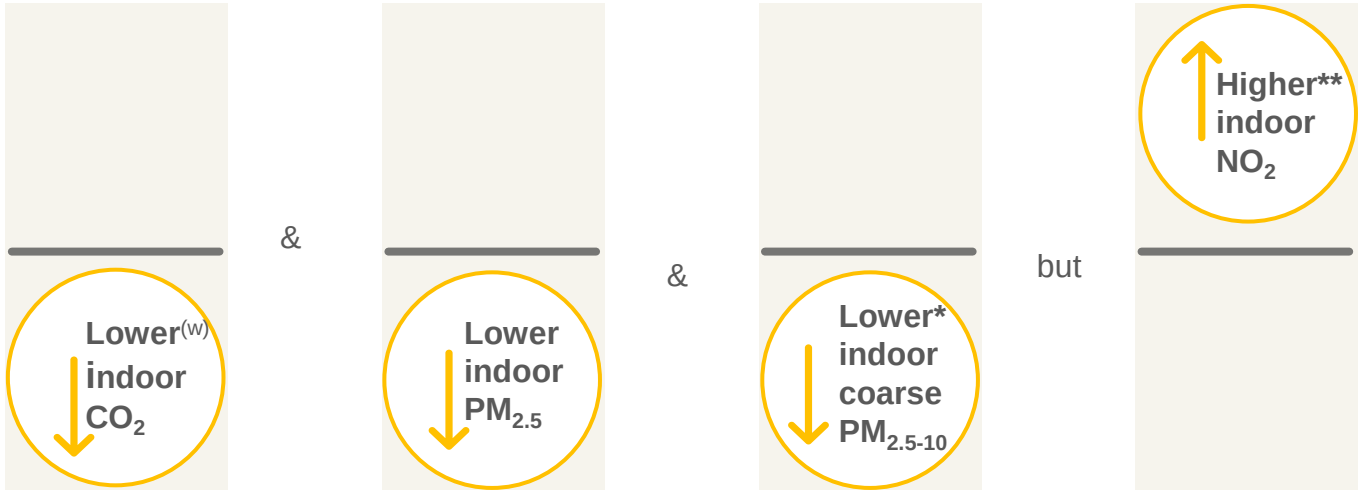
Main findings – the influence of increased supply rates

Of the four Passivhaus schools…

… School C mechanical supply and extract was fixed at 8 L/s per person in both seasons…

…meeting the **2018 BB101** requirements for **indoor CO_2** (ESFA, 2018).

Compared to the other schools, after controlling for influencing factors, **school C** also had significantly:



(w) In the heating season
* Potential influence of new carpet.
** Potential influence of surface materials on the depletion rates of NO_2 in indoor air: non-white paint in school C does not contain TiO2 which increases the rate of photocatalytic reactions of NO_2 in indoor air.

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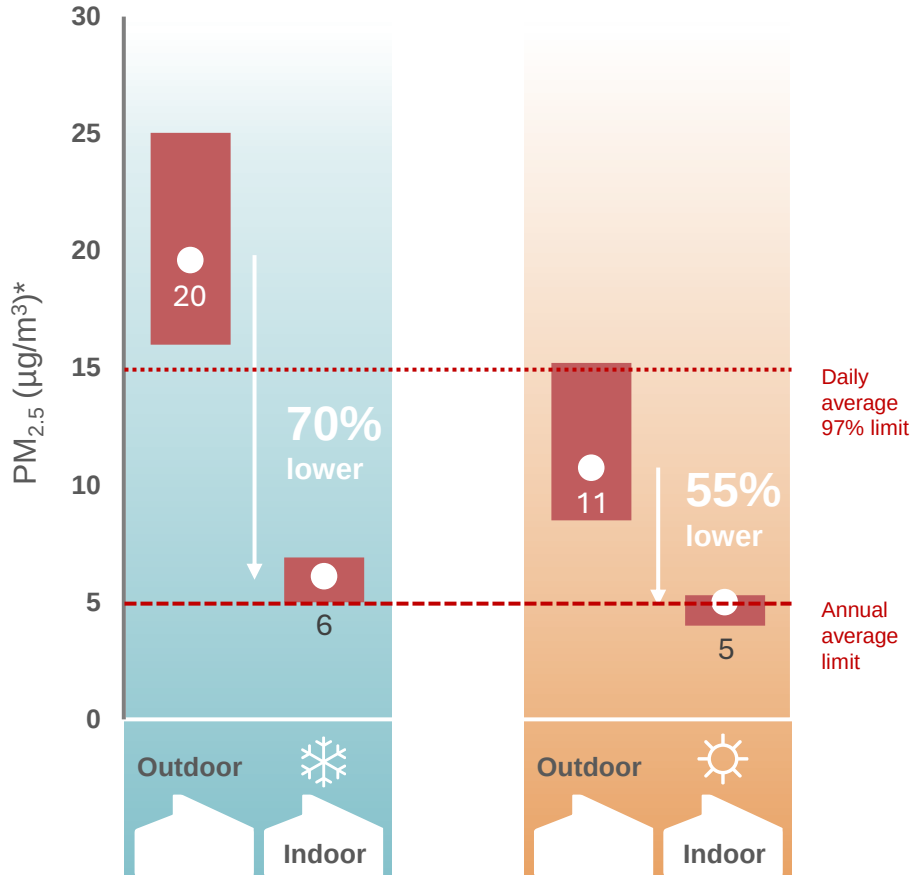
Main findings - indoor $PM_{2.5}$

Supply of outdoor air also introduces outdoor air pollution (at the point of inlet).

Mechanically supplied air in Passivhaus schools is **filtered**, capturing most of outdoor $PM_{2.5}$.

