WHY HAVEN’T WE STARTED FIXING SCHOOLS?

A SOLUTION TO MEET THE MOMENT

BARRY STEPHENS

WHY VENTILATE

BETTER VENTILATION MEANS BETTER HEALTH

- More is better?

California Study of 168 Classrooms[1]

Increasing classroom VRs from the California average (8.5 cfm per person) to the State standard of 15 cfm would decrease Illness Absences by 3.4%

Texas Study of 120 Classrooms[2]

Median CO2 levels were 28% higher than ASHRAE limit

Washington & Idaho Study of 434 Classrooms[3]

A 1000 PPM increase in CO2 was associated with a 10% - 20% increase in student absence

WHY VENTILATE

BETTER VENTILATION MEANS BETTER PERFORMANCE

Harvard Study[4]

On average, a 400 ppm increase in CO_2 was associated with a 21% decrease in cognitive function scores

70-school Study in Southwestern US[5]

Students' mean mathematics scores were increased by 0.5% per 2 cfm/person increase in ventilation rate within the range of 2 – 15 cfm

54-school Study across USA[6]

Math and Reading scores were 14% higher when VRs were greater than 10 cfm/student compared to scores when VRs were less than 5 cfm/student

- More *is* better

(4) Allen, et al., Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures..."

Why Ventilate?
Lower Risk of Virus Spread

Indoor Air 2003; 13: 237–245
www.blackwellpublishing.com/ina

INDOOR AIR
ISSN 0905-6947

Risk of indoor airborne infection transmission estimated from carbon dioxide concentration

Abstract The Wells–Riley equation, which is used to model the risk of indoor airborne transmission of infectious diseases such as tuberculosis, is sometimes problematic because it assumes steady-state conditions and requires measurement of outdoor air supply rates, which are frequently difficult to measure and often vary with time. We derive an alternative equation that avoids these problems by determining the fraction of inhaled air that has been exhaled previously by someone in the building (rebreathed fraction) using CO_2 concentration as a marker for exhaled-breath exposure. We also derive a non-steady-state version of the Wells–Riley equation which is especially useful in poorly ventilated environments when outdoor air supply rates can be assumed constant. Finally, we derive the relationship between the average number of secondary cases infected by each primary case in a building and exposure to exhaled breath and demonstrate that there is likely to be an achievable critical rebreathed fraction of indoor air below which airborne propagation of common respiratory infections and influenza will not occur.

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Key words: Carbon dioxide; Infectious disease risk modeling; Wells–Riley equation; Basic reproductive number; Communicable disease control; Respiratory tract infections; Indoor air pollution.

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Why Ventilate?
Lower Risk of Virus Spread

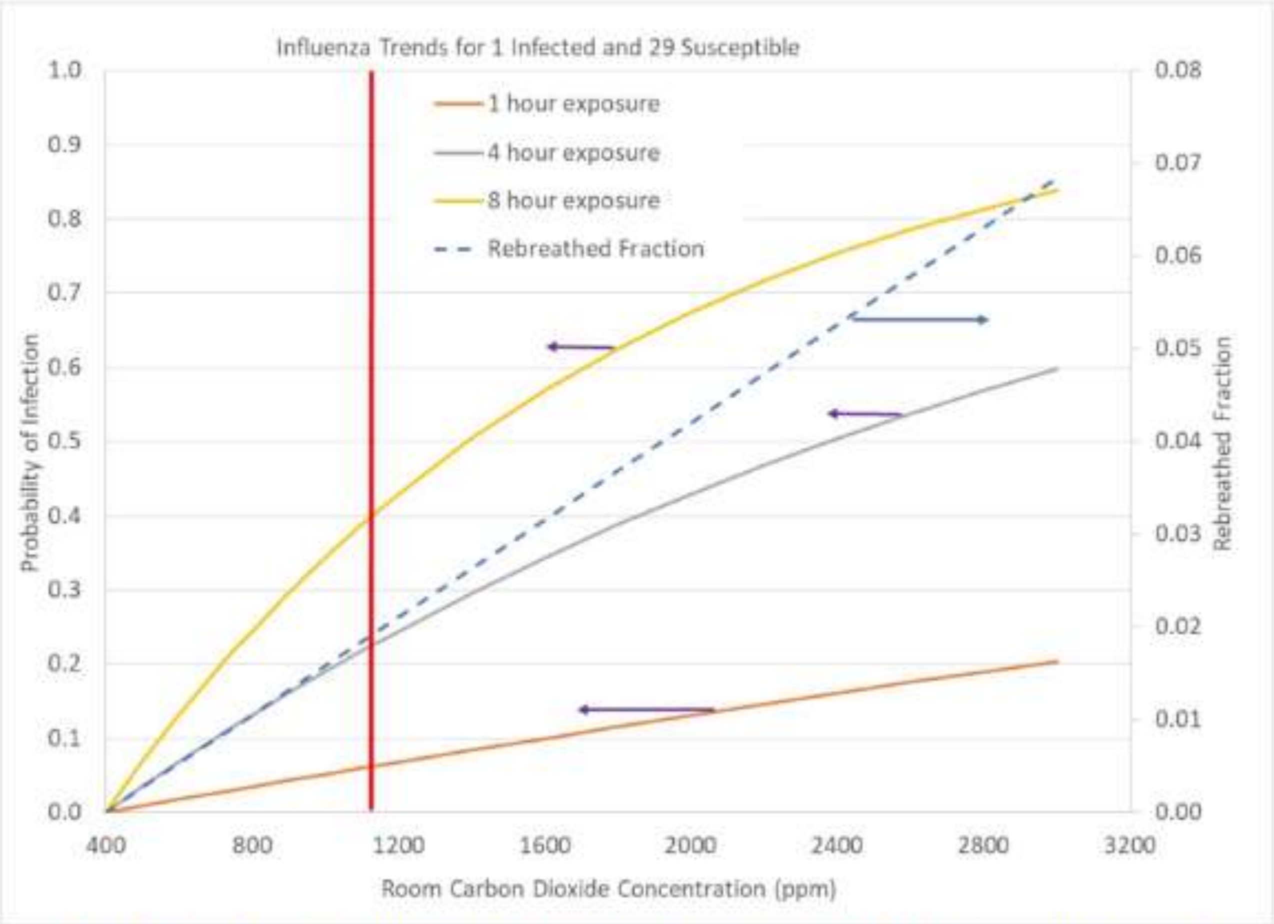

Figure 6 Probability of infection in a room with 1 infected person and 29 susceptible persons.

Schools!

It is widely known, after multiple studies across North America, Europe and beyond, that schools have poor IAQ and health.

Impacts include learning impairment, reduced cognitive function and increased illness and absence.

PPS says it will comply after state clarifies air quality recommendations

Aimee Green - The Oregonian/OregonLive

In a sweeping about-face, Oregon's largest school district on Friday said it will "strive" to increase a key measure of air quality to bare minimum levels long-trumpeted by a wide swath of experts nationwide.

Portland Public Schools' announcement comes after an investigation by The Oregonian/OregonLive in May found nearly 500 classrooms with subpar ventilation rates that experts said could increase the risk of airborne-disease transmission as well as lower the ability of students to learn in stuffy classrooms with stale air.

The district's announcement also comes on the heels of clarified guidance from the Oregon Health Authority, brought about by questions raised by The Oregonian/OregonLive this month. On Thursday, the health authority told school officials it "recommends a range of 3-6 air changes per hour" along with other efforts to improve indoor air quality.

SQ SERIES – DECENTRALIZED VENTILATION

VS500SQ h (HRV)   VS500SQ e (ERV)

- Simple ductless installation
- Below ceiling mount; optimized to create healthy, comfortable classroom
- No internal ductwork minimizes installation time and cost
- Exceptionally quiet operation:
  - Example L_{PA}=10 dB: A Pin Dropping
  - Example L_{PA}=20 dB: Leaves Rustling
  - SQ Series: L_{PA}=23.6 dB @3M, 50% flow
  - Example L_{PA}=30 dB: A Whisper / Library
  - SQ Series: L_{PA}=31.5 dB @1M, 50% flow
- Standard CO_2 sensor for DCV
- Easy filter access
- Post-conditioning option available
- Great for classrooms; libraries
- UL/CSA Listed

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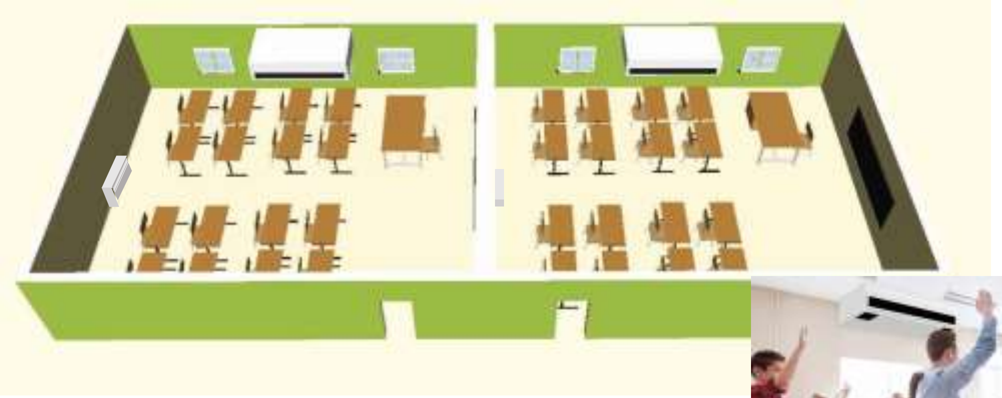
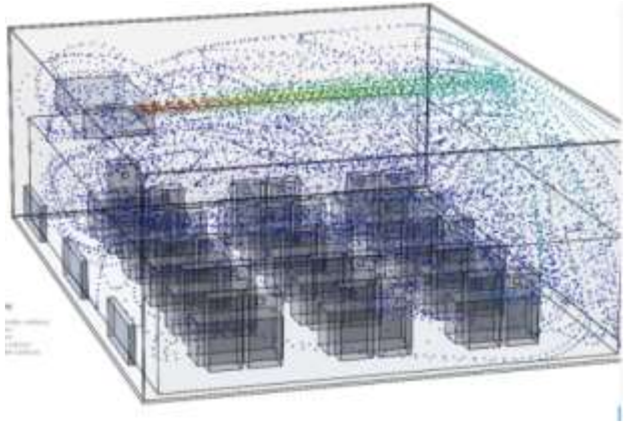
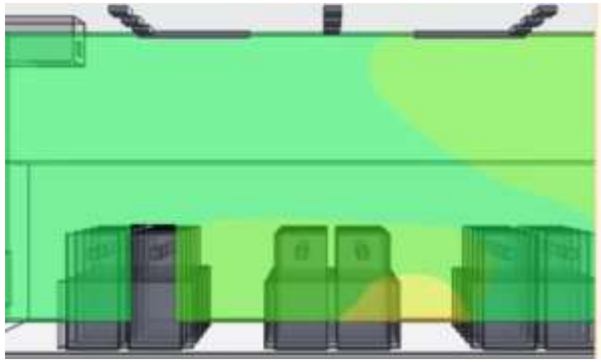
SO ADVANCED THAT ITS SIMPLE







- Simple ductless installation reduces cost and time of install
- Health:
- DCV operation with standard CO_2 sensor maintains superior air quality for health and human performance
- Comfort:
- Very low air velocity at student level
- Comfortable fresh air temperature through high recovery effectiveness

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NYCSCA PILOT TEST INSTALL

NYCSCA wanted to test efficacy of the model, did a temporary installation. Followed up with additional units installed.

HILLSBORO, OR INSTALLATION

Hillsboro, OR school pilot in conjunction with NEEA. Units are partially installed in the drop ceiling, reducing the profile.

HILLSBORO, OR INSTALLATION

These units are HRVs, requiring a condensate drain. ERVs typically do not need condensate drains or pumps.

HILLSBORO, OR INSTALLATION

View outdoors with supply and exhaust hoods.

WINDHAM, ME UNIT VENTILATOR UPGRADE

Existing Unit Ventilators, to be replaced with VS500 SQe units. We utilized the existing hydronic heating system for post-heating.

WINDHAM, ME UNIT VENTILATOR UPGRADE

Shown with a three damper setup. Supply and return dampers are closed, a re-circ damper is opened during heating season to do morning warmup before start of school. At start of school the re-circ damper is closed, supply and return dampers are opened for 100% Outside Air.

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WINDHAM, ME UNIT VENTILATOR UPGRADE

We utilized existing penetrations for supply
and return ducts, later the ducting is covered with
A simple framing.

CFD – VS 500 SQ

Classroom – Fairbank school - Toronto

06.2023 – 2VV - R&D Department

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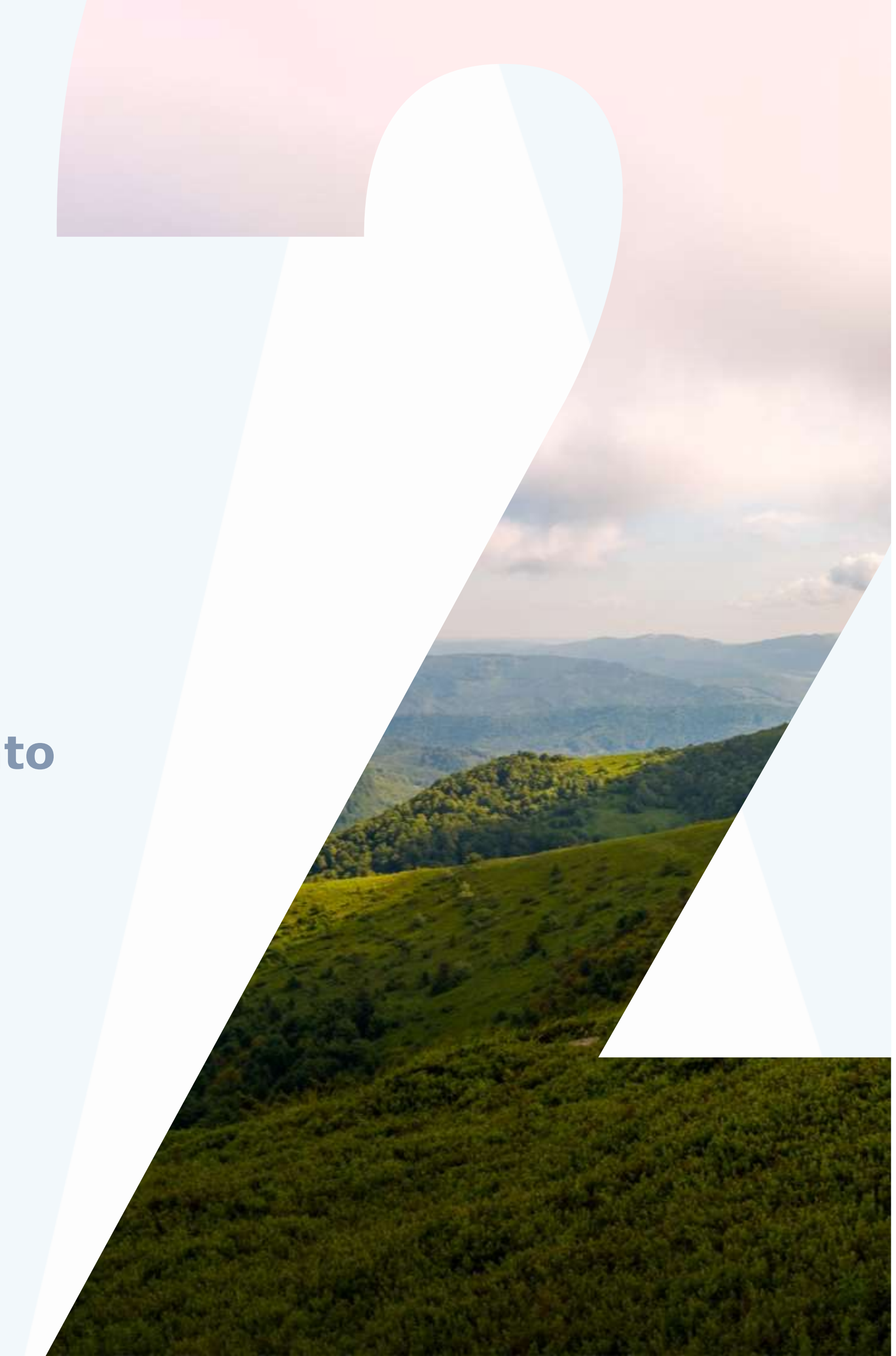
Making Buildings Healthy – Efficient – Smarter



CFD

- **The aim of the simulations is to show the air flow and the distribution of CO_2 concentration in a classroom ventilated by a decentralized recuperative ventilation unit VS500 SQ**

CFD

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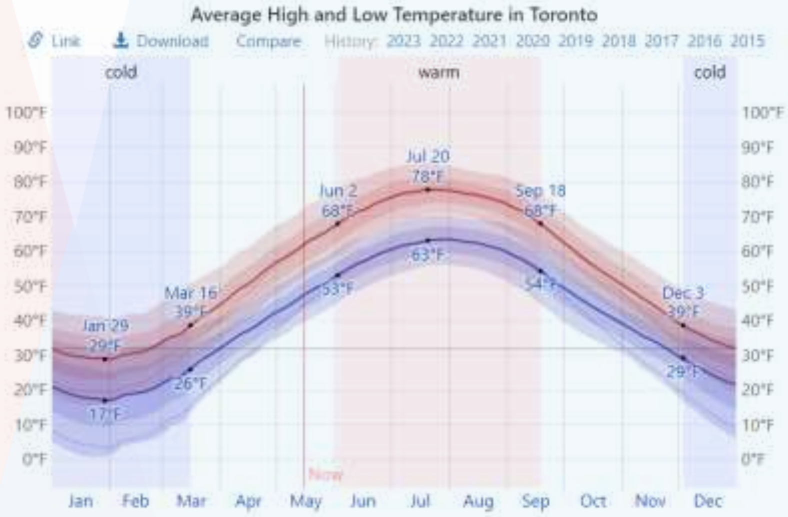
source: https://www.google.com/maps

- **Building´s location**

- **Fairbank Memorial Community School**
  - Toronto, Ontario, Canada

Weather in the area - average temperature



The daily average high (red line) and low (blue line) temperature, with 25th to 75th and 10th to 90th percentile bands. The thin dotted lines are the corresponding average perceived temperatures.