Monitoring shows:

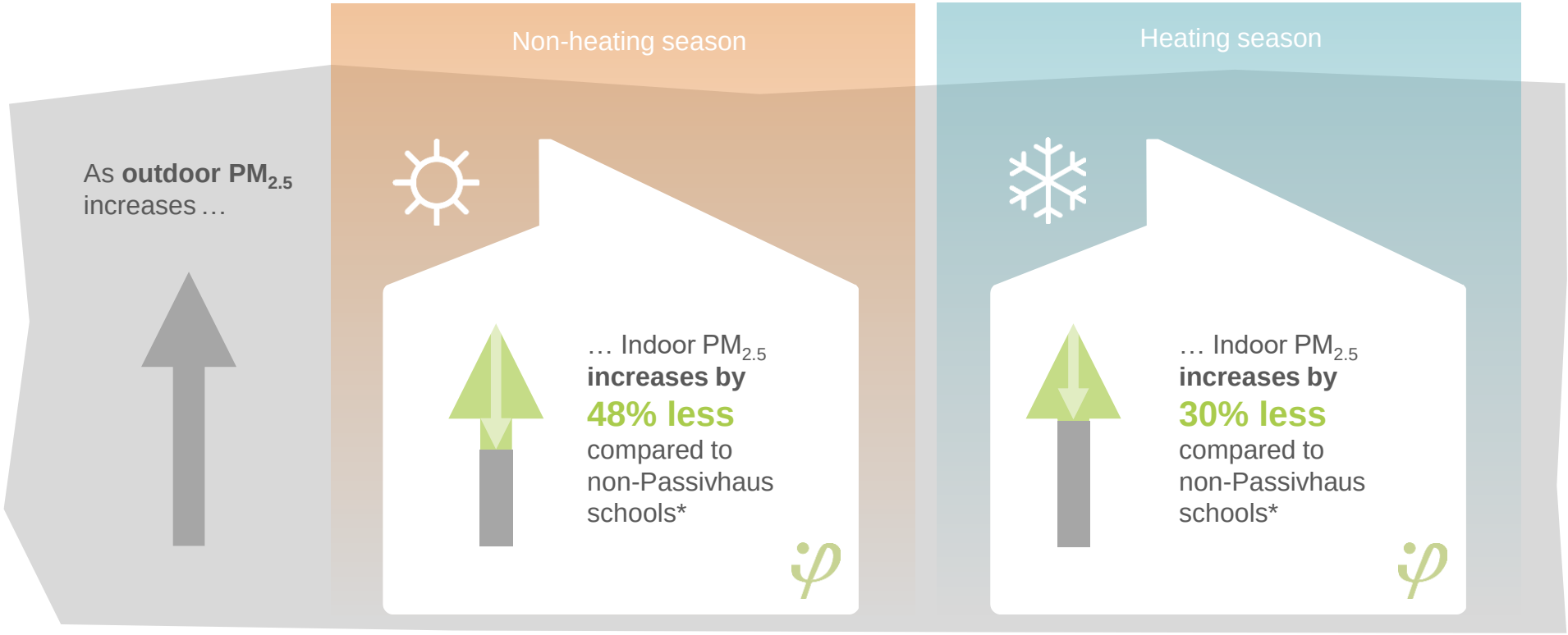
Indoor levels are lower than outdoor levels, as expected, confirming $PM_{2.5}$ is mainly outdoor sourced.



*Daily average concentration aggregation, occupied hours

Main findings - determinants of indoor $PM_{2.5}$

Compared to baseline UK primary schools, indoor concentrations and indoor to outdoor concentration ratios are **lower** in Passivhaus schools.



*Based on SINPHONIE-UK findings in Chatzidiakou et al. (2015) in baseline schools an indoor $PM_{2.5}$ increase by 0.27 (0.03) µg/m^3 for every 1 µg/m^3 increase of outdoor $PM_{2.5}$.

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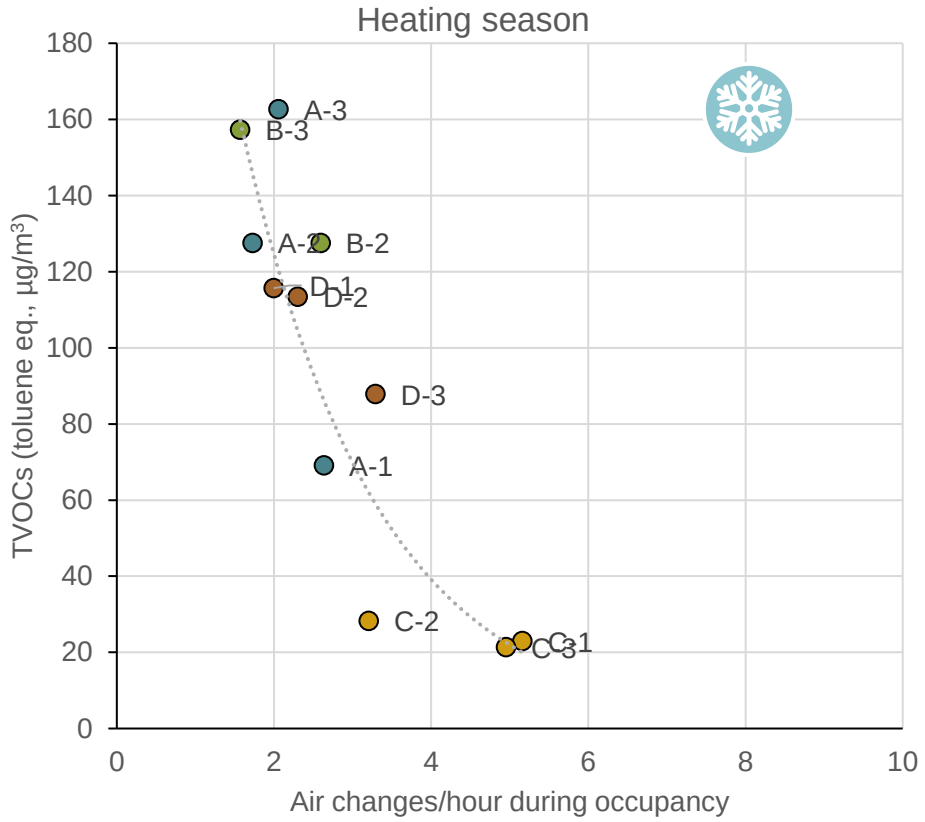
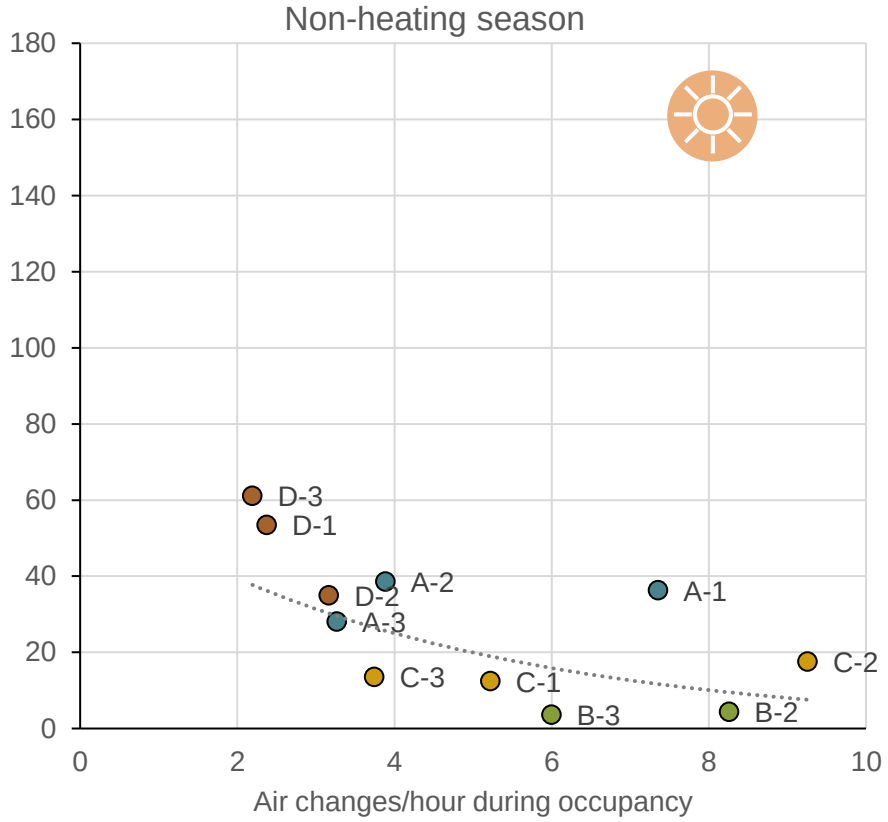
Main findings – TVOCs

Indoor levels of the **$TVOC_{GS}$ metric** (toluene equivalent):
… decrease as air exchanges rates increase.
… are higher in the heating season compared to the non-heating season.

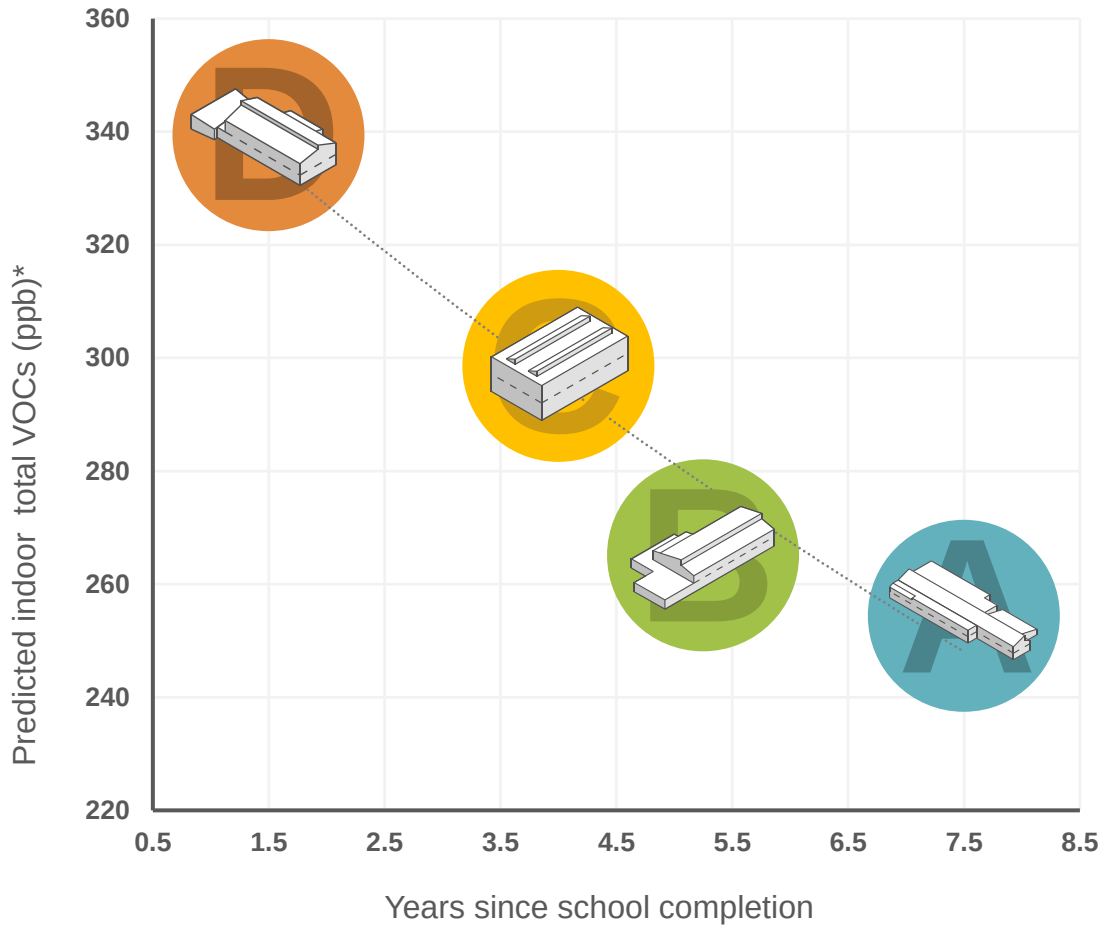




Main findings – strength of TVOC emissions from building materials/furnishings

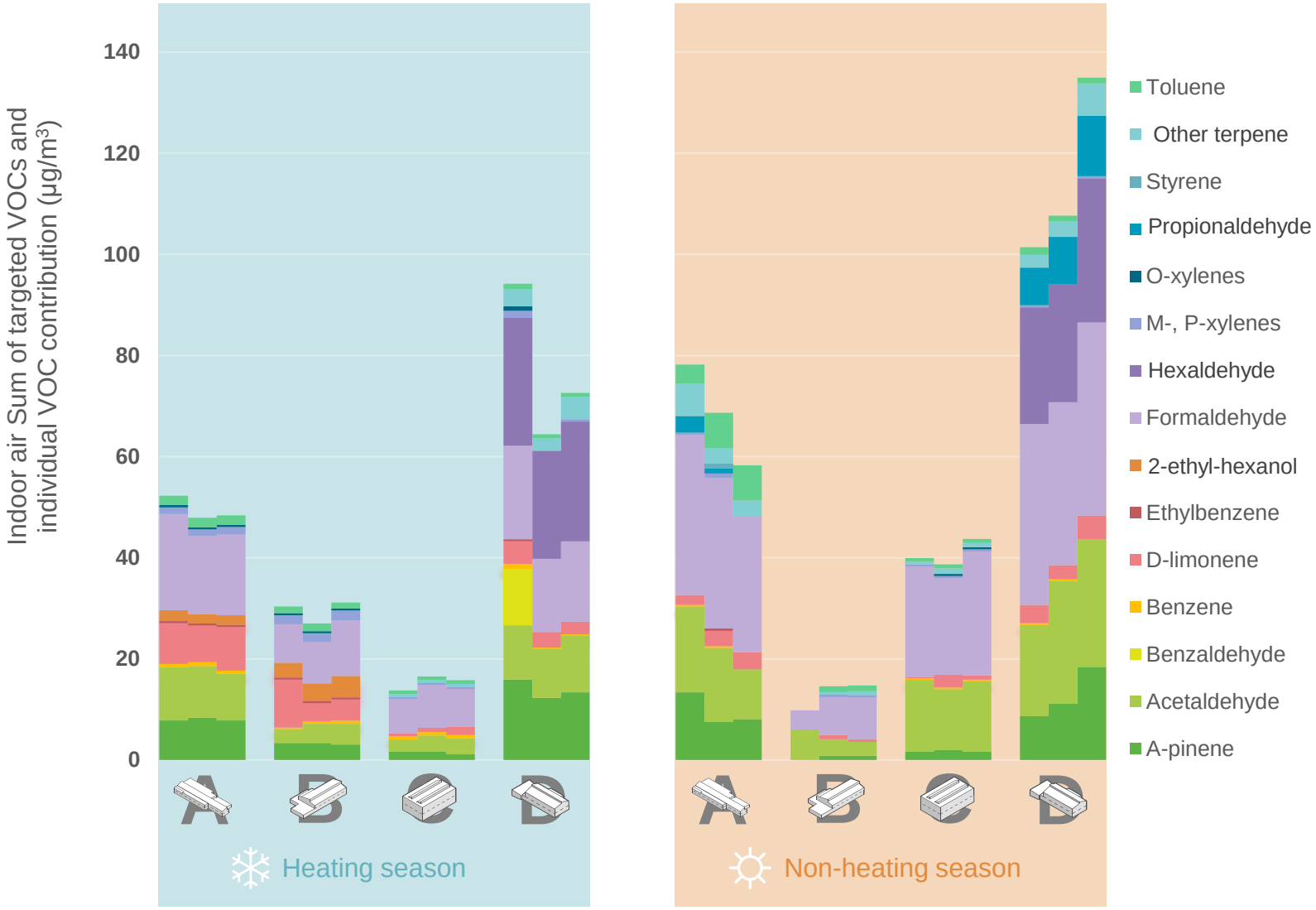
$TVOC_{DR}$ **primary emissions** from materials decrease with **building age** across the four Passivhaus schools.

Differences can be observed several years after delivery.