Average	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High	30°F	31°F	39°F	51°F	63°F	72°F	77°F	76°F	68°F	56°F	45°F	35°F
Temp.	24°F	25°F	32°F	44°F	55°F	64°F	70°F	69°F	62°F	50°F	39°F	30°F
Low	18°F	19°F	27°F	38°F	48°F	57°F	63°F	62°F	55°F	44°F	34°F	25°F

https://weatherspark.com/y/19863/Average-Weather-in-Toronto-Canada-Year-Round

Outdoor CO_2 – concentration Canada

3.1 OUTDOOR CONCENTRATIONS

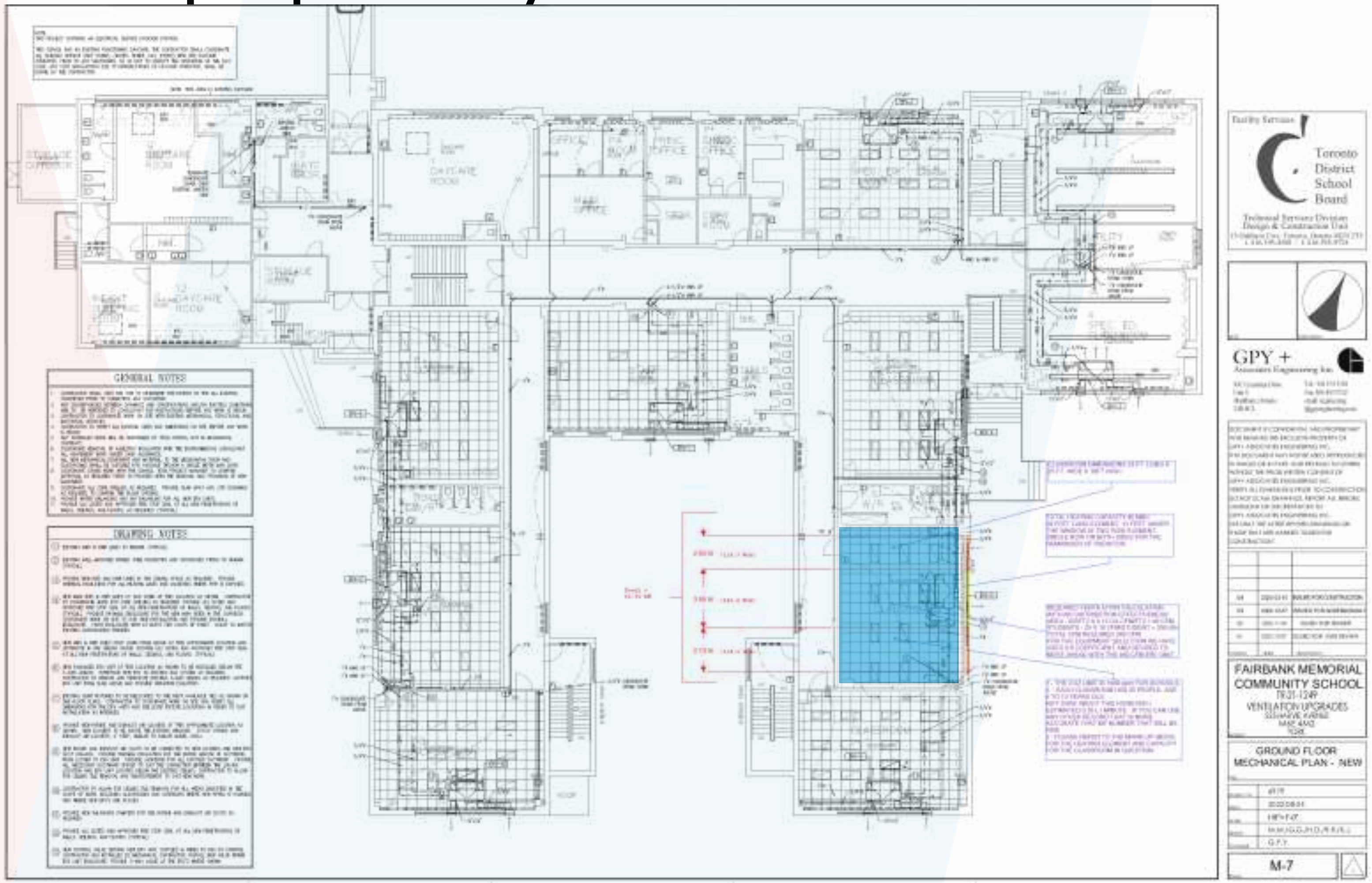
In a Health Canada study, the median and 95th percentiles of average hourly CO_2 concentrations measured outside of 4 schools located in Ottawa were 419 and 532 ppm, respectively (MacNeill et al. 2016) (see Table 2). In the published literature, normal ambient outdoor ground-level CO_2 concentrations in the range of 328 to 442 ppm have been reported in the United States, Europe, Australia, and Japan (Muscatiello et al. 2015; Haverinen-Shaughnessy, Moschandreas and Shaughnessy 2011; Simoni et al. 2010; Ziska et al. 2001).

Location	Season	No. homes/ schools/ daycare centres	No. of samples	Average hourly concentration (ppm) Mean	Minimum	Median	75th percentile	95th percentile	Maximum	Reference
OUTDOOR										
Ottawa, Ontario (outside of schools)	Fall	4	5313	523	294	419	453	532	5047	MacNeill et al (2016)

https://www.canada.ca/en/health-canada/services/publications/healthy-living/residential-indoor-air-quality-guidelines-carbon-dioxide.html

CFD

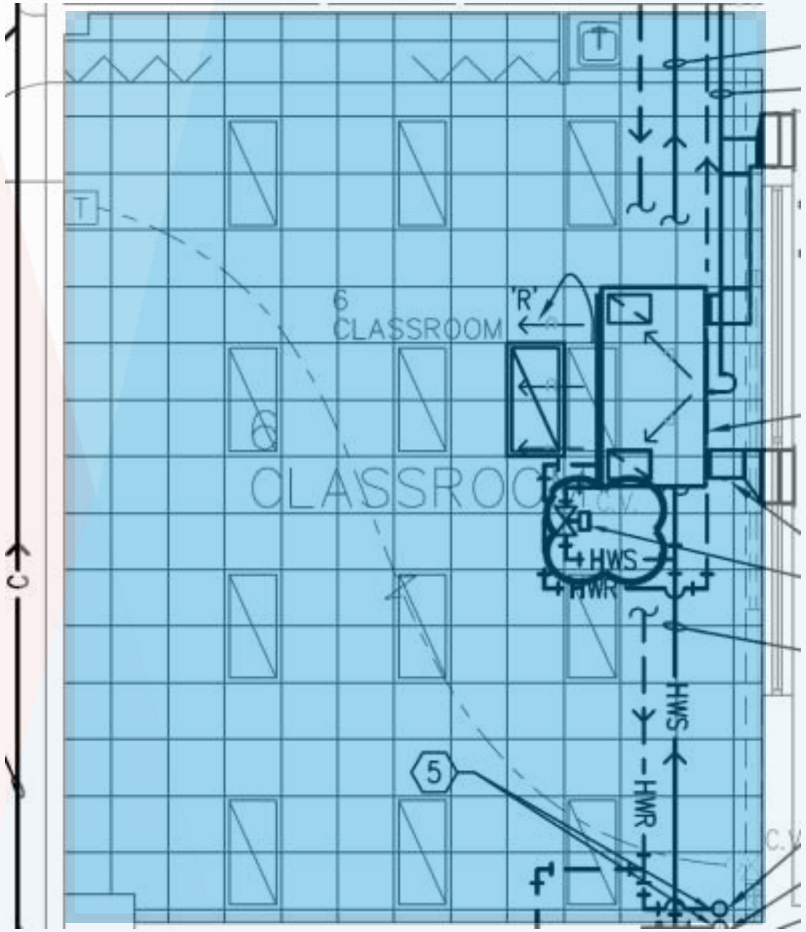
- **Floor plan provided by the customer**



- Simulated classroom is highlighted blue on the floor plan

CFD

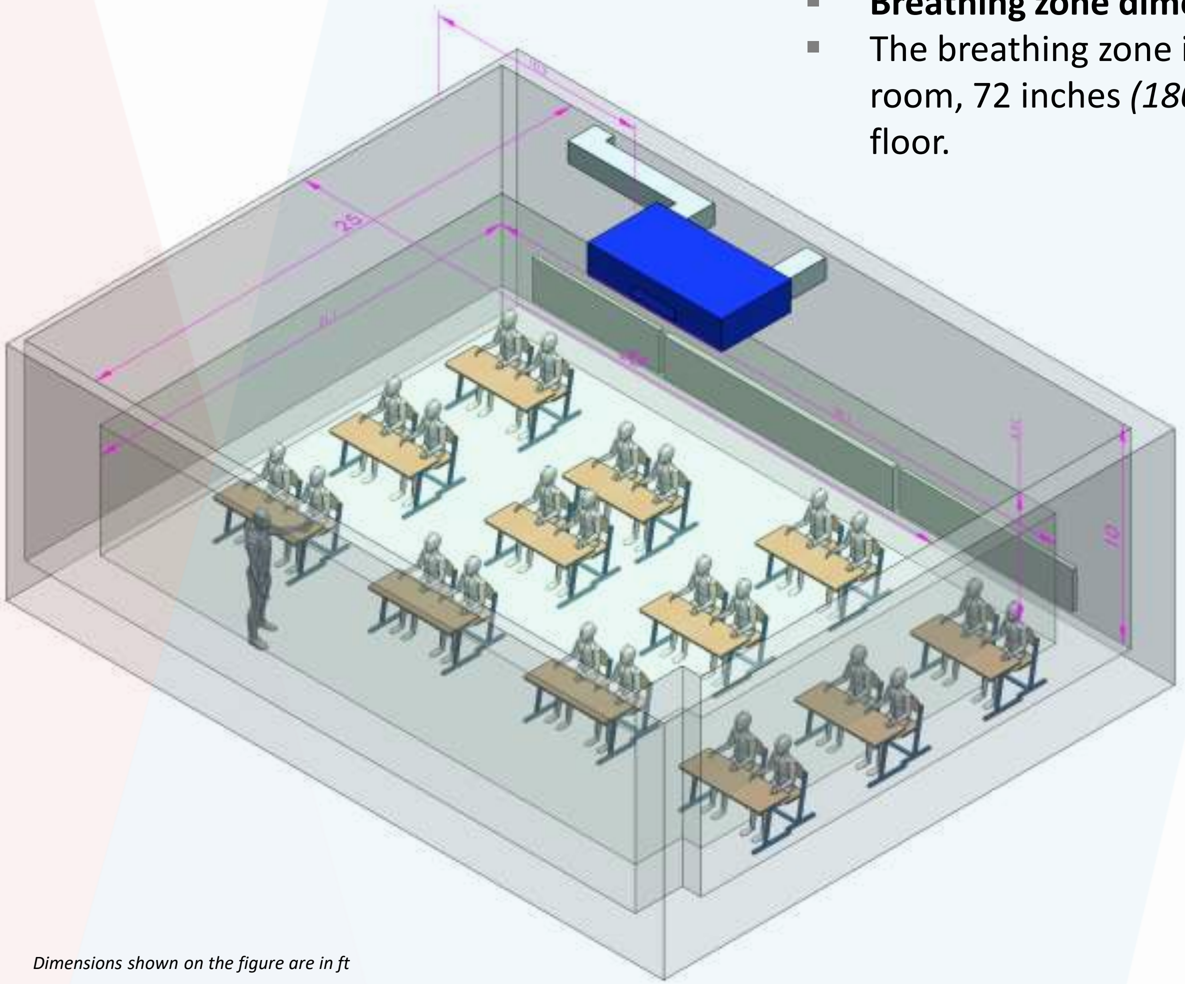
- **Floor plan provided by the customer – simulated classroom**



- **Classroom dimensions:**
  - 33 ft *(10,06 m)* long X 25 ft *(7,62 m)* wide and ceiling height is 10 ft *(3,05 m)*
  - floor area is 825 ft^2 *(76,65 m^2)*
  - room internal volume 8250 ft^3 *(233,6 m^3)*

CFD

- **Simplified building - simulation model**



Dimensions shown on the figure are in ft

- **Breathing zone dimensions (*highlighted in green*):**
- The breathing zone is at 2 ft *(600 mm)* from the perimeter walls of the room, 72 inches *(1800 mm)* in height and 3 inches *(75 mm)* from the floor.

- **Air handing unit position:**
- The heat recovery unit is located 10,3 ft *(≈ 3140 mm)* from the right shorter wall of the room *(see picture),* 2,14 ft *(≈ 652 mm)* from the rear wall of the room *(exterior wall)* and its upper side is adjacent to the ceiling of the room. *(The unit is connected by a square pipe 12“x12“)*

- **Internal equipment and people model**:
- The layout of the school benches corresponds to the floor plan supplied by the customer
- Children's model corresponds to 8-10 years old

VS 500 SQ – Classroom – 1. Simulation variant - Isothermal

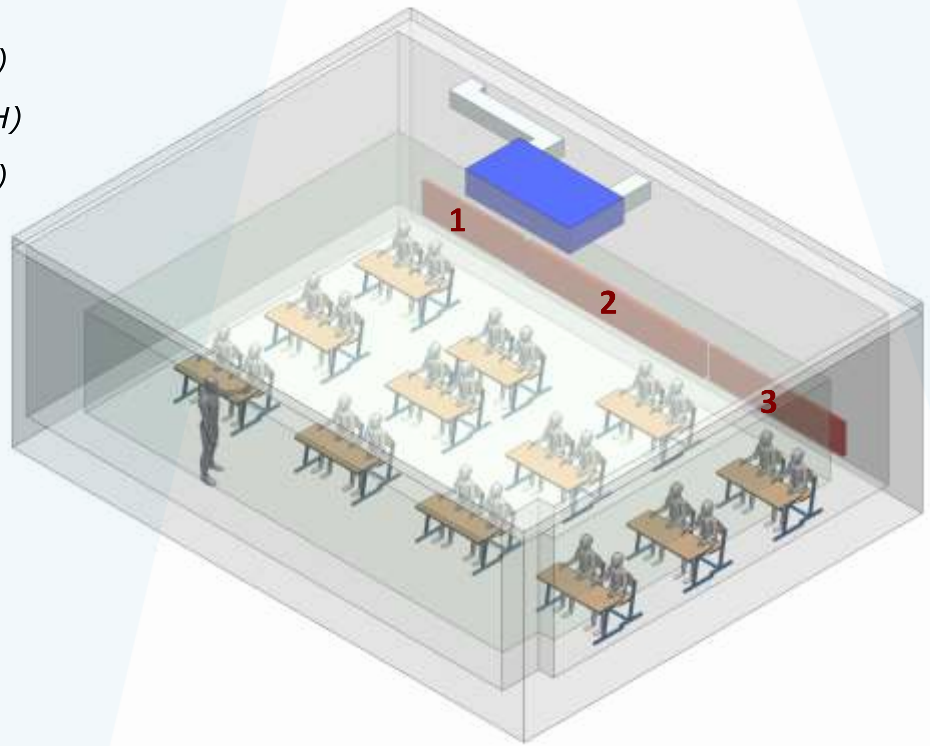
- **Used dimensions of internal space for simulation**
  822,6 ft^2 floor space *(76,4 m^2)*
  (pillars in the corners of the room are considered in the model for simulations)
- **Internal space for simulation is 8226 *ft^3*** *(232,29 m^3)*
- The classroom's ceiling high is 10 ft *(3,05 m)*
- **Outside air CO_2 concentration 450 ppm**
- Initial inside air CO_2 concentration 1000 ppm
- **Units' airflow 450 cfm** *(764,55 m^3/h)* **@ 71,6°F** *(22 °C)*
- **24 students and 1 teacher inside the classroom -** CO_2 production 15 l/h per student and 17 l/h per teacher **- total CO_2 production is 377 l/h**
- People inside the classroom are considered only as a source of CO_2 in the simulation, heat energy emitted by people is not consider in the simulation
- Heat transfer by radiation is not considered in the simulation
- The surrounding *(inner walls of the building)* school classrooms are adiabatic - without heat transfer
- The heat source is not considered, we consider a balanced temperature of 22°C inside the classroom
- The goal is to show the distribution of air flow speeds and CO_2 concentrations in a ventilated school classroom

VS 500 SQ – Classroom – 2. Simulation variant – Non-Isothermal

- In order to show the effect of convective air flow due to the heat source in the school classroom *(heating elements)* on the air flow in the classroom, due to incomplete information about the material properties of the surrounding walls and the surrounding conditions and to simplify the calculation, the power of the heat sources was set to cover the temperature difference between the required classroom temperature and the supply air temperature of the @ 450 cfm *(764,55 m^3/h)* ventilation unit that was set at 59°F *(15°C).* Heating power temp. the resource was relatively divided among the heating elements in the school classroom according to the maximum heating output.
- **Heat sources:**

1. heating element *(1.row – lenght 2,04 m)* - 390 W *(1330 MBH)*
2. heating element (*2.rows – lenght 3,66 m)* - 888 W *(3032 MBH)*
3. heating element *(1.row – lenght 2,74 m)* - 524 W *(1787 MBH)*

- The position of the heating elements approximately according to the available documents provided by the client
- **Total heating power in the simulation 1802 W *(6149 MBH)***
- **Units' airflow 450 cfm** *(764,55 m^3/h)* **@ 59°F** *(15 °C)*
- The other boundary and initial conditions are the same as in the first variant *(isothermal variant)*



CFD

VS 500 SQ – Classroom

- **Evaluation of simulations:**
- **Goals:**
- Volume goals were monitored in the simulations - average air flow velocities, average air temperatures *(non-isothermal case)* and the concentration of average CO_2 concentrations in the school classroom and its breathing *(residence)* zone
- **The convergence criteria** *(according to computing time and our computing capabilities)* of the listed quantities were set as follows:
- air flow velocity: 0,01 m/s *(≈ 0,0328 ft/s)*
- temperature: 0,1 °C *(32,18 °F)*
- CO_2 concentrations: 5 ppm

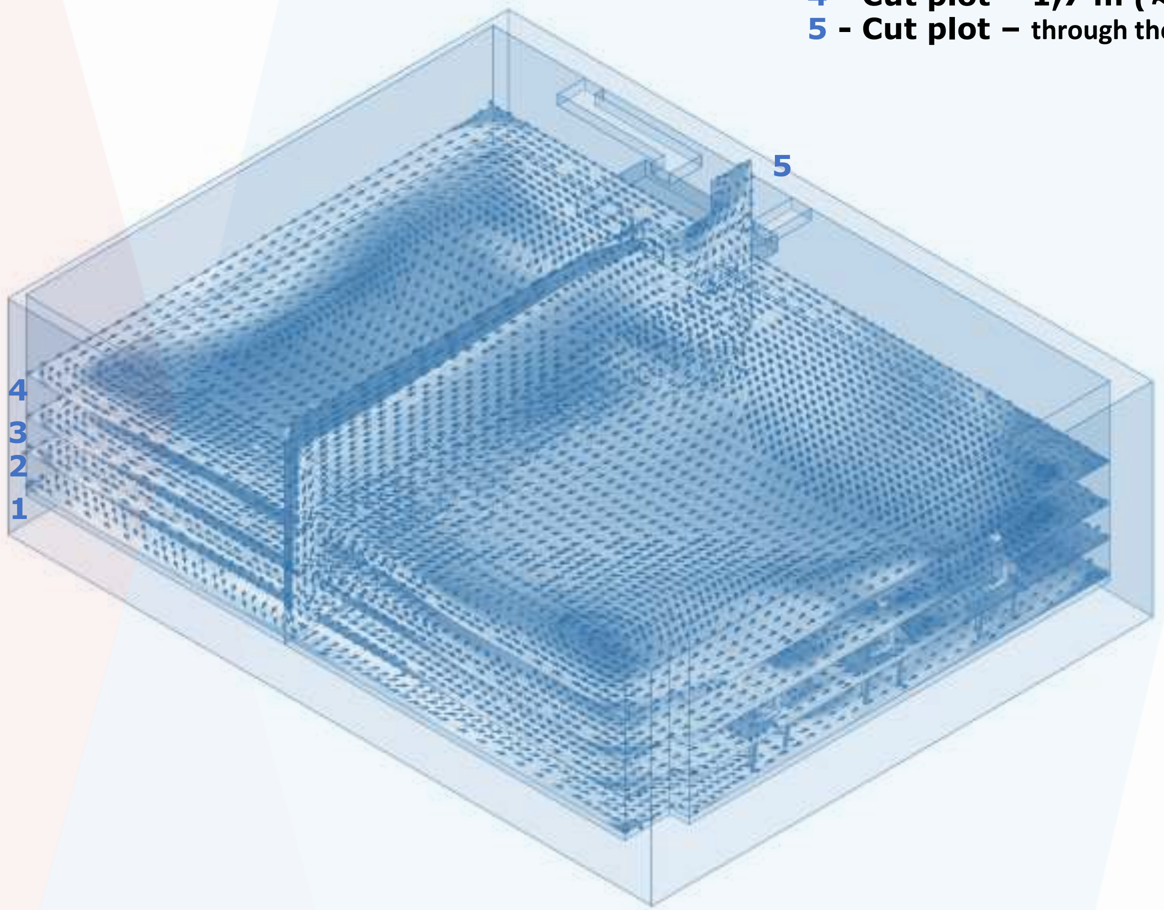
- **Graphical results:**
- **Cut plots of the school classroom were made for graphic representation:**
- At heights of 0,1 m *(≈0,03 ft) (ankle level)*, 0,6 m *(≈0,18 ft) (waist level of a seated person)*, 1,1 m *(≈0,34 ft) (waist level of a standing person - head level of a seated person)* and 1,7 m *(≈0,52 ft) (head level of a standing person)*, and through the center of the ventilation unit
- These cut plots show the distribution of velocities, temperatures and CO_2 concentrations
- The results are also displayed using isosurfaces and streamlines

CFD

VS 500 SQ – Classroom

- **Cut plots scheme:**

1 - Cut plot – 0,1 m *(≈0,03 ft)* above the floor
2 - Cut plot – 0,6 m *(≈0,18 ft)* above the floor
3 - Cut plot – 1,1 m *(≈0,34 ft)* above the floor
4 - Cut plot – 1,7 m *(≈0,52 ft)* above the floor
5 - Cut plot – through the center of the unit