*Predicted indoor $TVOC_{PID}$ (ppb) at night in the heating season by school. Evidence of Persistent sources of VOCs through comparison of night-time investigation of TVOC-PID concentrations across four schools, showing decreasing strength of emissions with building age.

Main findings – specific VOCs



Of the 17 targeted VOCs and aldehydes…

Not detected: TCE, T4CE

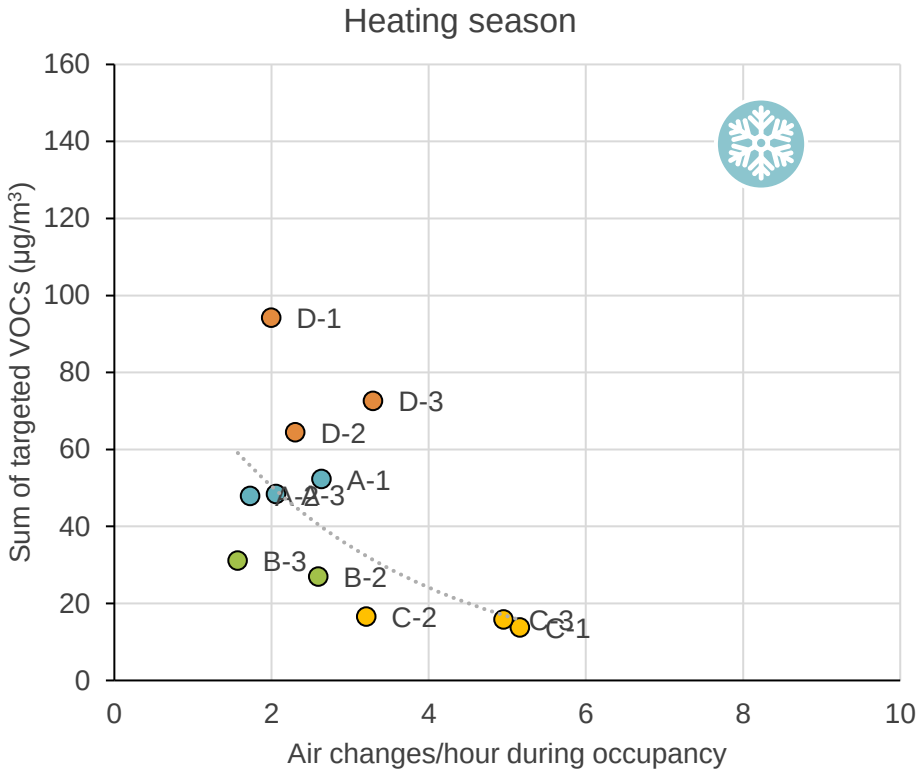
Formaldehyde, limonene and pinene were detected in all schools.

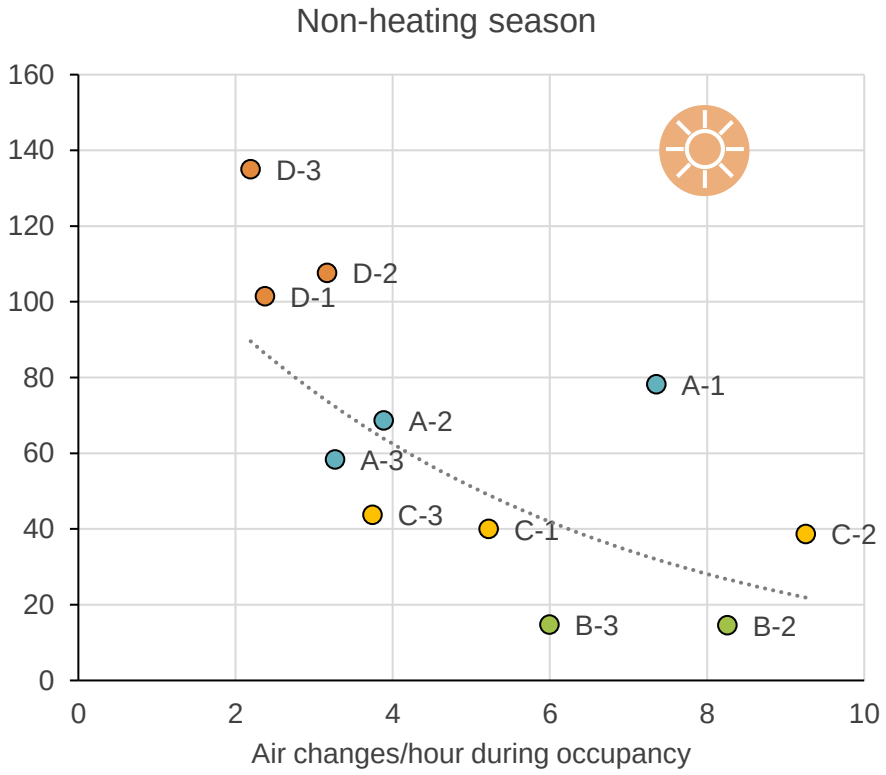
Type of VOCs varied with school: **Hexanal** only detected in school D. **2-ethyl-hexanol** only in schools A and B.

Seasonal variations were not consistent across different types of VOCs: aldehyde emissions increased in the summer.

Main findings – determinants of sum of targeted VOCs (TtVOCs)

The **sum of targeted VOCs :**
… Decreases with higher **air changes per hour** during occupied hours
… Is lower in the heating **season** compared to the non-heating season (except school B).





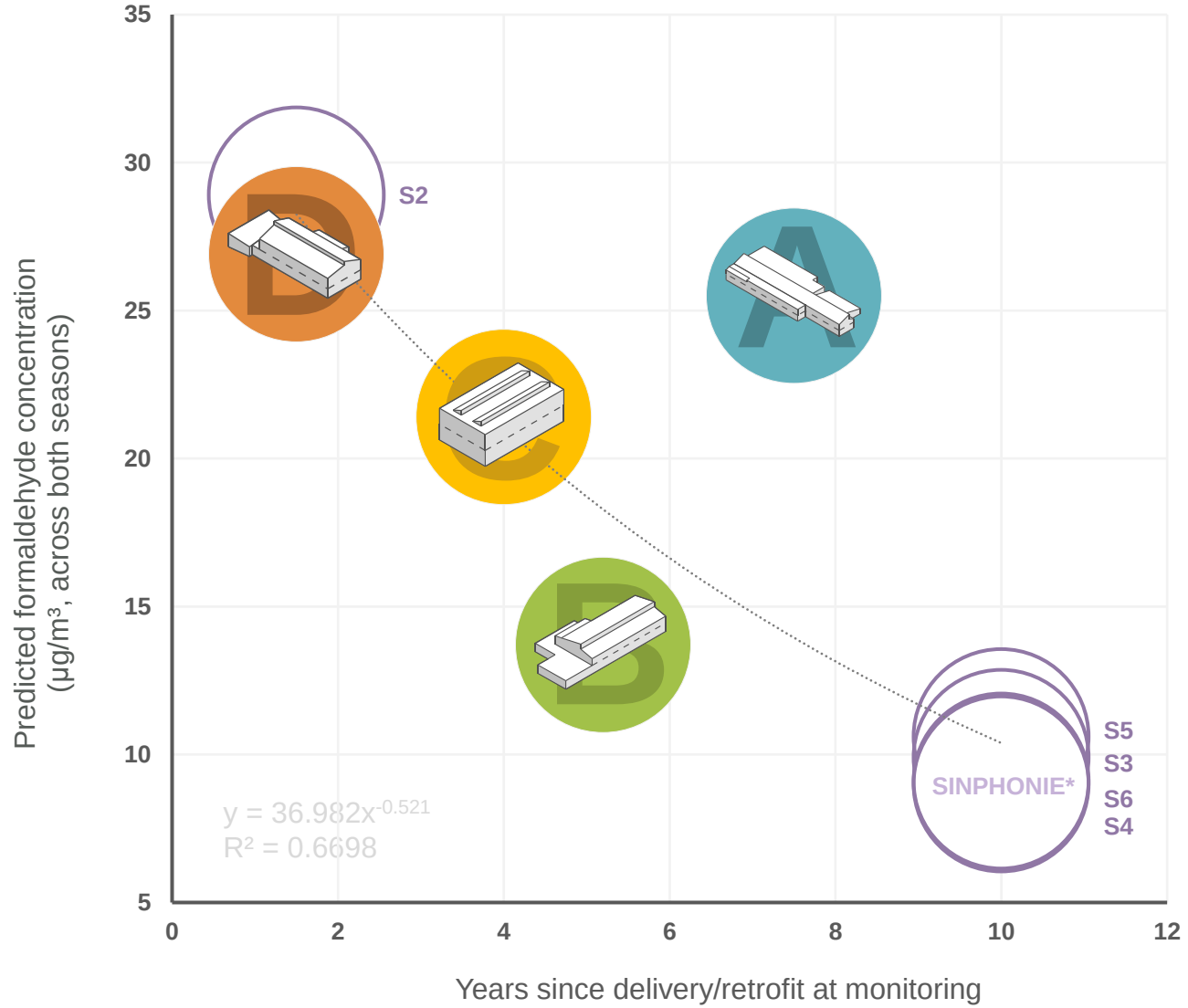
Main findings – determinants of formaldehyde