CFD 1. Simulation variant

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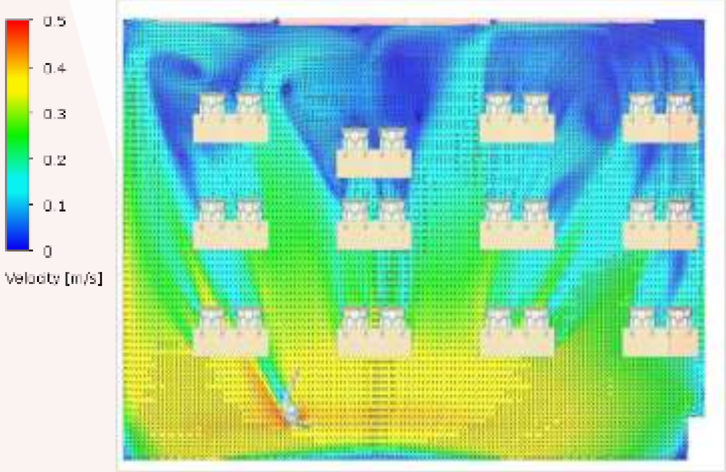
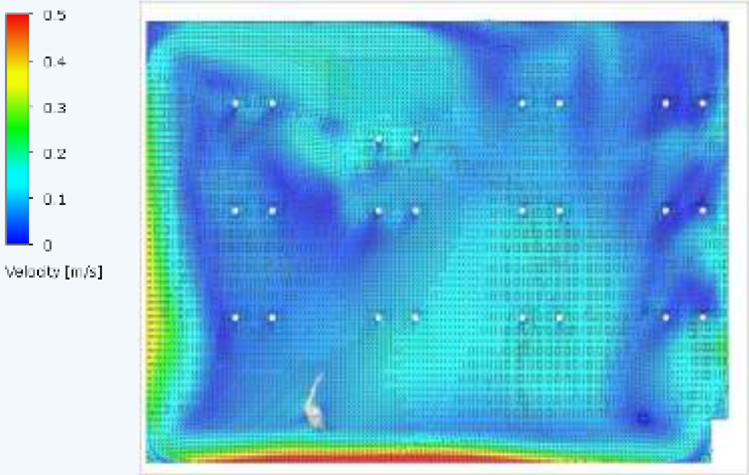
VS 500 SQ – Classroom

- **Cut plots – Air velocity**

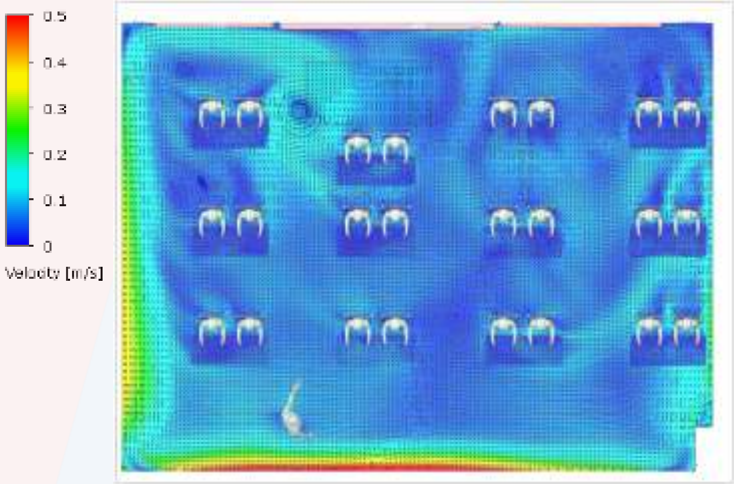
Cut plots – 0,1 m, 1,1 m, 0,6 m, 1,7 m – air velocity *(displayed interval 0-0,5 m/s)*



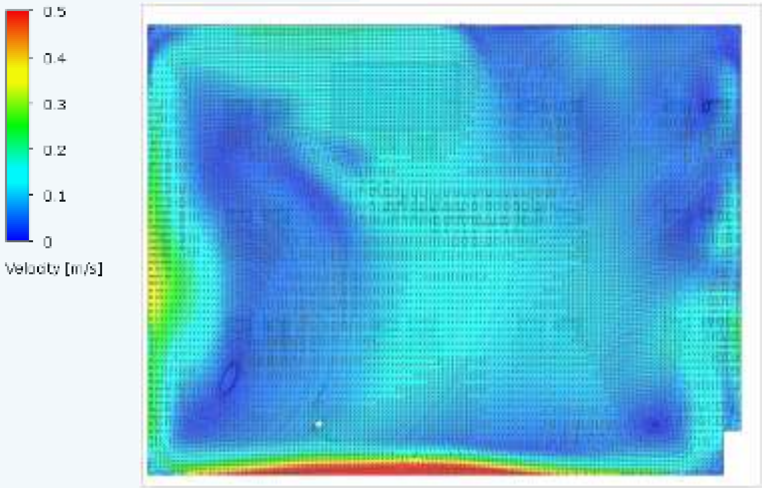
1- Cut plot – 0,1 m above the floor – air velocity



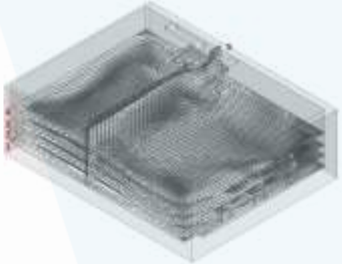
3 - Cut plot – 1,1 m above the floor – air velocity



2 - Cut plot – 0,6 m above the floor – air velocity



4 - Cut plot – 1,7 m above the floor – air velocity



CFD 1. Simulation variant

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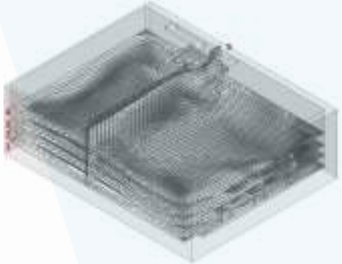
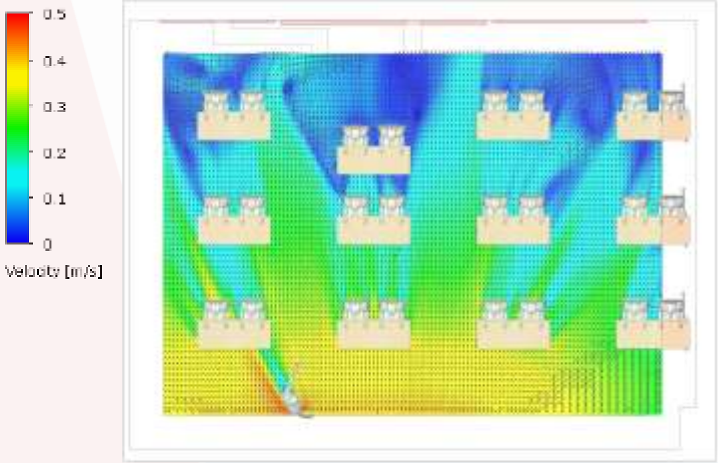


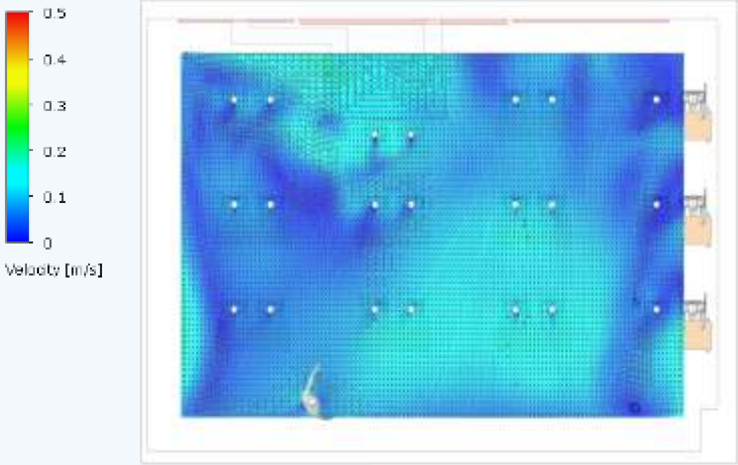
VS 500 SQ – Classroom

- Cut plots – Air velocity – breathing zone

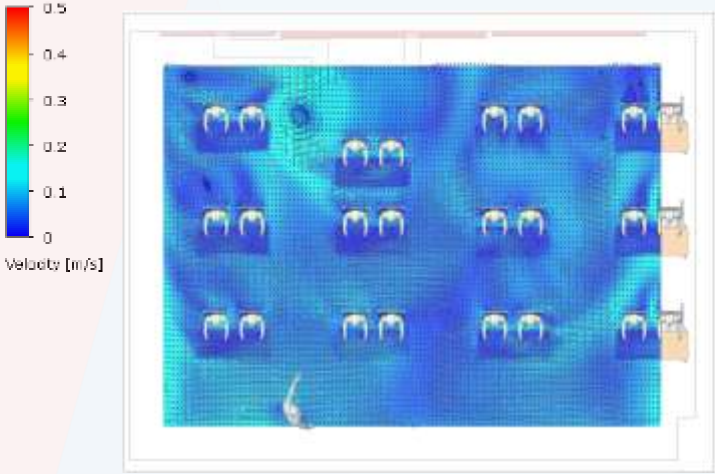
Cut plots – 0,1 m, 1,1 m, 0,6 m, 1,7 m – air velocity *(displayed interval 0-0,5 m/s)*



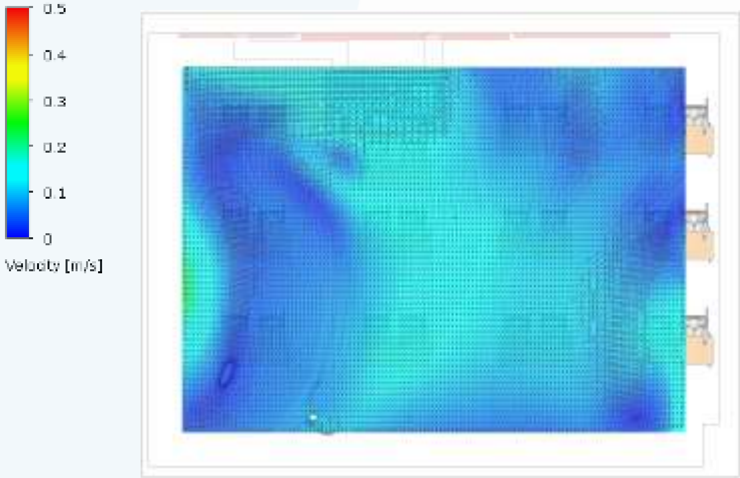
1- Cut plot – 0,1 m above the floor – air velocity



3 - Cut plot – 1,1 m above the floor – air velocity



2 - Cut plot – 0,6 m above the floor – air velocity



4 - Cut plot – 1,7 m above the floor – air velocity

CFD 1. Simulation variant

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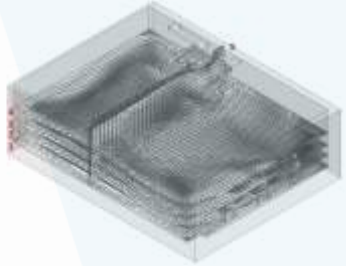
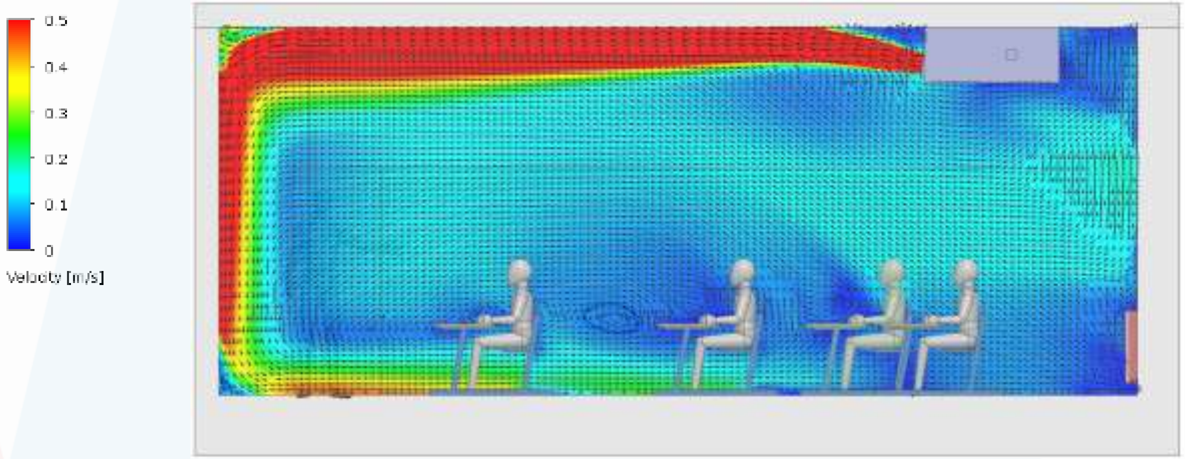
VS 500 SQ – Classroom

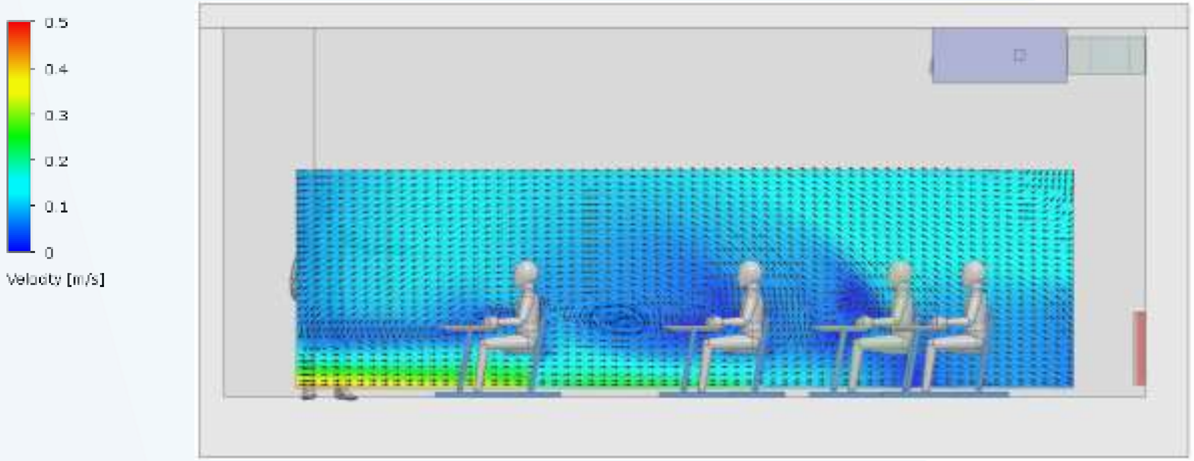
- **Cut plots – Air velocity**

Cut plot – through the center of the unit – air velocity *(displayed interval 0-0,5 m/s)*





5 - Cut plot – through the center of the unit **– air velocity** *(displayed interval 0-0,5 m/s)*

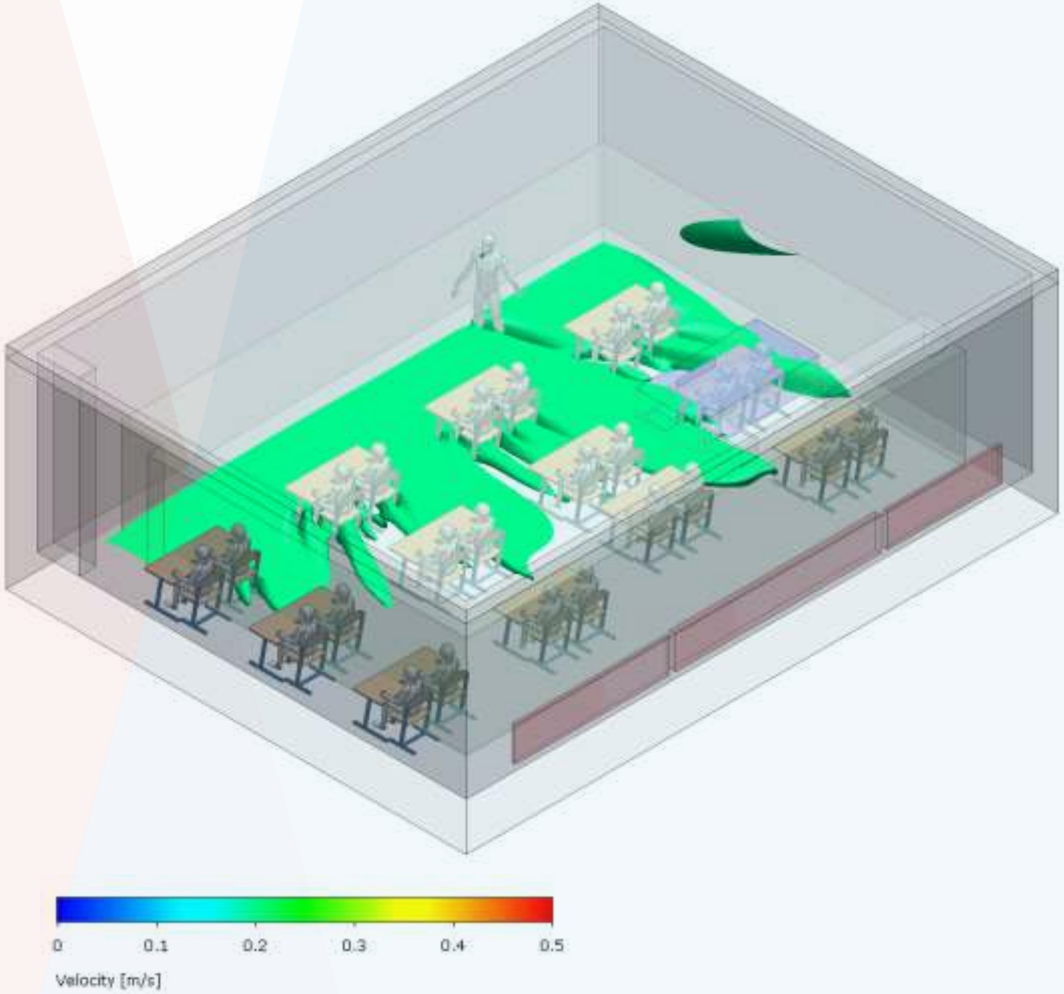


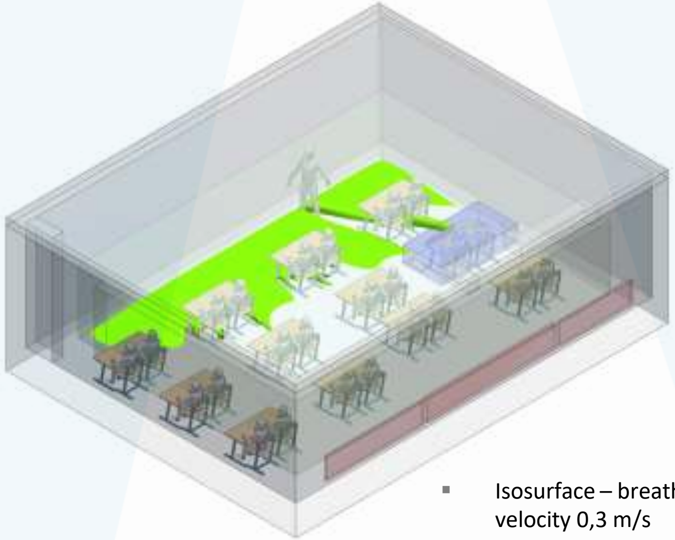
5 - Cut plot – through the center of the unit **– air velocity – breathing zone -** *(displayed interval 0-0,5 m/s)*