Higher than expected
formaldehyde levels in school

Attributed to:

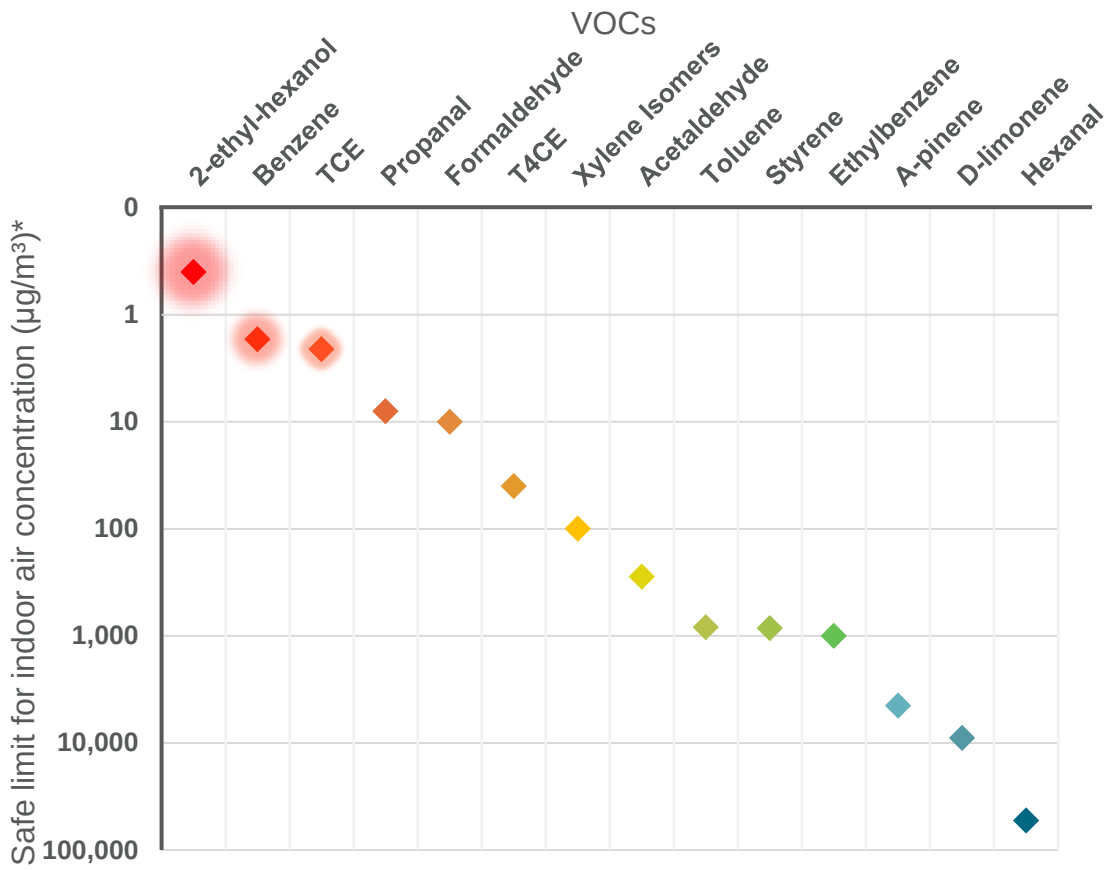
Higher indoor temperatures.
(While the linear model controls for indoor temperature, its effect on formaldehyde formation is exponential.)

Use of **PVC/vinyl** instead of **rubber** anti-slip flooring.



* Schools indicated in purple are from the 'Schools Indoor Pollution and Health: Observatory Network in Europe' research project initiated and funded by the European Parliament, 2010-2014, to assess outdoor/indoor school environment (Chatzidiakou et al. 2015).

Main findings – VOC reference concentrations



*Selected reference concentrations (RfCs) for VOCs. Limits for indoor air concentrations, from existing guidance, based on toxicity or carcinogenicity effects. The value for 2-ethyl-hexanol is a reference exposure limit suitable for indoor air quality screening purposes due to limited evidence.

Are the measured VOC concentrations relevant to health?

Reference concentrations for **selected VOCs** can be used to evaluate indoor air concentrations of VOCs in relation to occupant health.