CFD 1. Simulation variant

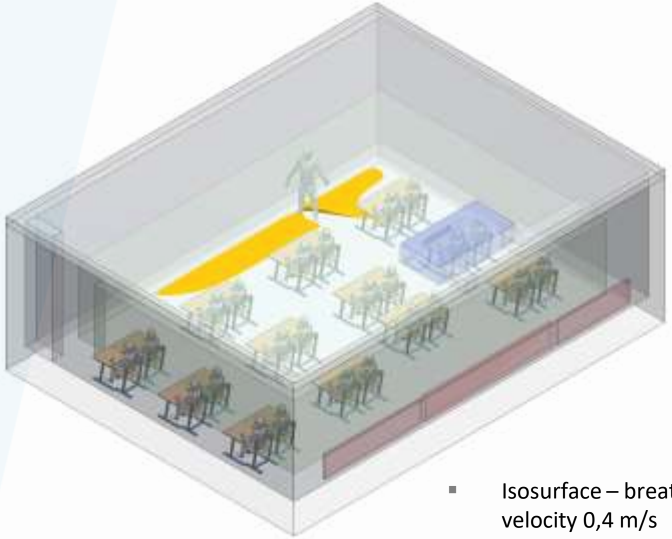
VS 500 SQ – Classroom

- Isosurface – air velocity 0,2 m/s – breathing *(residential)* - zone





- Isosurface – breathing zone - air velocity 0,3 m/s



- Isosurface – breathing zone - air velocity 0,4 m/s

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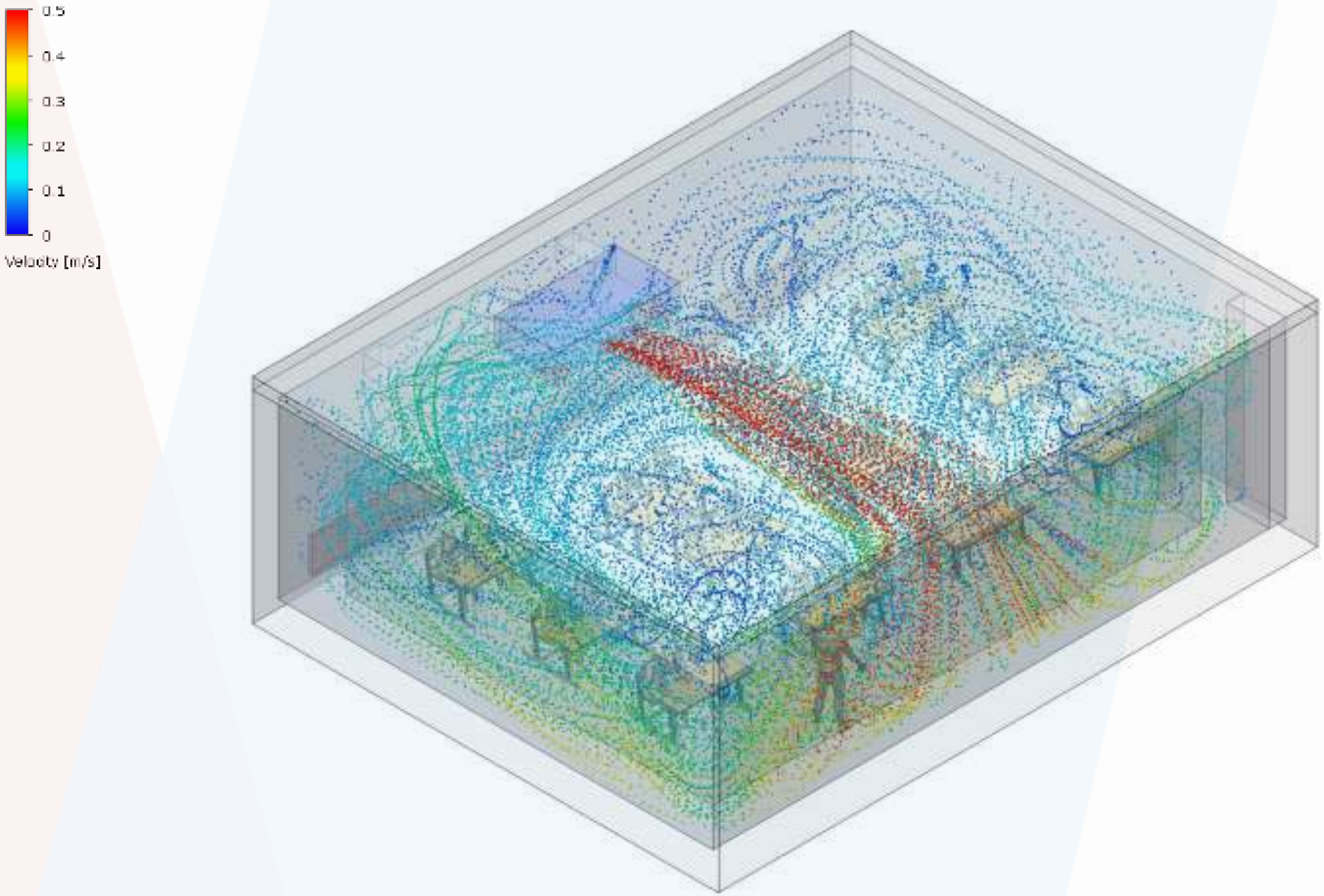
CFD 1. Simulation variant

VS 500 SQ – Classroom

- Flow trajectories colored by air velocity *(displayed interval 0-0,5 m/s)*



CFD 2. Simulation variant

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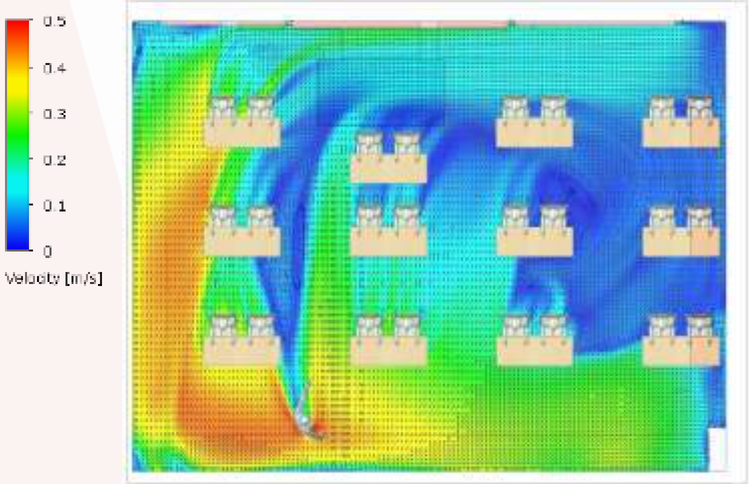
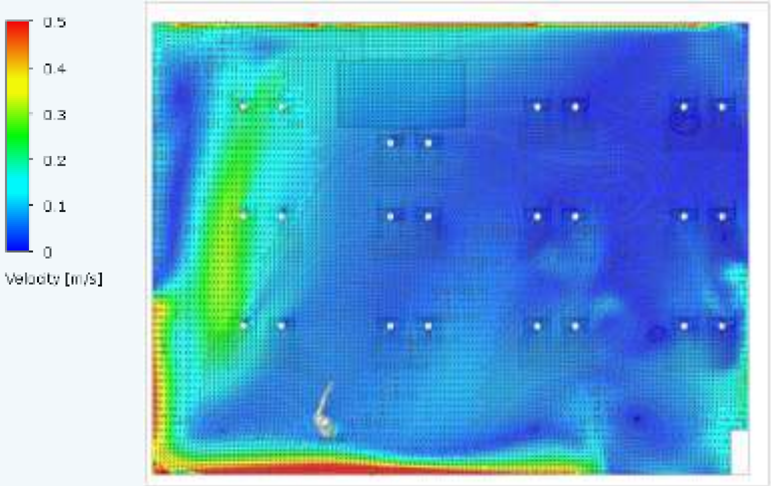
VS 500 SQ – Classroom

- Cut plots – Air velocity

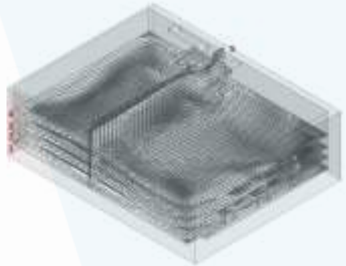
Cut plots – 0,1 m, 1,1 m, 0,6 m, 1,7 m – air velocity *(displayed interval 0-0,5 m/s)*

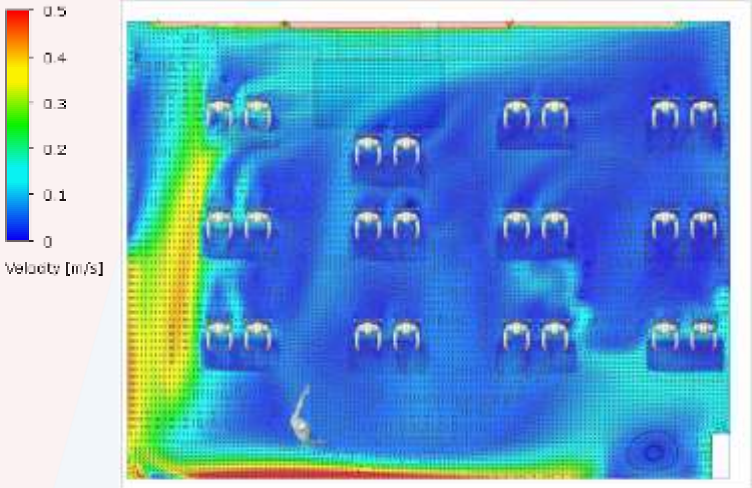


1- Cut plot – 0,1 m above the floor – air velocity

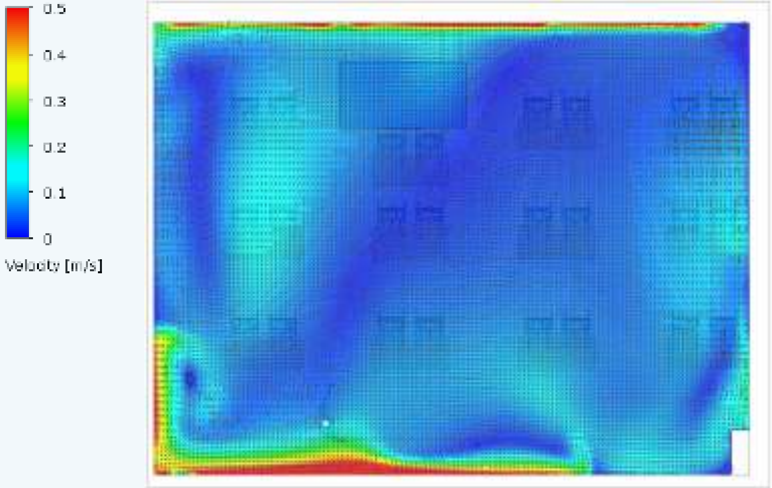


3 - Cut plot – 1,1 m above the floor – air velocity





2 - Cut plot – 0,6 m above the floor – air velocity



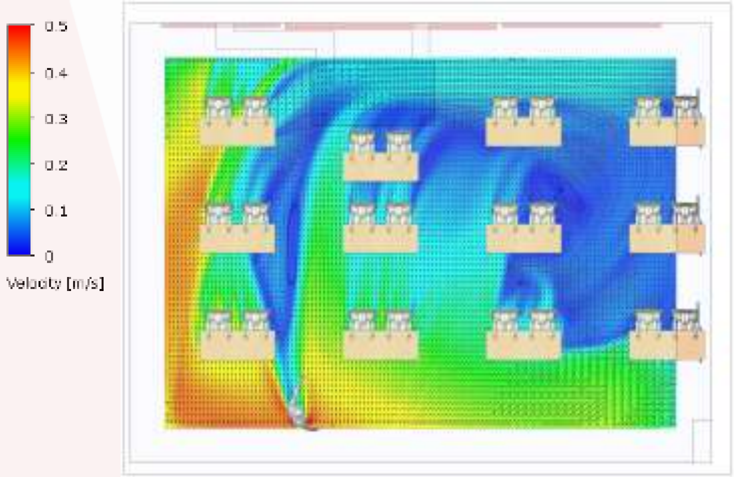
4 - Cut plot – 1,7 m above the floor – air velocity

CFD 2. Simulation variant

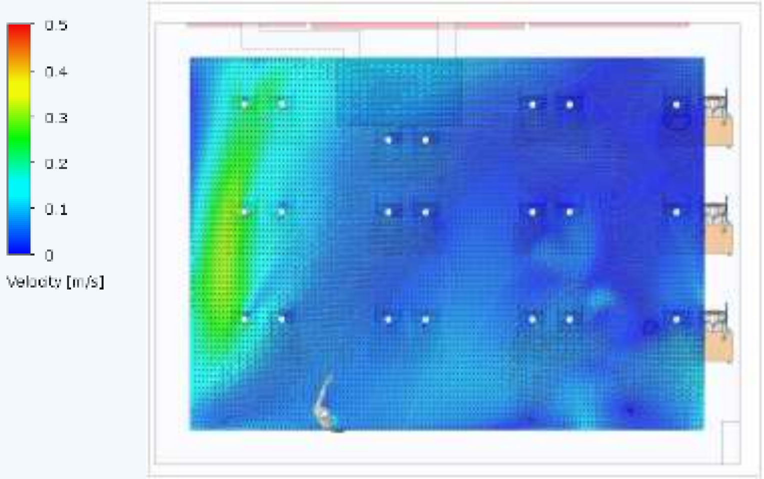
VS 500 SQ – Classroom

- Cut plots – Air velocity – breathing zone

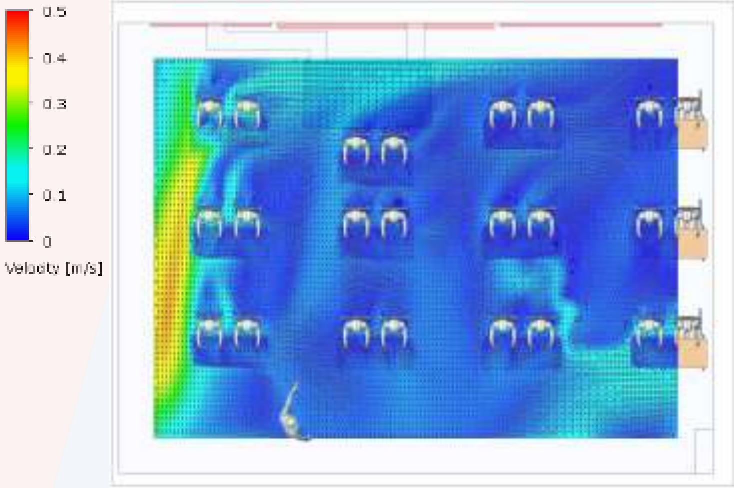
Cut plots – 0,1 m, 1,1 m, 0,6 m, 1,7 m – air velocity *(displayed interval 0-0,5 m/s)*



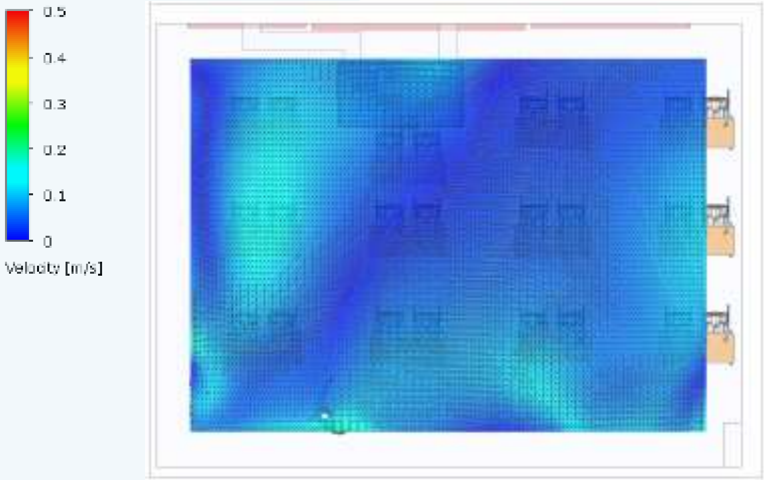
1- Cut plot – 0,1 m above the floor – air velocity



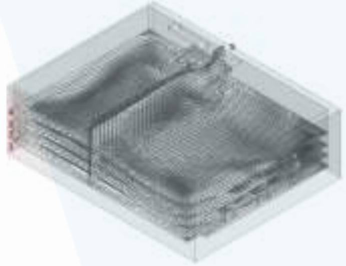
3 - Cut plot – 1,1 m above the floor – air velocity



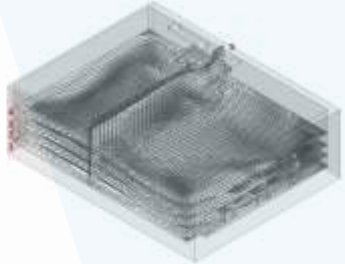
2 - Cut plot – 0,6 m above the floor – air velocity



4 - Cut plot – 1,7 m above the floor – air velocity



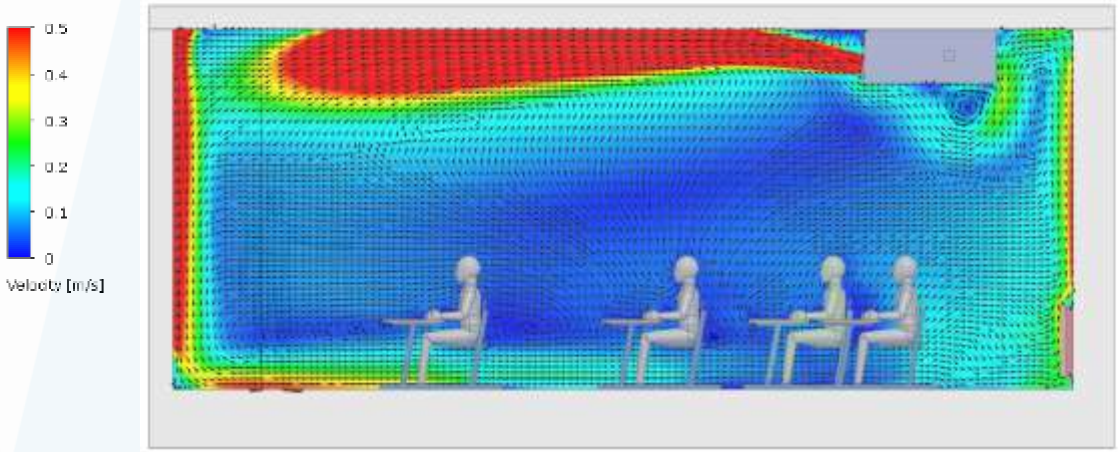
CFD 2. Simulation variant



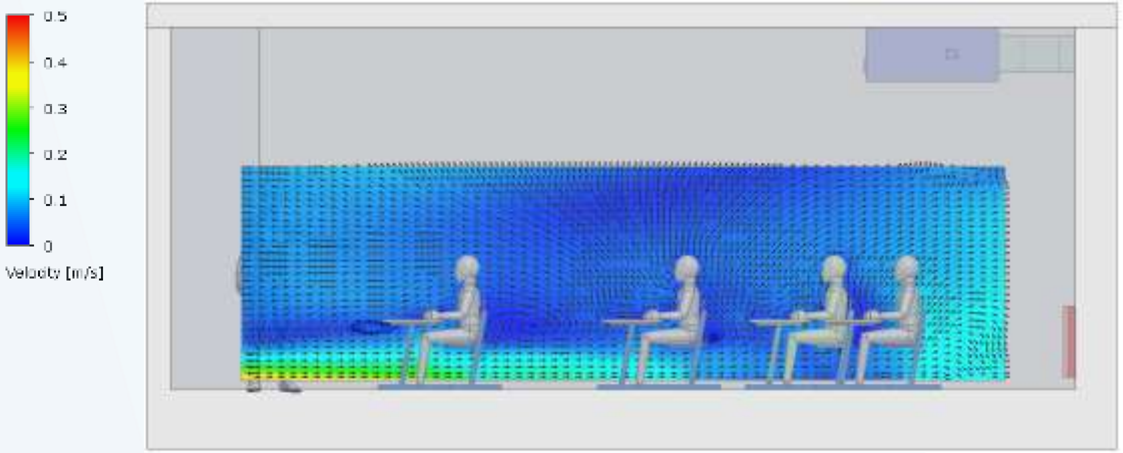
VS 500 SQ – Classroom

- Cut plots – Air velocity

Cut plot – through the center of the unit – air velocity *(displayed interval 0-0,5 m/s)*



5 - **Cut plot** – through the center of the unit – **air velocity** *(displayed interval 0-0,5 m/s)*



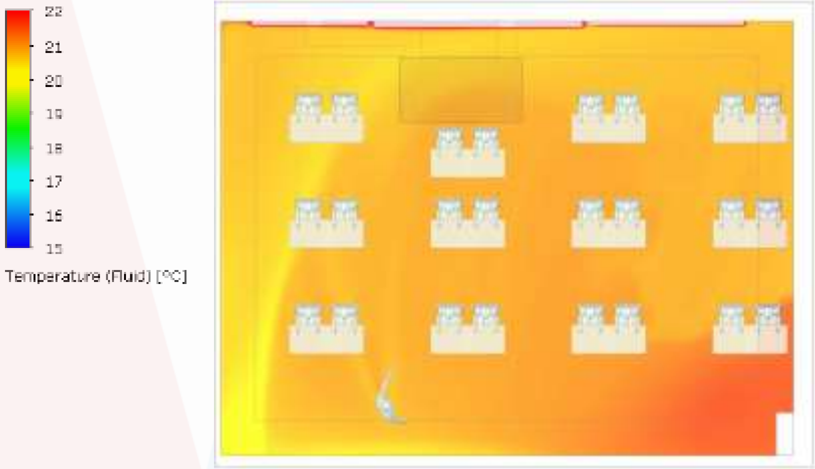
5 - **Cut plot** – through the center of the unit – **air velocity** – **breathing zone** - *(displayed interval 0-0,5 m/s)*

CFD 2. Simulation variant

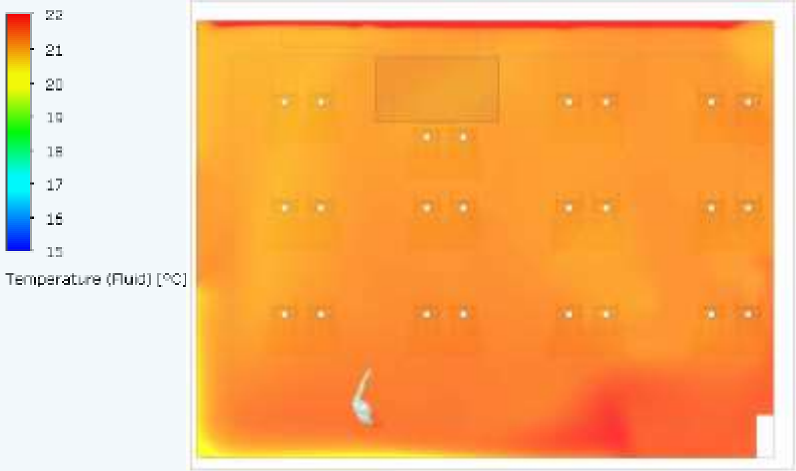
VS 500 SQ – Classroom

- Cut plots – Air temperature

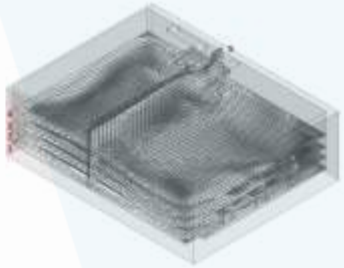
Cut plots – 0,1 m, 1,1 m, 0,6 m, 1,7 m – air temperature *(displayed interval 15-22°C)*

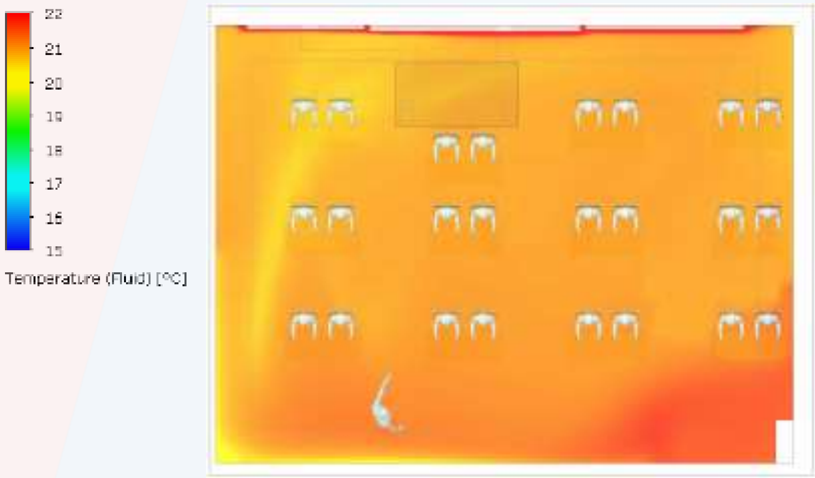


1- Cut plot – 0,1 m above the floor – air temperature

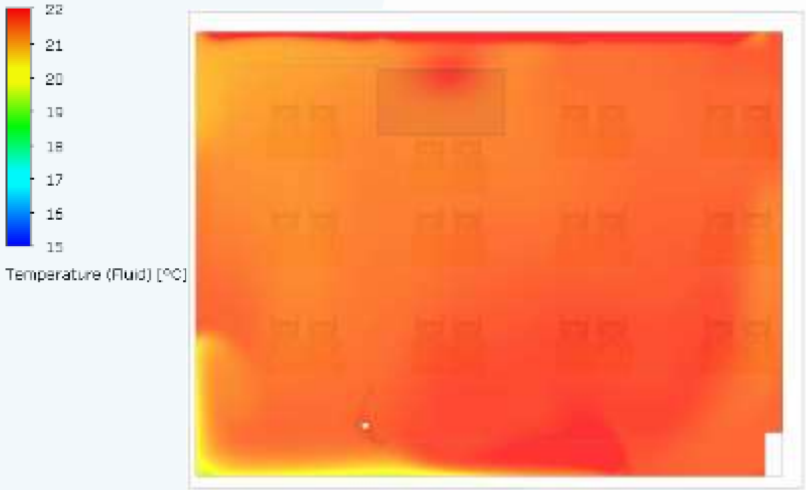


3 - Cut plot – 1,1 m above the floor – air temperature





2 - Cut plot – 0,6 m above the floor – air temperature



4 - Cut plot – 1,7 m above the floor – air temperature

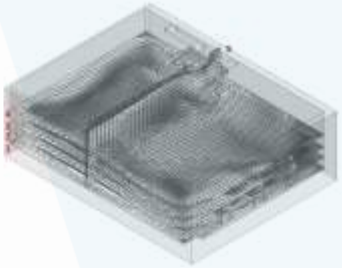
CFD 2. Simulation variant

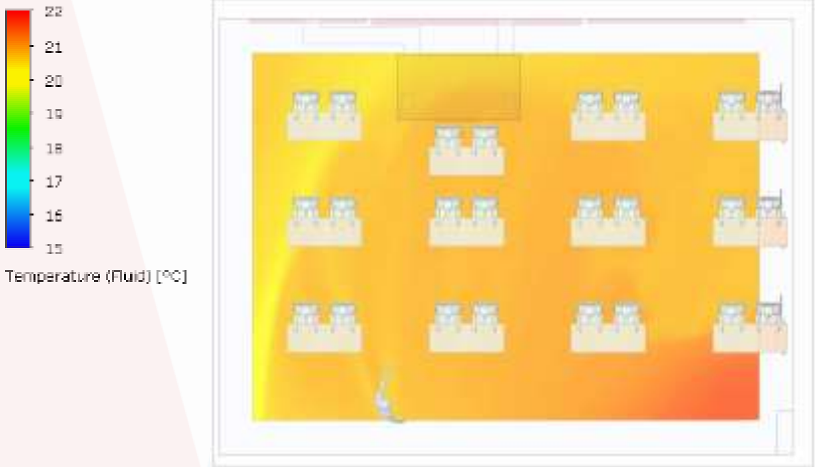
PARTNER
IN VENTILATION
2VV.CZ

VS 500 SQ – Classroom

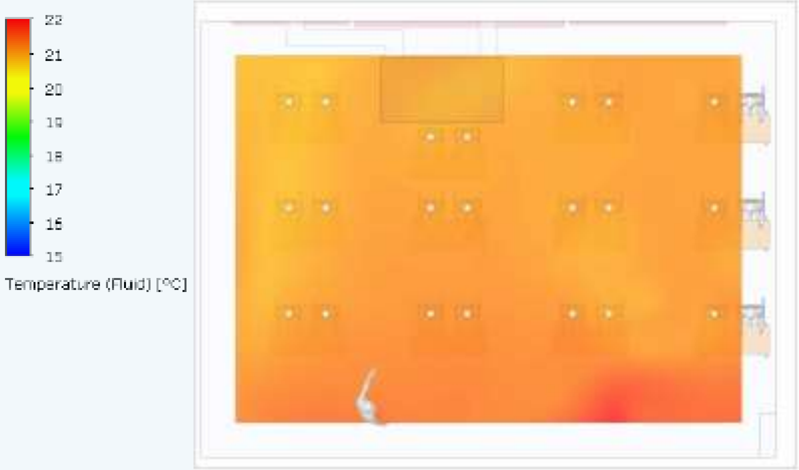
- **Cut plots – Air temperature – breathing zone**

Cut plots – 0,1 m, 1,1 m, 0,6 m, 1,7 m – air temperature *(displayed interval 15-22°C)*

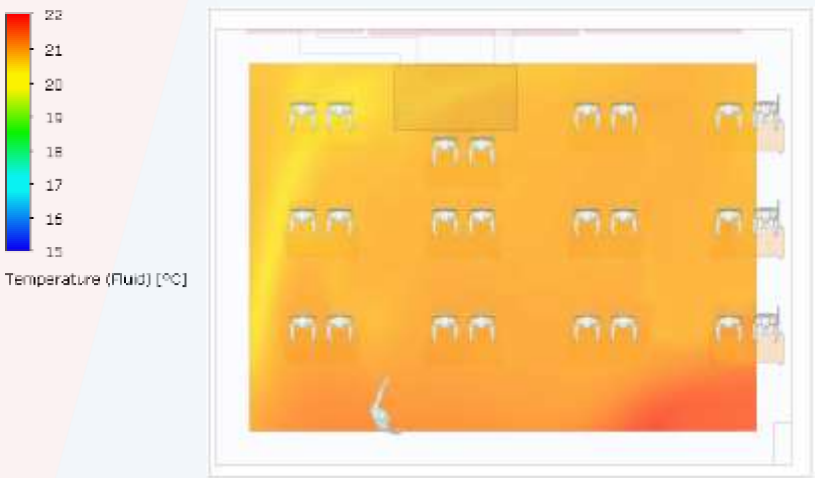




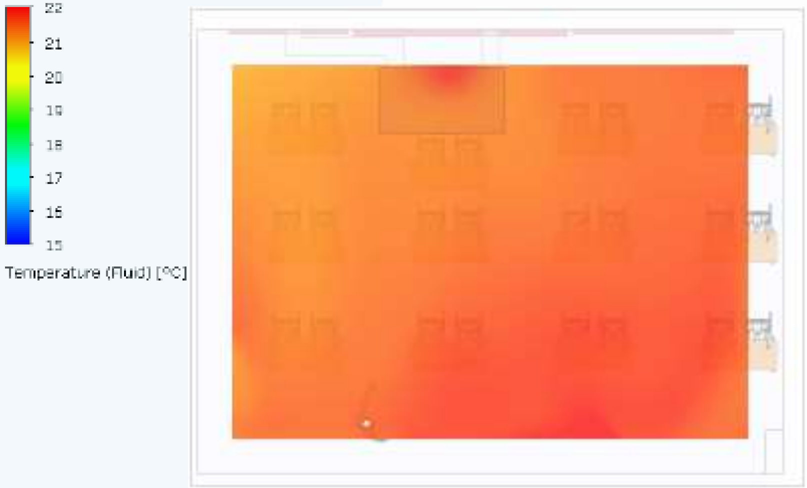
1- Cut plot – 0,1 m above the floor – air temperature



3 - Cut plot – 1,1 m above the floor – air temperature



2 - Cut plot – 0,6 m above the floor – air temperature



4 - Cut plot – 1,7 m above the floor – air temperature

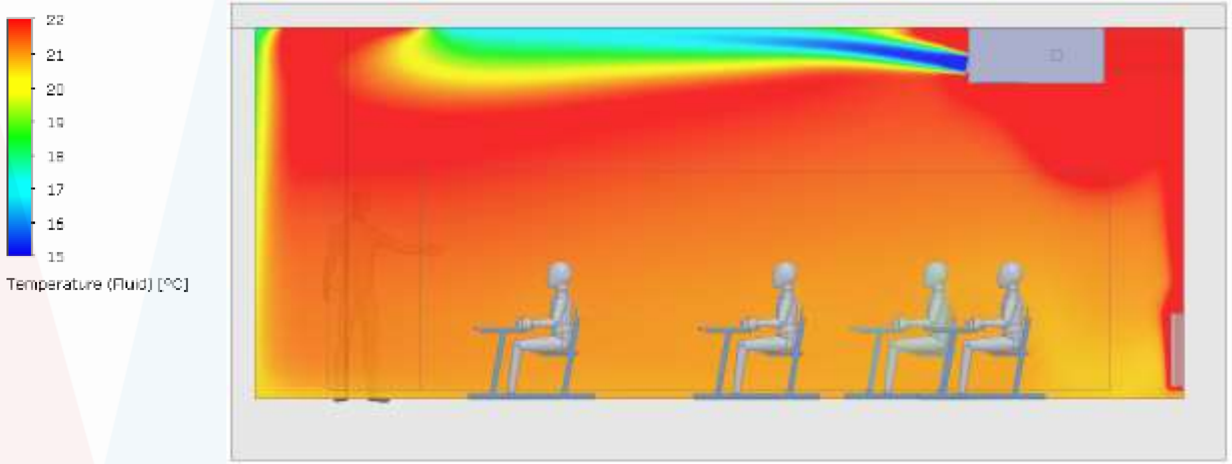
CFD 2. Simulation variant

PARTNER
IN VENTILATION
2VV.CZ

VS 500 SQ – Classroom

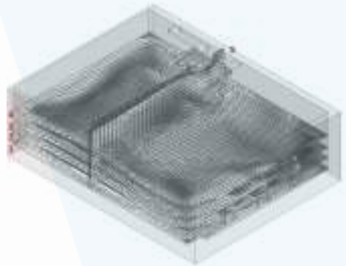
- **Cut plots – Air temperature**

Cut plot – through the center of the unit – air temperature *(displayed interval 15-22°C)*



5 - Cut plot – through the center of the unit **– air temperature** *(displayed interval 15-22°C)*

5 - Cut plot – through the center of the unit **– air temperature – breathing zone -** *(displayed interval 15-22°C)*

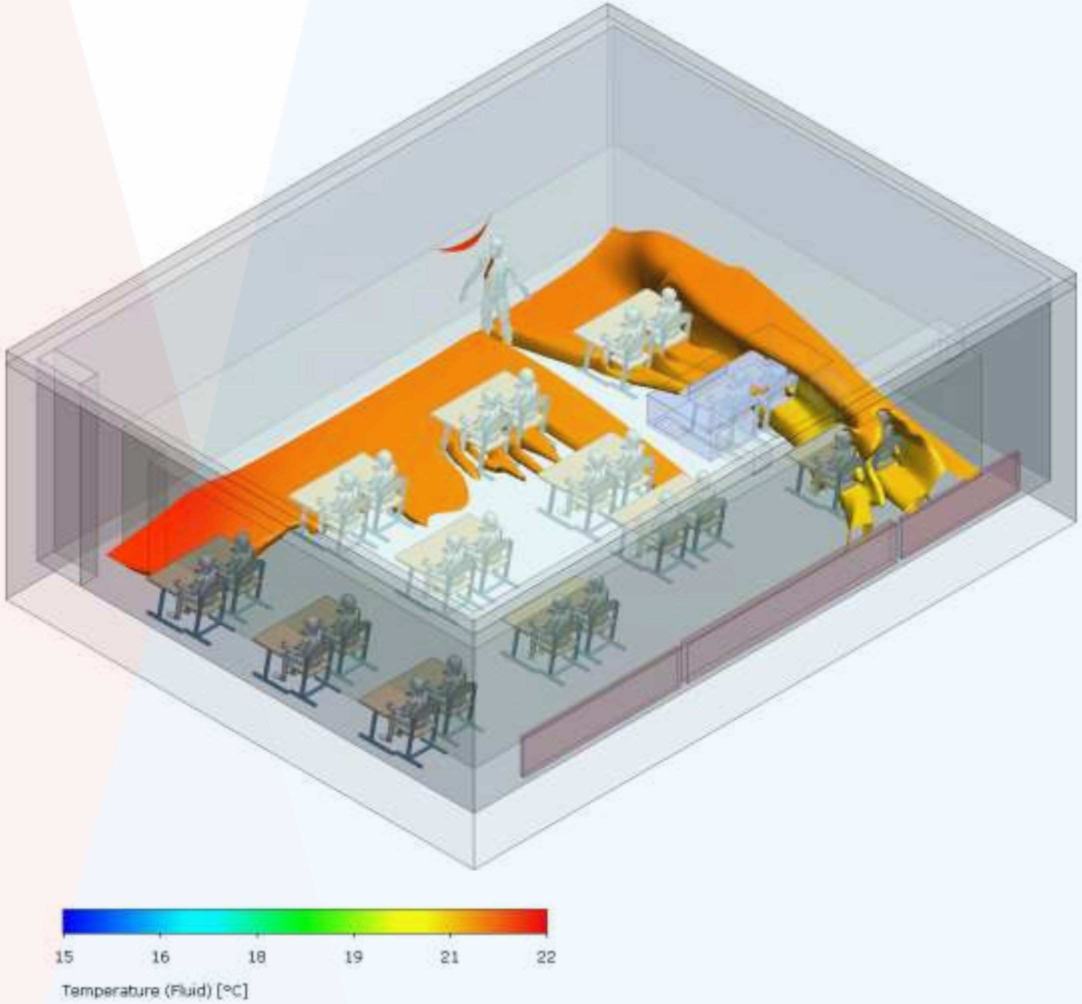


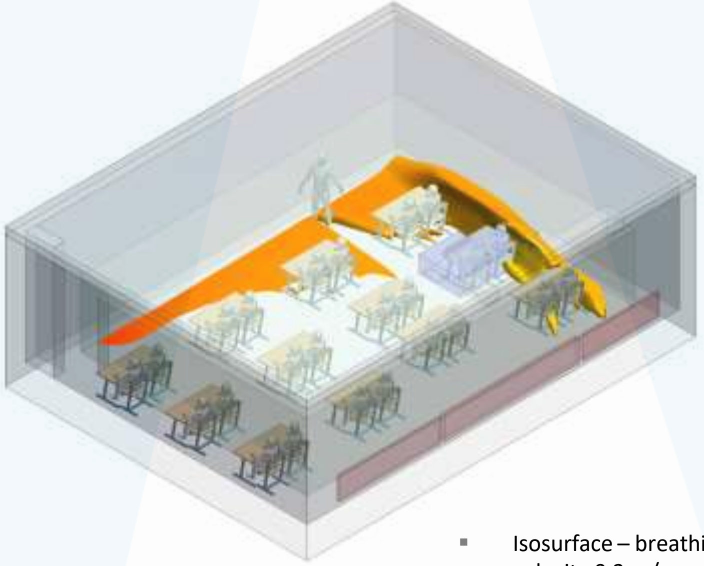
- The resulting average temperature in the classroom is 21,5 °C *(70,7 °F).*

CFD 2. Simulation variant

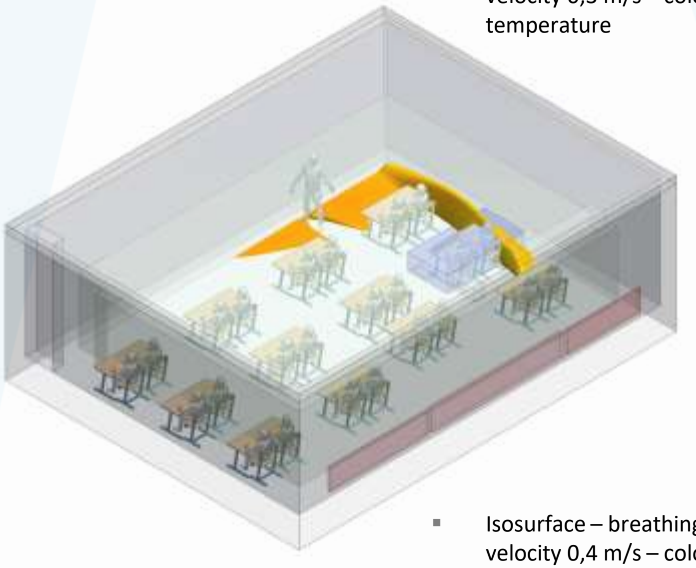
VS 500 SQ – Classroom

- **Isosurface – air velocity 0,2 m/s – colored by air temperature– breat *(residential)* - zone**





- Isosurface – breathing zone - air velocity 0,3 m/s – colored by air temperature