Hazard Quotients = Measured / Reference

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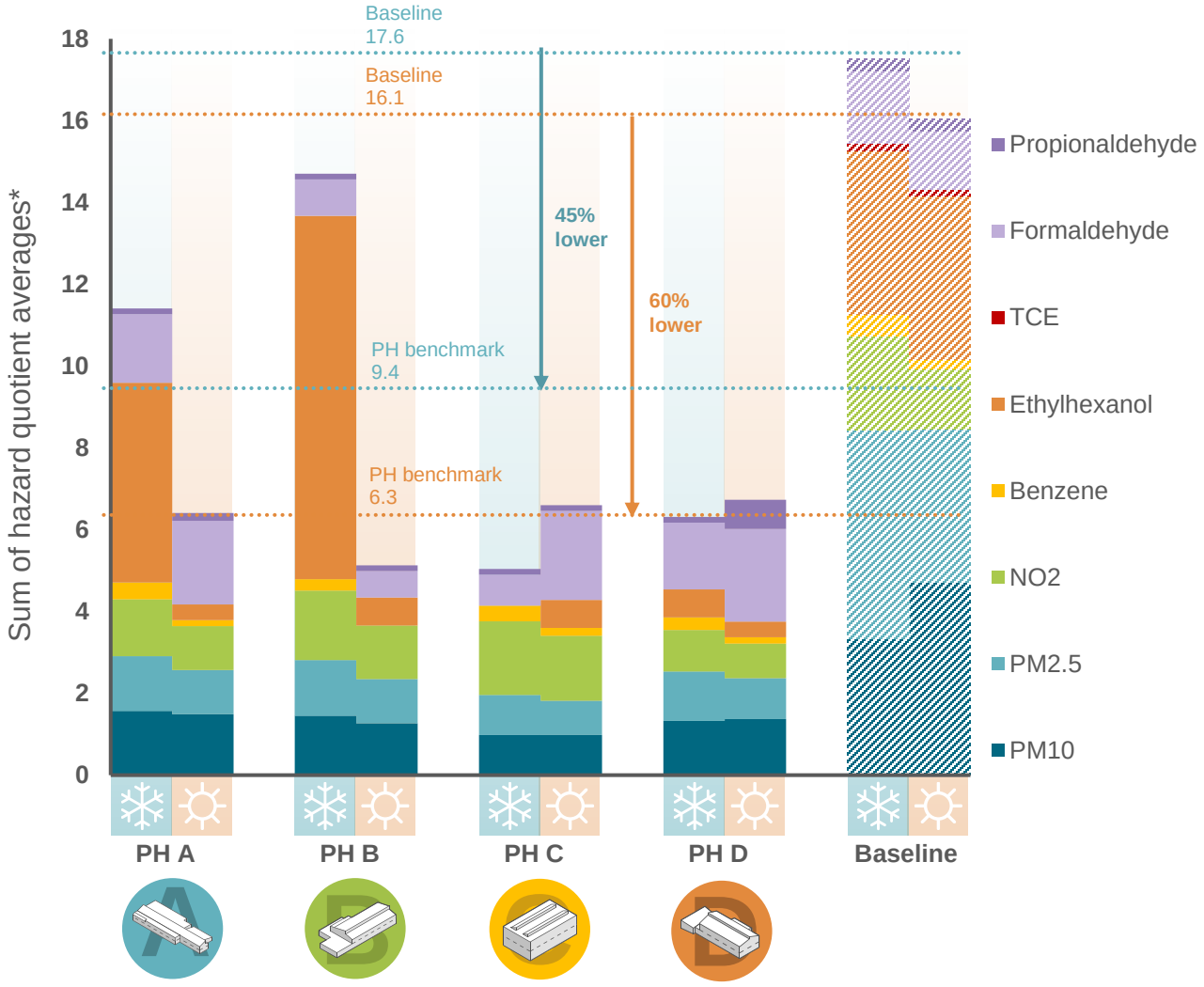
Main findings – total Indoor Air Quality (IAQ) health-relevant Hazard Index (HI)



*Total indoor air quality health related index (HI) - sum of hazard quotient averages (selected VOCs, NO_2, $PM_{2.5}$ and PM10)

The hazard quotient for each pollutant should not exceed 1 to ensure no adverse health effects.

Health relevant Index is the **sum of hazard quotients** and can be used **to assess how hazardous indoor air pollution may be** for the occupants (BSI Standard 17772-1: 2017).

Higher ventilation rates associated with better IAQ.

Highest ventilation rates and lowest total IAQ-HI during the focused investigation period:

School C in

School B in

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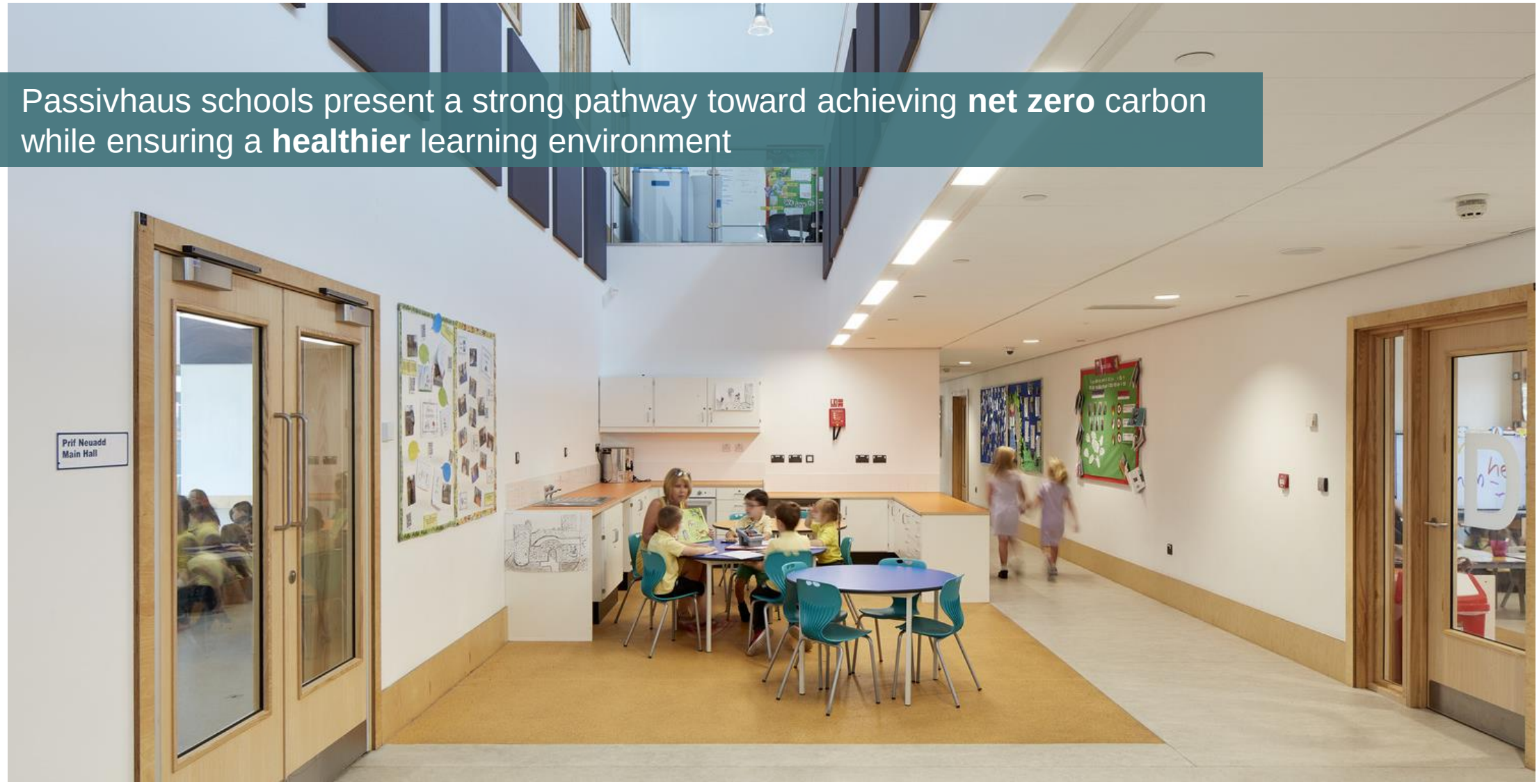
Implications of findings

Implications of findings



Passivhaus schools present a strong pathway toward achieving **net zero** carbon while ensuring a **healthier** learning environment

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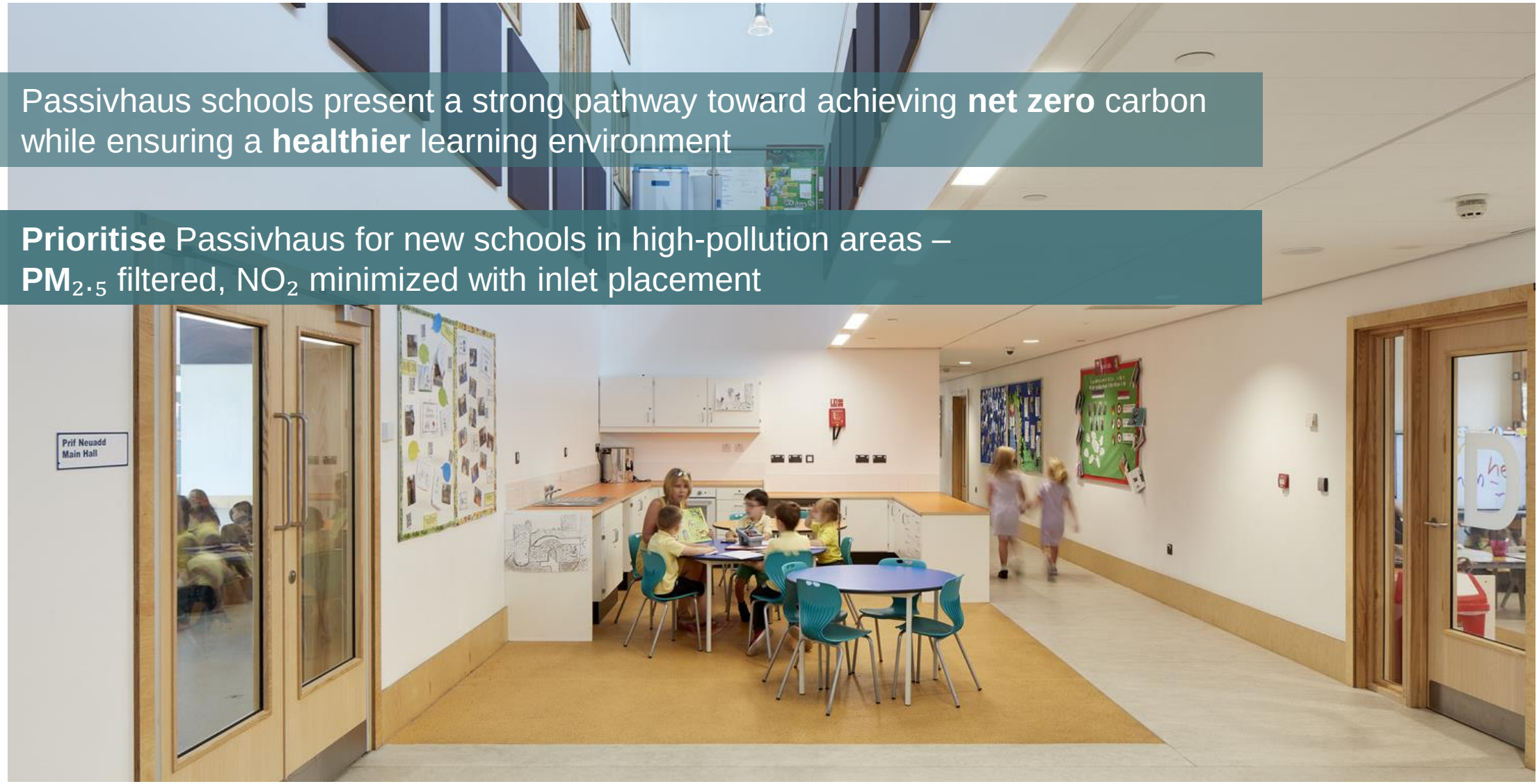
Implications of findings



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Prioritise Passivhaus for new schools in high-pollution areas –
$PM_{2.5}$ filtered, NO_2 minimized with inlet placement

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Shift from compliance-based to **source-informed VOC monitoring** – material-specific focus is needed

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Thank you

Presentation and graphical contributions: Seb Laan Lomas and Katie de Silva.

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