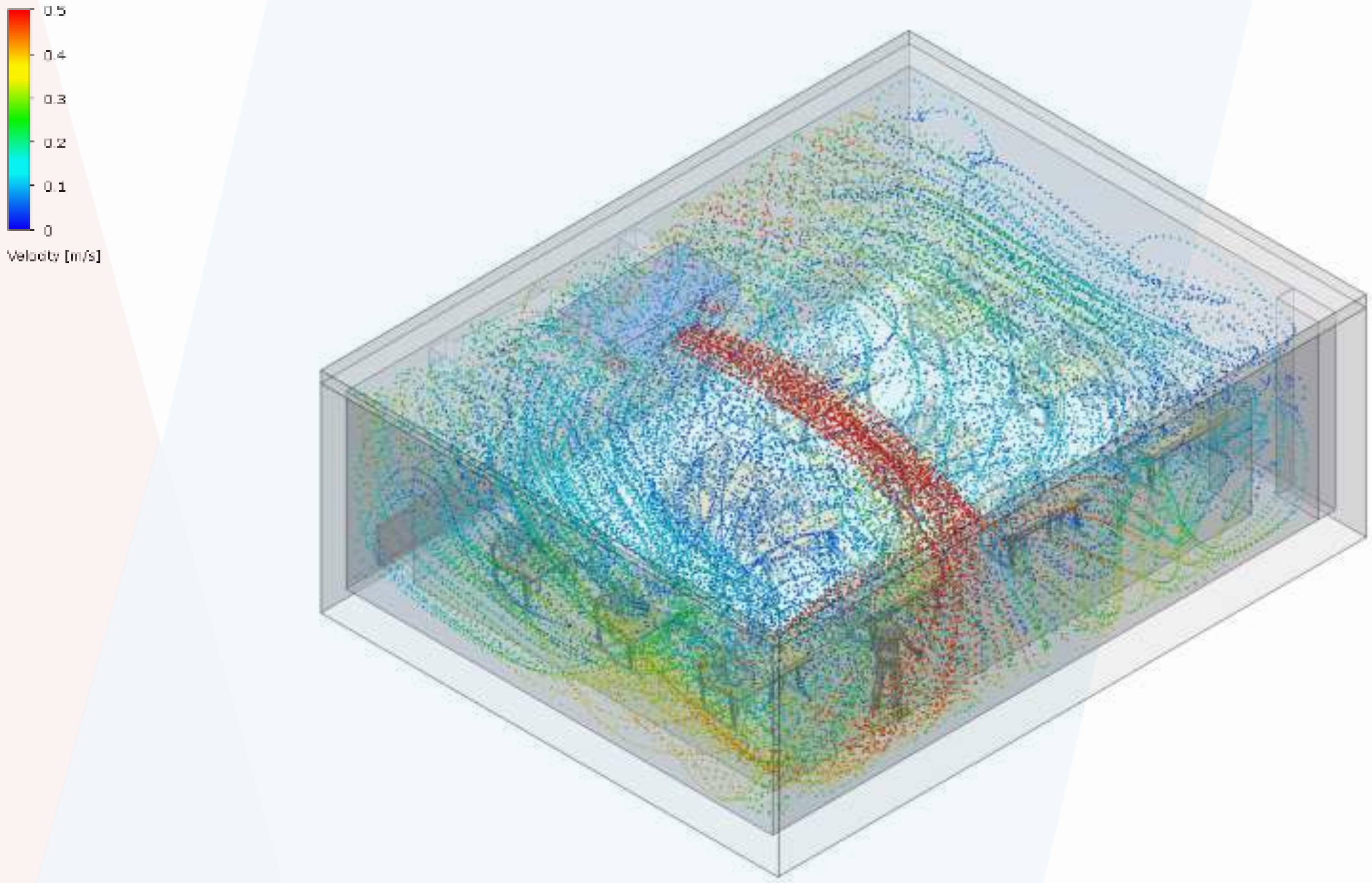
- Isosurface – breathing zone - air velocity 0,4 m/s – colored by air temperature

CFD 2. Simulation variant

PARTNER
IN VENTILATION
2VV.CZ

VS 500 SQ – Classroom

- **Flow trajectories colored by air velocity *(displayed interval 0-0,5 m/s)***



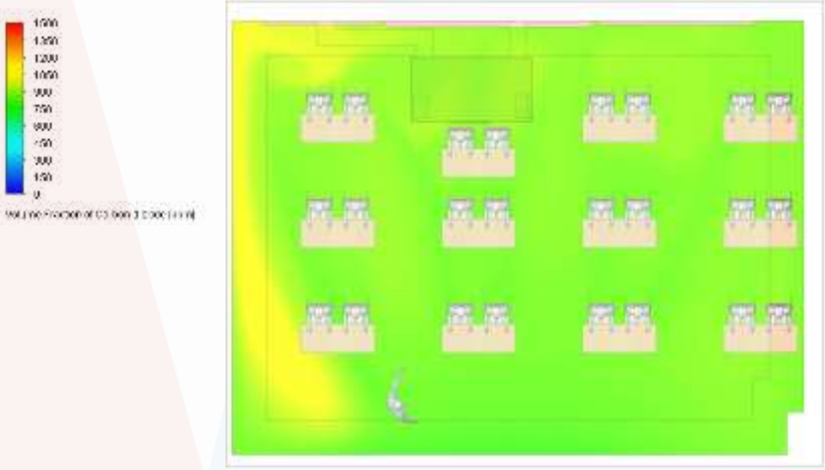
CFD 1. Simulation variant

PARTNER
IN VENTILATION
2VV.CZ

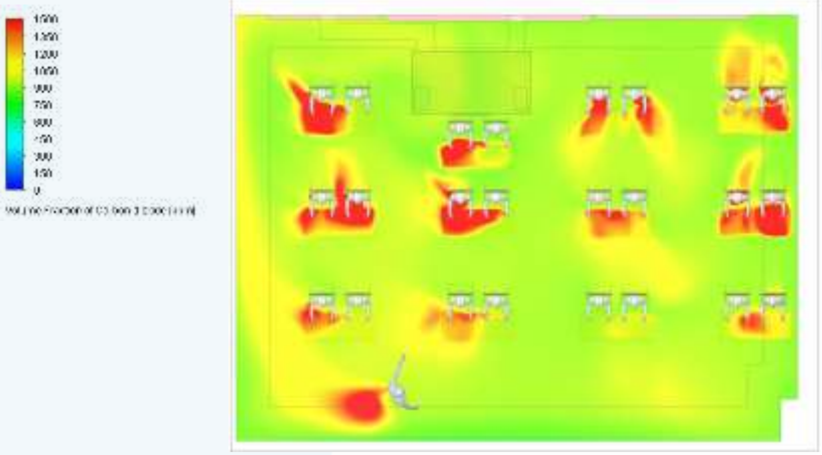
VS 500 SQ – Classroom

- Cut plots – CO_2 concentration

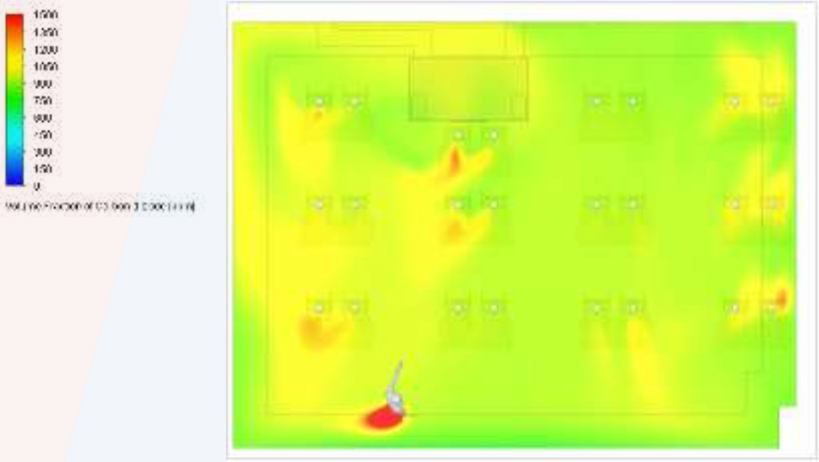
Cut plots – 0,1 m, 1,1 m, 0,6 m, 1,7 m – **CO_2 concentration** *(displayed interval 0-1500 ppm)*



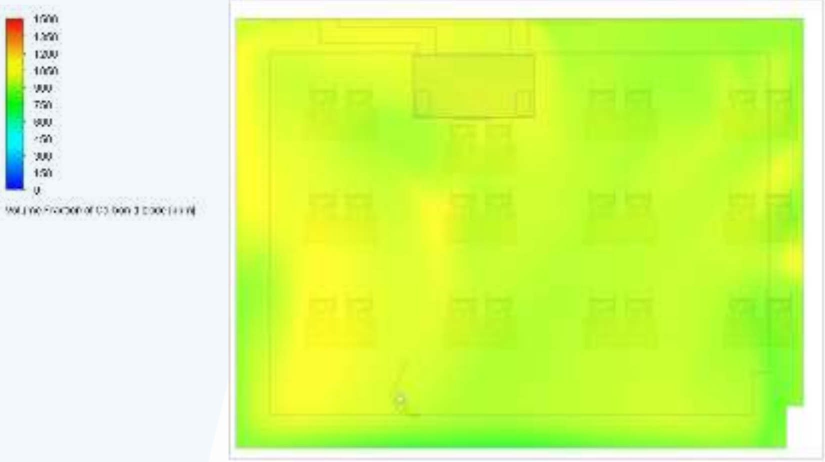
1- Cut plot – 0,1 m above the floor – CO_2 concentration



2 - Cut plot – 1,1 m above the floor – CO_2 concentration



3 - Cut plot – 0,6 m above the floor – CO_2 concentration



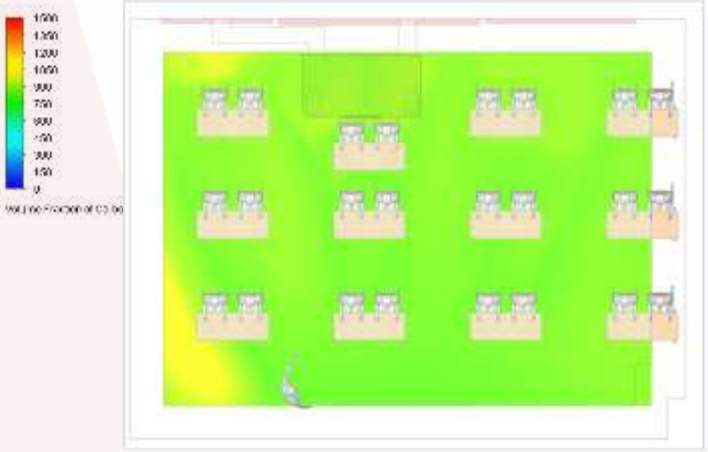
4 - Cut plot – 1,7 m above the floor – CO_2 concentration

CFD 1. Simulation variant

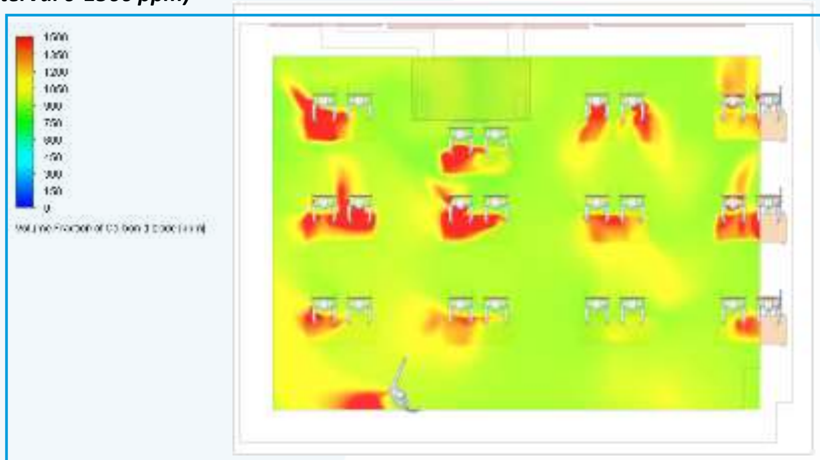
VS 500 SQ – Classroom

- Cut plots – breathing zone - CO_2 concentration

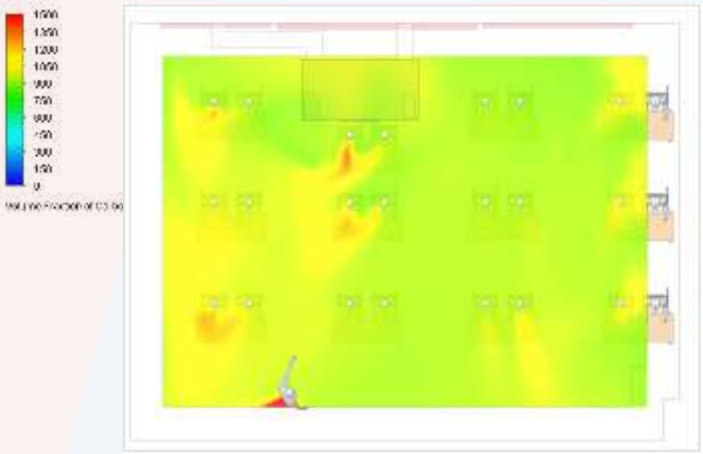
Cut plots – 0,1 m, 1,1 m, 0,6 m, 1,7 m – **CO_2 concentration** *(displayed interval 0-1500 ppm)*



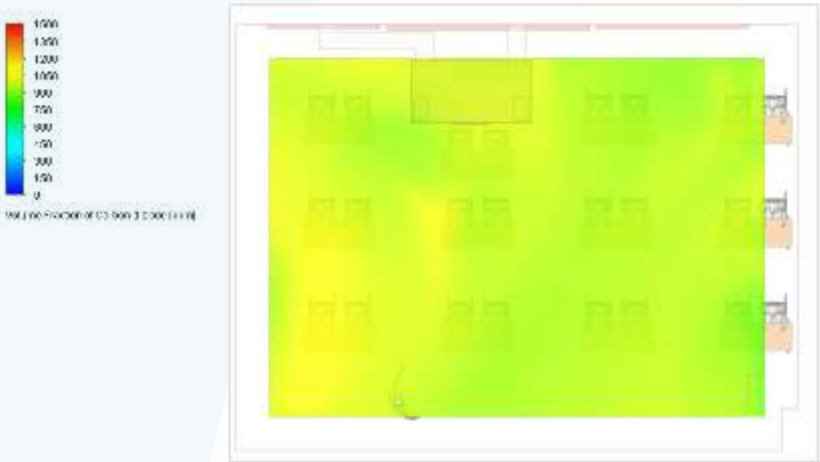
1- Cut plot – 0,1 m above the floor – CO_2 concentration



2 - Cut plot – 1,1 m above the floor – CO_2 concentration



3 - Cut plot – 0,6 m above the floor – CO_2 concentration



4 - Cut plot – 1,7 m above the floor – CO_2 concentration

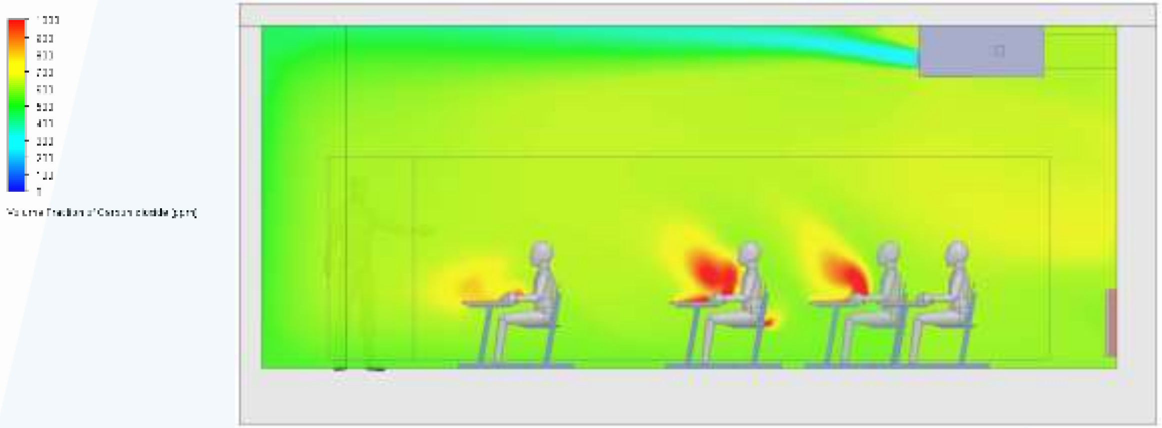
CFD 1. Simulation variant

PARTNER
IN VENTILATION
2VV.CZ

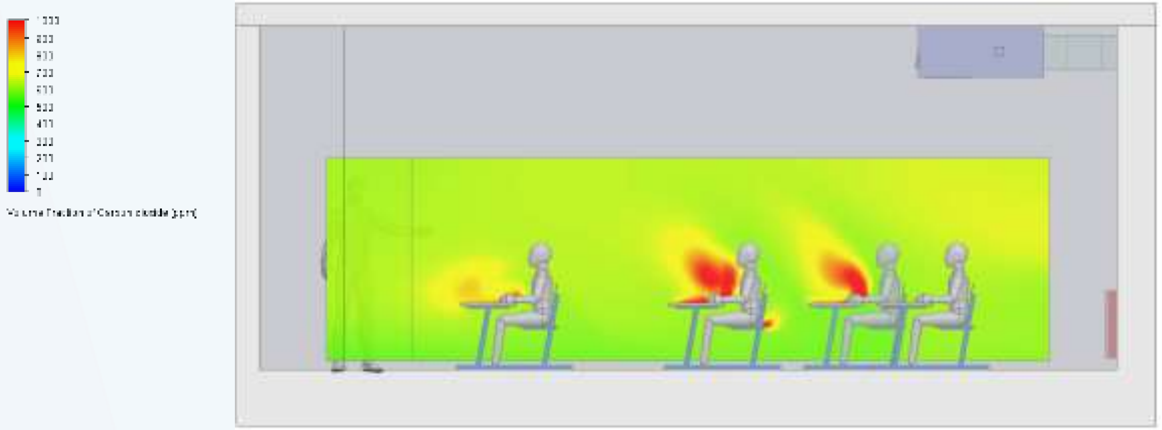
VS 500 SQ – Classroom

- Cut plots – CO_2 concentration

Cut plot – through the center of the unit – CO_2 concentration *(displayed interval 0-1500 ppm)*



5 - Cut plot – through the center of the unit – CO_2 concentration *(displayed interval 0-1500 ppm)*



5 - Cut plot – through the center of the unit **– air velocity – breathing zone** – CO_2 concentration *(displayed interval 0-1500 ppm)*

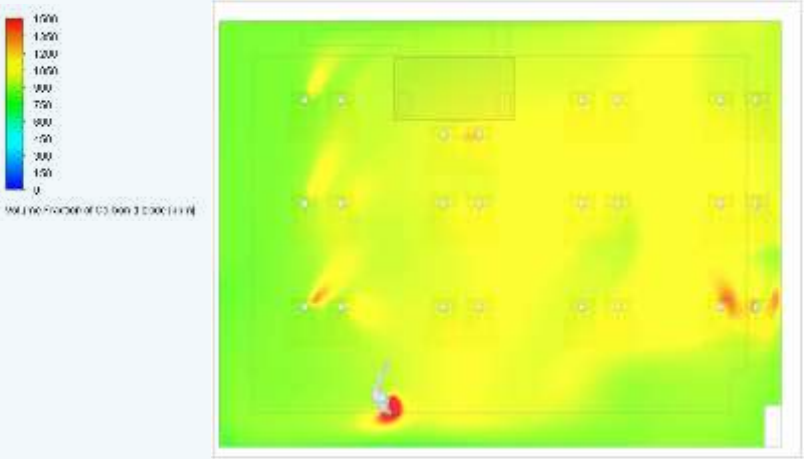
CFD 2. Simulation variant

VS 500 SQ – Classroom

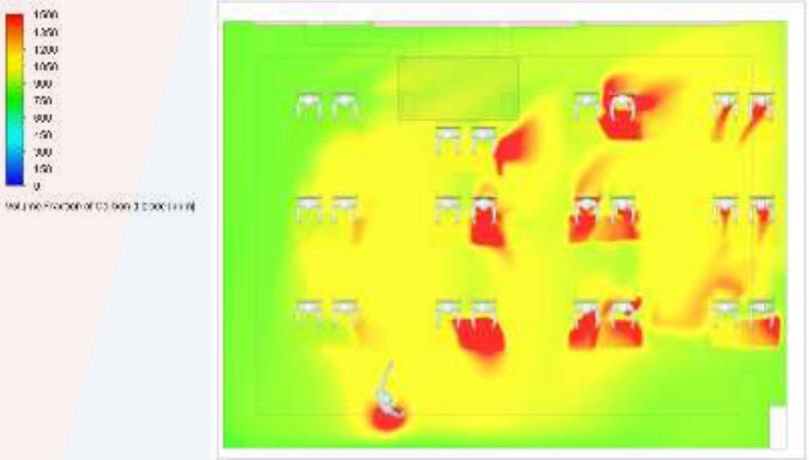
- Cut plots – CO_2 concentration

Cut plots – 0,1 m, 1,1 m, 0,6 m, 1,7 m – **CO_2 concentration** *(displayed interval 0-1500 ppm)*

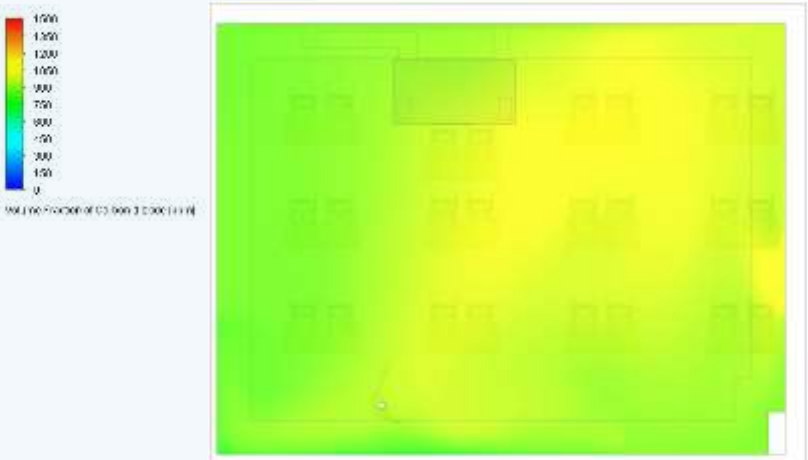
1- Cut plot – 0,1 m above the floor – CO_2 concentration



2 - Cut plot – 1,1 m above the floor – CO_2 concentration



3 - Cut plot – 0,6 m above the floor – CO_2 concentration



4 - Cut plot – 1,7 m above the floor – CO_2 concentration

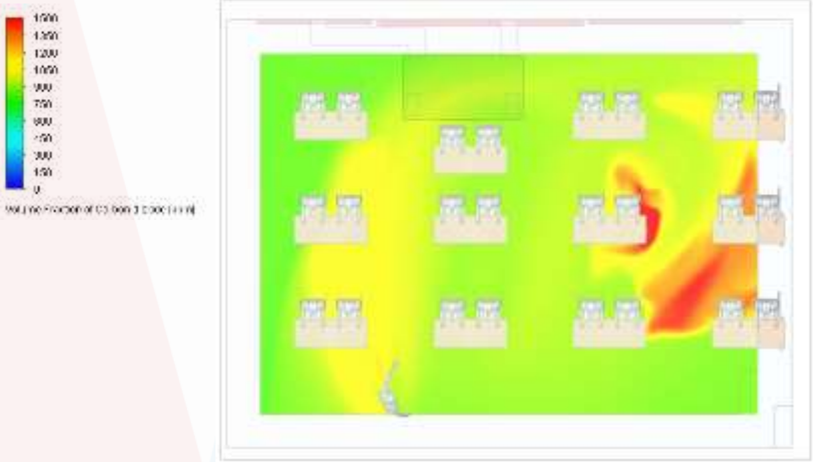
CFD 2. Simulation variant

PARTNER IN VENTILATION 2VV.CZ

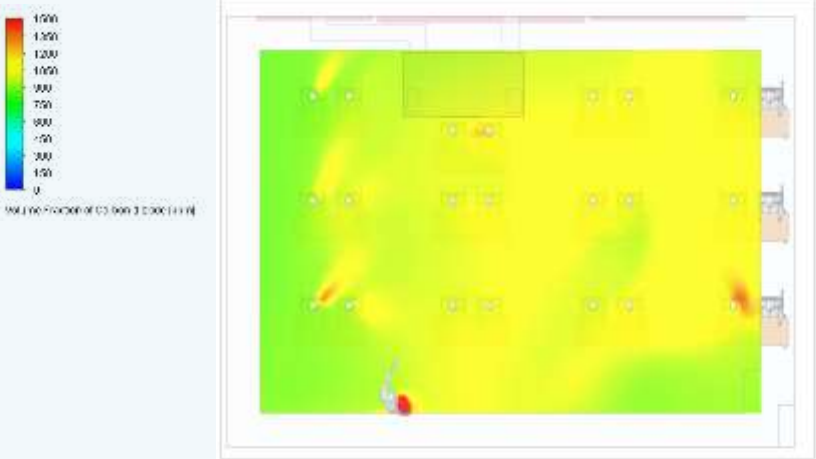
VS 500 SQ – Classroom

- Cut plots – breathing zone - CO_2 concentration

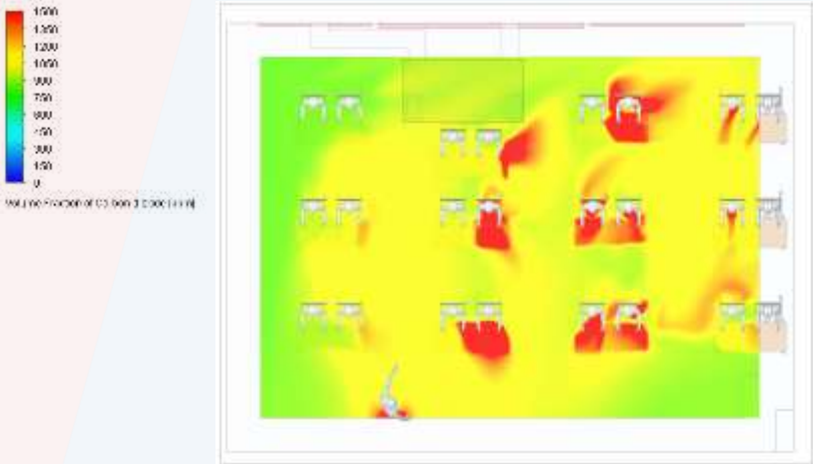
Cut plots – 0,1 m, 1,1 m, 0,6 m, 1,7 m – **CO_2 concentration** *(displayed interval 0-1500 ppm)*



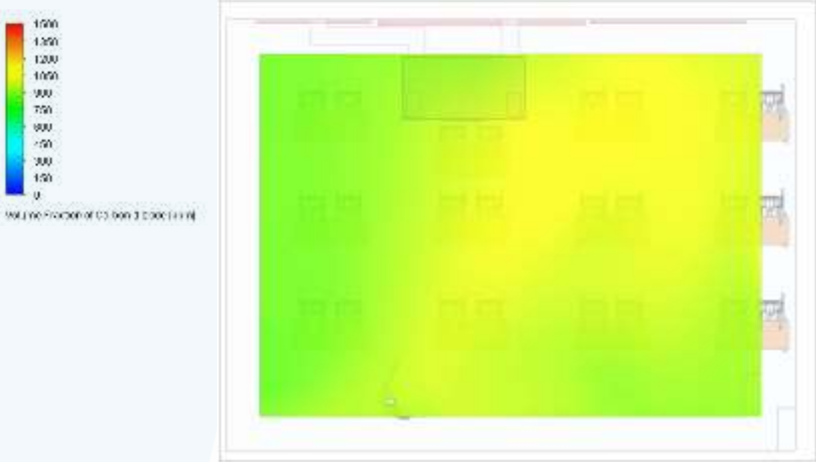
1- Cut plot – 0,1 m above the floor – CO_2 concentration



2 - Cut plot – 1,1 m above the floor – CO_2 concentration



3 - Cut plot – 0,6 m above the floor – CO_2 concentration

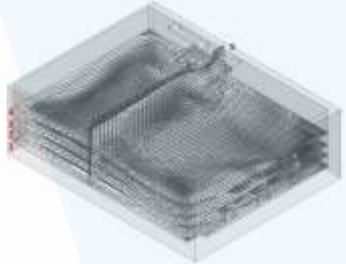


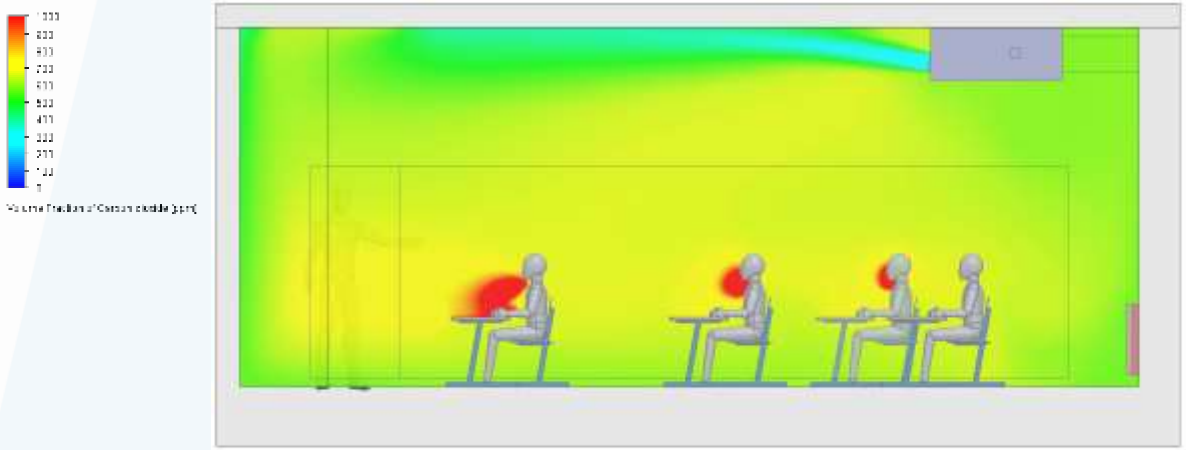
4 - Cut plot – 1,7 m above the floor – CO_2 concentration

VS 500 SQ – Classroom

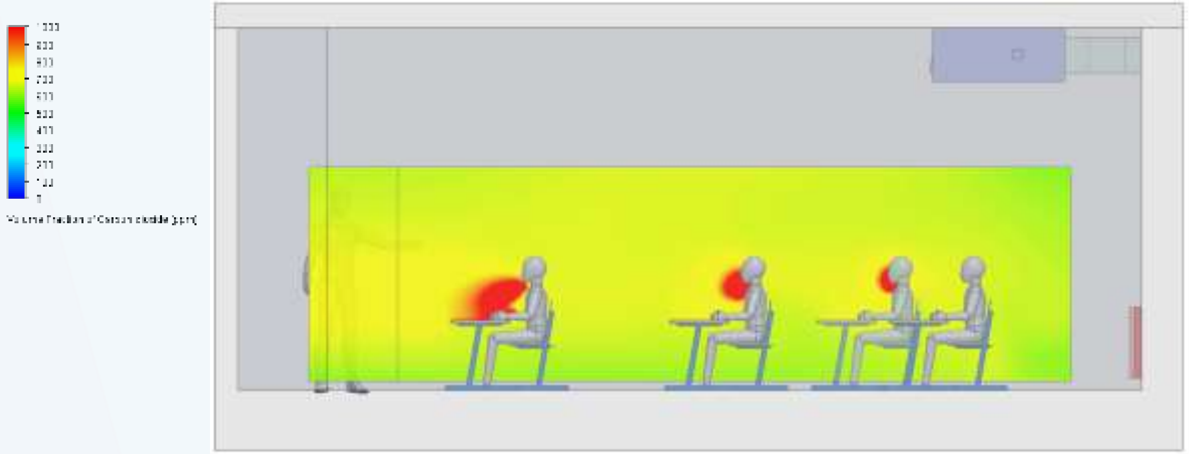
- Cut plots – CO_2 concentration

Cut plot – through the center of the unit – CO_2 concentration *(displayed interval 0-1500 ppm)*





5 - **Cut plot** – through the center of the unit – CO_2 concentration *(displayed interval 0-1500 ppm)*

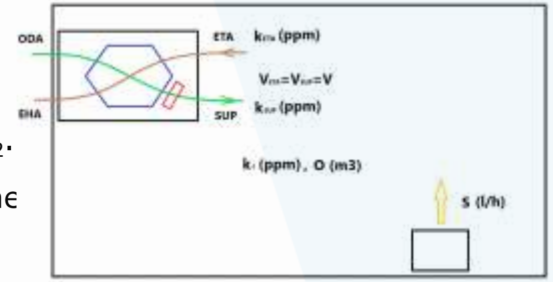


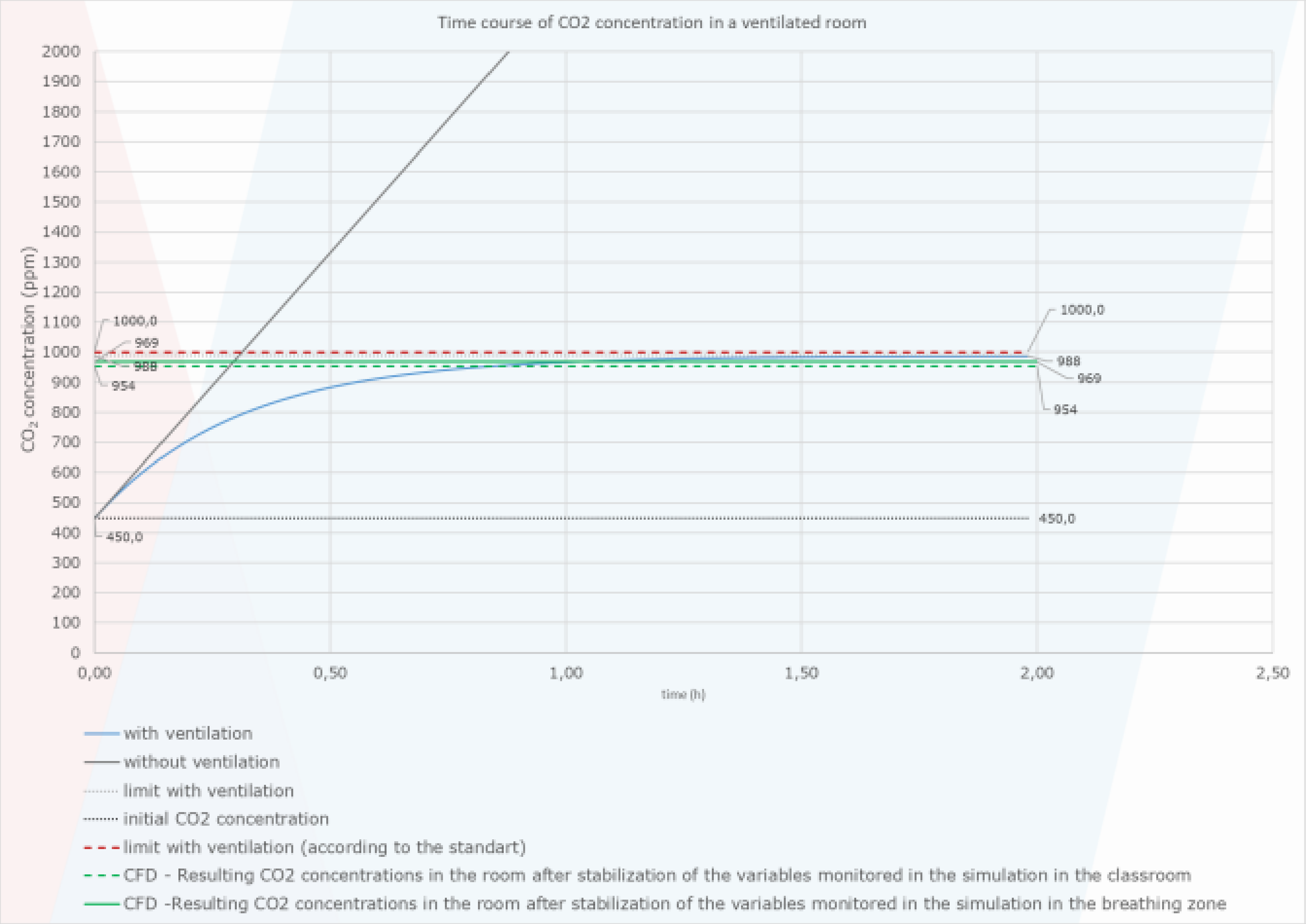
5 - **Cut plot** – through the center of the unit – **air velocity** – **breathing zone** – CO_2 concentration *(displayed interval 0-1500 ppm)*

Conclusion - balance sheet

CFD - VS 500 SQ – Classroom - Isothermal

- Comparison CFD with a theoretical computational model based on mass balance of CO_2.
- This model assumes perfect air mixing in the room, which means good ventilation in the classroom.



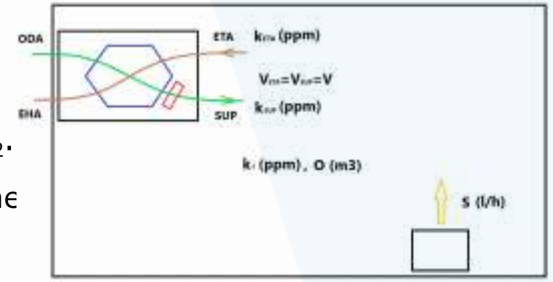


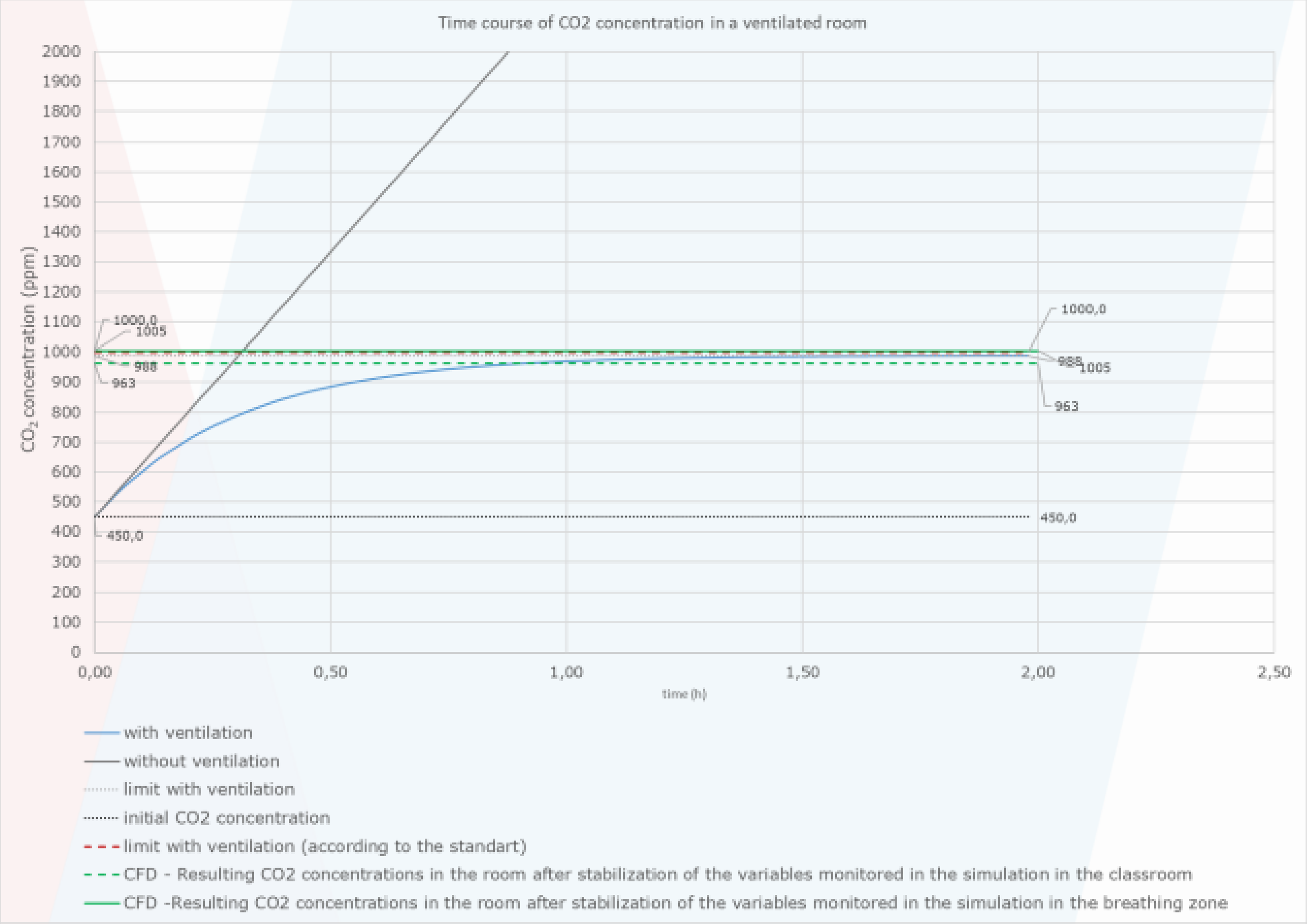
- By comparing the results of the theoretical calculation model and the results of the CFD simulations, it follows that the simulation shows *(after stabilization of the monitored physical quantities according to the set convergence criteria)* a similar average concentration of CO_2 in the monitored area of the classroom *(theoretical model CO_2 concentration 988 ppm and CFD 954 ppm),* which is around the upper limit of the limit 1000 ppm. **The average concentration of CO_2 in the CFD** *(after stabilization of the monitored physical quantities according to the set convergence criteria)* **simulation in the breathing zone is 969 ppm.**

Conclusion - balance sheet

CFD - VS 500 SQ – Classroom – Non-Isothermal

- Comparison CFD with a theoretical computational model based on mass balance of CO_2.
- This model assumes perfect air mixing in the room, which means good ventilation in the classroom.





- By comparing the results of the theoretical calculation model and the results of the CFD simulations, it follows that the simulation shows *(after stabilization of the monitored physical quantities according to the set convergence criteria)* a similar average concentration of CO_2 in the monitored area of the classroom *(theoretical model CO_2 concentration 988 ppm and CFD 963 ppm),* which is around the upper limit of the limit 1000 ppm.
- By comparing the results of the first simulation *(isothermal)* variant with the non-isothermal variant of the simulation, **the average concentration of CO2 in the breathing zone is higher - 1005 ppm - over the limit 1000 ppm *(isothermal variant 969 ppm)*.**

Conclusion - balance sheet

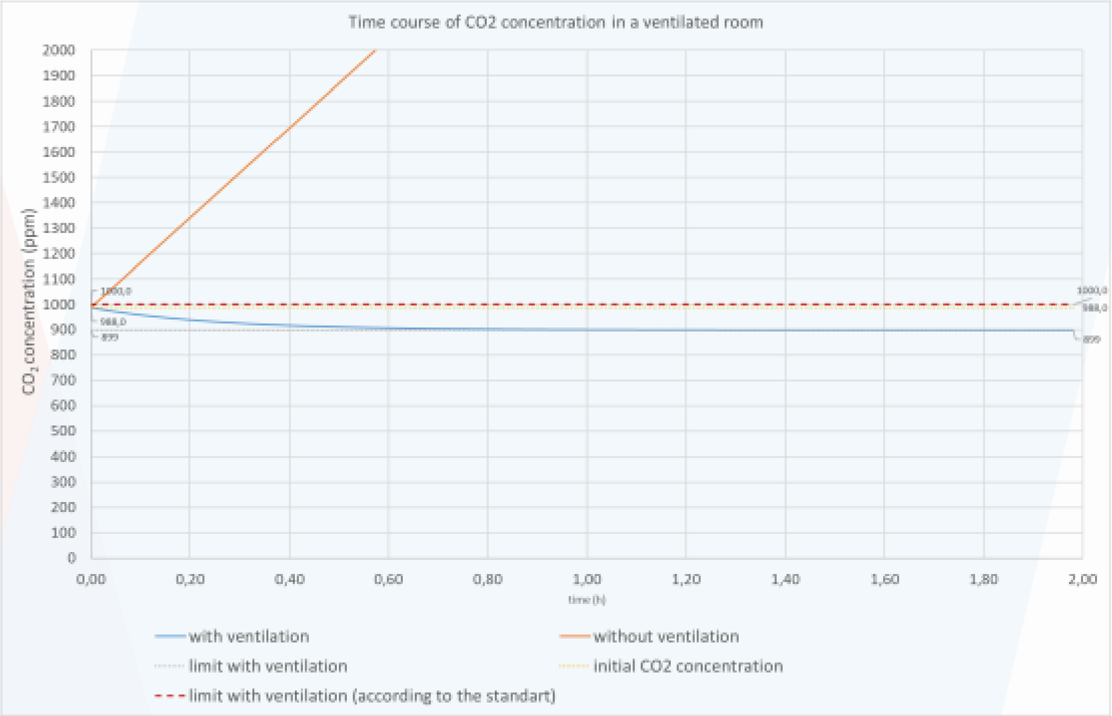
CFD - VS 500 SQ - Classroom

- The simulations show the use of the heat recovery ventilation unit VS 500 SQ under the given initial and boundary conditions.
- The non-isothermal simulation shows the effect of heating on the distribution of air flow velocity in the classroom.
- The theoretical calculation and the performed simulations show that when using the ventilation unit VS 500 SQ, with an air flow of 450 cfm *(764.55 m^3/h),* we are on the limit for a CO_2 concentration 1000 ppm set by Canadian legislation.
- The resulting concentration of CO_2 depends on the CO_2 production of people *(activity and age of people in the classroom)* and on the concentration of CO_2 in the supplied outdoor air - any deterioration of the mentioned parameters will lead to a deterioration to exceeding the CO_2 limit.

Conclusion - balance sheet

CFD - VS 500 SQ - Classroom

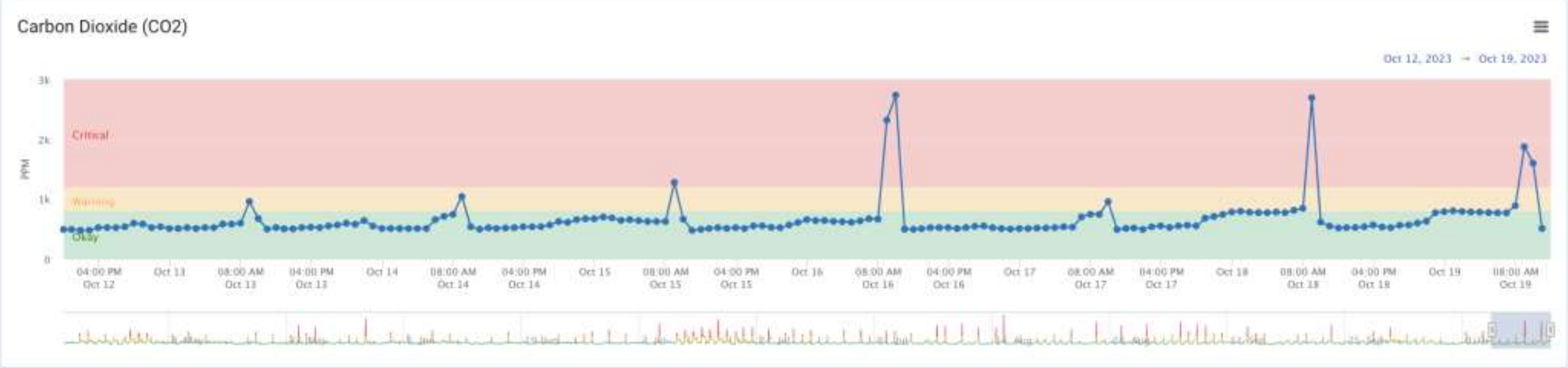
- Increased ventilation 539 cfm *(915,77 m³/h - boost)* during breaks can theoretically reduce classroom CO_2 concentrations by up to 90 ppm *(around 900 ppm)* in 45 minutes. During the lesson, the CO_2 concentration *(under the given conditions)* in the classroom will return to the 1000 ppm limit.



San Francisco High School

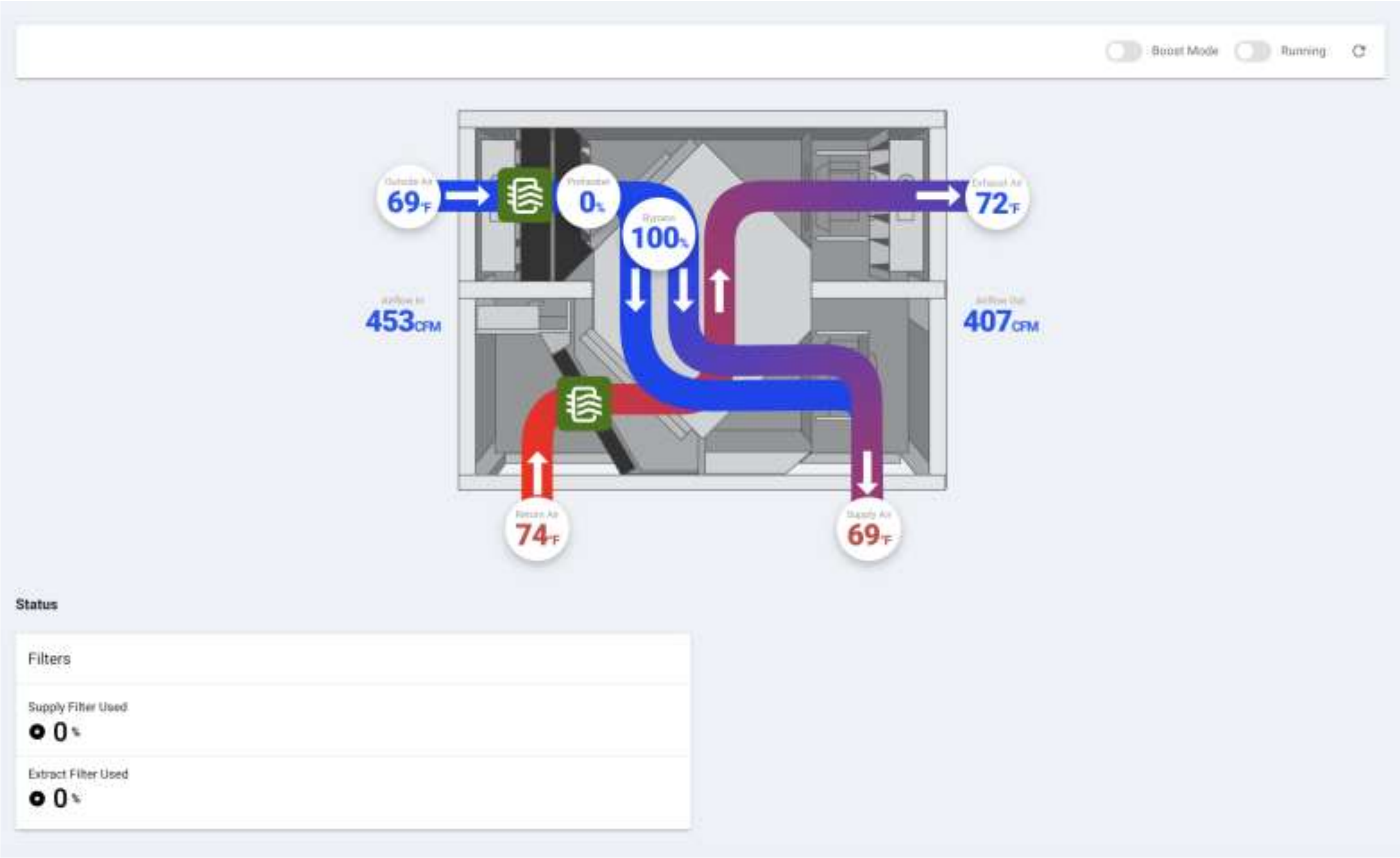
TMHS - SFUSD Readings			Class			Lunch			6800 cu. ft	At 430 cfm = 3.8 air changes per hour			
VS500 in Room 218			No class			Mtgs.							
Demand Controlled Ventilation													
			216			218			218				
Date		Time	Telaire			Telaire				Outside	Return	Supply	
Mode	CFM	of Day	Room T	CO2		Room T	CO2		CO2	Air	Air	Air	Bypass
Wed	160	7:00 AM	70	465		69	417		440	55	68	66	0
5.8.19	171	8:00 AM	70	487		69	421		440	55	68	66	0
DCV	170	8:30 AM	72	715		69	423		440	56	68	66	0
	158	9:00 AM	73	927		69	417		440	57	68	66	0
Mostly	158	9:20 AM	74	1052		69	424		420	58	68	66	0
Cloudy	169	9:50 AM	73	1532		69	437		440	59	68	65	46
in AM		9:55 AM	73	1627									
	169	10:00 AM	74	1669		69	433		460	59	68	65	52
		10:08 AM	74	1727									
	168	10:15 AM	74	1821		69	426		440	59	68	64	60
		10:25 AM		1900									
	203	10:30 AM	74	1958		69	441		460	60	68	63	82
		10:35 AM	74	2001									
	215	10:55 AM	74	2001		70	450		460	61	68	63	100
	221	11:25 AM	75	1291		70	457		480	62	68	64	100
	204	Noon	73	1023		70	461		480	63	68	65	100
	169	12:55 PM	73	824		70	424		440	64	69	65	100
	445	1:30 PM	75	1147		73	635		720	63	72	66	100
	445	1:40 PM	75	1287		73	663		760	63	73	66	100
	445	1:50 PM	76	1349		73	657		740	64	73	66	100
	446	2:00 PM	76	1423		74	659		740	64	73	67	100
	446	2:30 PM	77	1370		75	661		760	64	74	67	100
	222	3:15 PM	75	612		74	461		500	63	73	66	100
	158	4:00 PM	75	549		74	425		440	64	73	67	100

Demand Control Utilizing IAQ Monitoring



VENTACITYSYSTEMS

Controls With Notifications Key to IAQ Management



Notifications For:

- Filters
- Efficiency
- Economizing

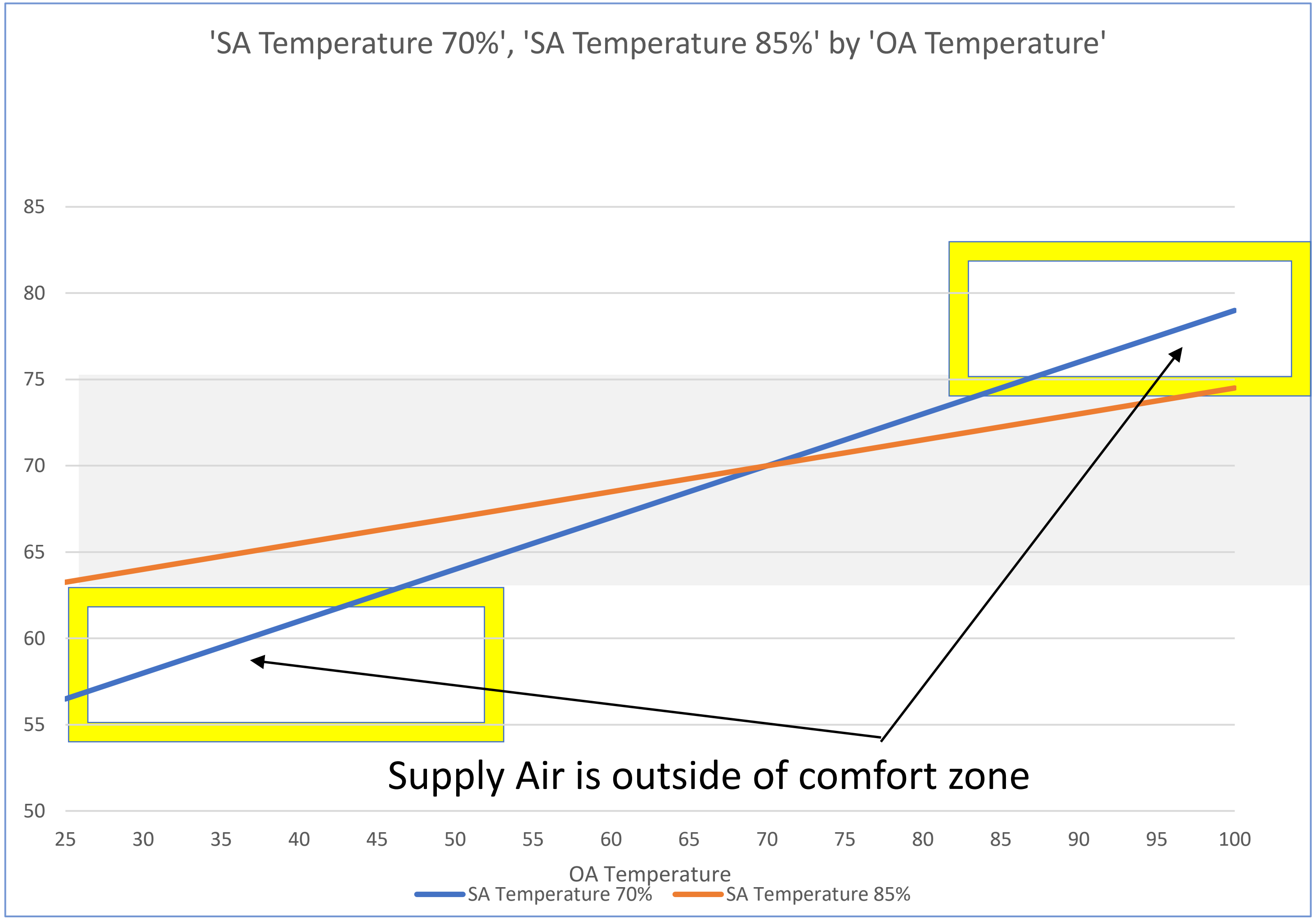
SIGNIFICANT ROI

Ventacity Comparison: North Beach Elementary
ERV-1 @ 3000CFM, 1"W.C.

Assumption	Parameter		Competitor		Ventacity
	Fan Power (W)		6114		3421
	Delivered (SA) Temperature Deg F		53.4		57.8
	Heat Recovered (W)		30785		34956
	Heat Recovered (BTU/h)		104976		119200
*	Hours per day		*10*		*10*
*	Days per month		25		25
*	Months per year		9		9
	Heat Recovered per month (kW.h)		7696		8739
	Heat Recovered per year (kW.h)		69266		78651
	HRV/ERV CoP		**5.0**		**10.2**
	Heat Load from fresh HRV/ERV air (W)		15772		11613
	Heat Load from fresh HRV/ERV air (BTU/h)		53784		39600
*	heat Pump CoP (heating)		1		1
	Heat pump power to heat HRV/ERV SA (W)		15772		11613
	Power: Heat Pump Plus fan (W)		21886		15034
*	Electrical rate $/kWh		0.15		0.15
	Monthly electric bill HRV/ERV Power plus Power to heat fresh air. $	$	821	$	564
	Annual electic bill to heat fresh air $	$	7,387	$	5,074
	Savings Per Unit	**$**	**2,313**		
	Savings for 6 Units	**$**	**13,876.37**		
	Savings for 6 Units over 10 Years	**$**	**138,763.75**		

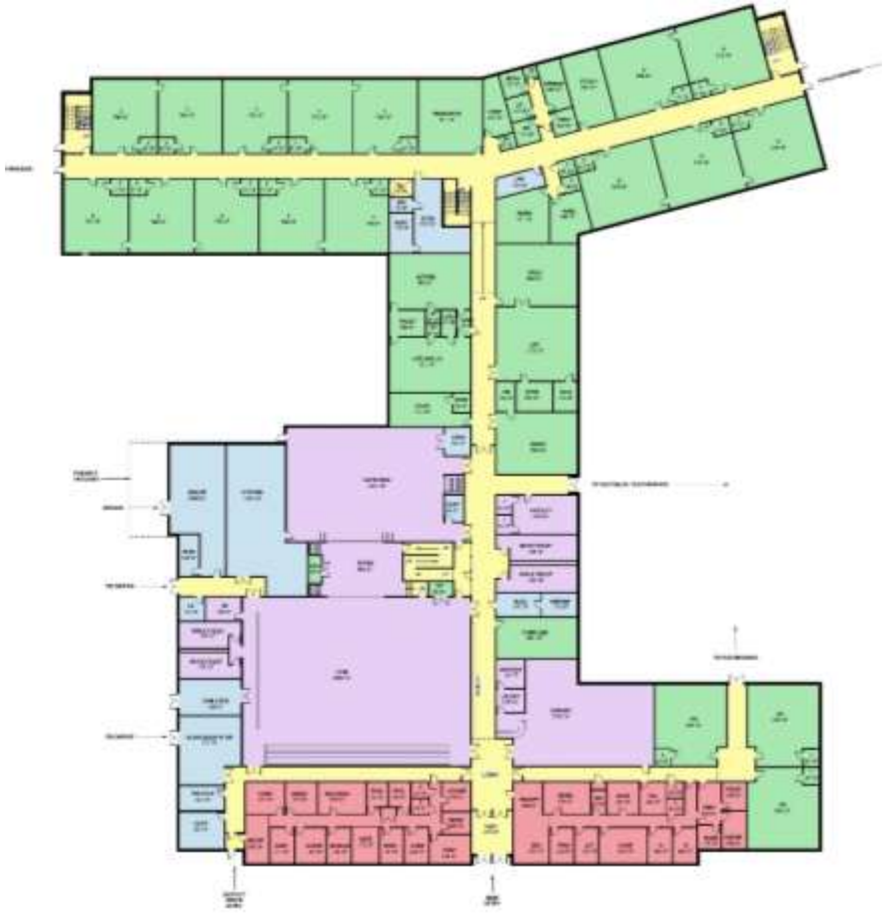
- **BIGGER VOLUMES EQUALS BIGGER SAVINGS**
- **SCHOOL USED TEN YEAR BOND – SAVINGS MORE THAN COVERED INCREASED COST OF PROJECT OVER LIFE OF LOAN**
- **COP IS *<u>DOUBLE</u>* THAT OF CONVENTIONAL ERVS**

Design for OFF



VENTACITYSYSTEMS

Application: Schools



- **Classroom Strategies:**

- **Individual Classroom ERVs**
- CO_2 Demand control potential
- Minimize ductwork

- **Central Systems**
- Can use demand control with zone dampers
- Possibility for reduced equipment sizing with diversity if not all spaces used simultaneously
- Heat Recovery VRF or Hybrid VRF
  ideal for balancing heating/cooling as students
  move through the building

- **Quiet equipment operation critical**

THANK YOU, from all of us at www.Ventacity.com!

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