Personalized Ventilation in Office Buildings. A Solution for Increased Thermal Comfort, Health and Energy Efficiency

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Indoor Air Quality (IAQ)



Refers to air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants.

Contaminants: Particulate matter (PM2.5, PM10), gases (CO_2, CO, VOCs), biological pollutants (mold, pollen).

Sources: Building materials, outdoor air pollution, indoor activities (cooking, cleaning), HVAC systems.

Effects:

Short-term effects: Irritation of eyes, nose, and throat; headaches; dizziness; fatigue

Long-term effects: Respiratory diseases, heart disease, cancer.

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Indoor Air Quality (IAQ)



Importance for Occupants:

Enhances cognitive function, productivity, and overall well-being.

Reduces the risk of indoor health concerns.

Strategies for Improvement:

Ventilation improvements to increase fresh air supply.

Use of air purifiers and enhanced filtration in HVAC systems.

Regular maintenance of indoor environments to reduce pollutant sources.

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Total Volume Ventilation or Personalized Ventilation?



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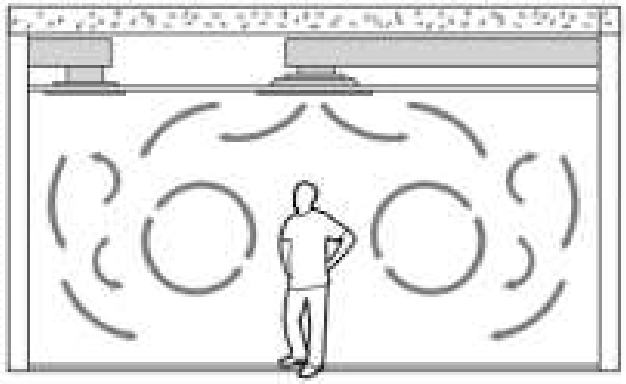
Total Volume Ventilation (TVV)

Definition: A conventional ventilation strategy that circulates air throughout the entire volume of an indoor space to dilute contaminants.

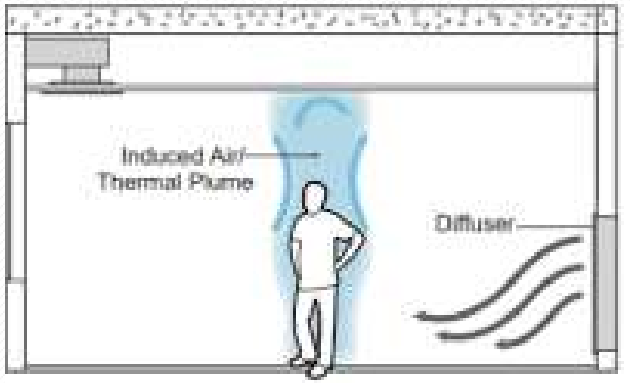
Air Distribution: Distributes air uniformly across the space, often without specific targeting towards the breathing zone of occupants.

Objective: To maintain overall air quality and thermal comfort across the entire room or building.

Limitations: May not effectively address localized pollutants or individual comfort needs; can lead to energy inefficiency due to the need to condition large volumes of air.



Mixing Ventilation



Displacement Ventilation

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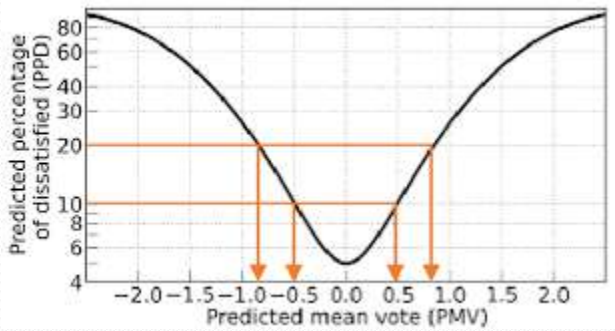
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Total Volume Ventilation (TVV)

- **Overview of TVV:**
  - TVV circulates air throughout the entire indoor space, aiming for uniform air quality and temperature. While effective for overall air mixing, this method can lead to significant energy consumption.

- **Energy Inefficiency:**
  - **Heating and Cooling Large Volumes:** Conditioning the entire volume of air within a space, regardless of occupancy, leads to unnecessary energy use.
  - **Lack of Personalization:** The inability to adjust based on individual needs or localized conditions results in over-conditioning, further increasing energy wastage.
  - **Poor Adaptability to Climate Change:** With increasing temperature extremes due to climate change, the energy demand for maintaining comfort through TVV rises, exacerbating its inefficiency.





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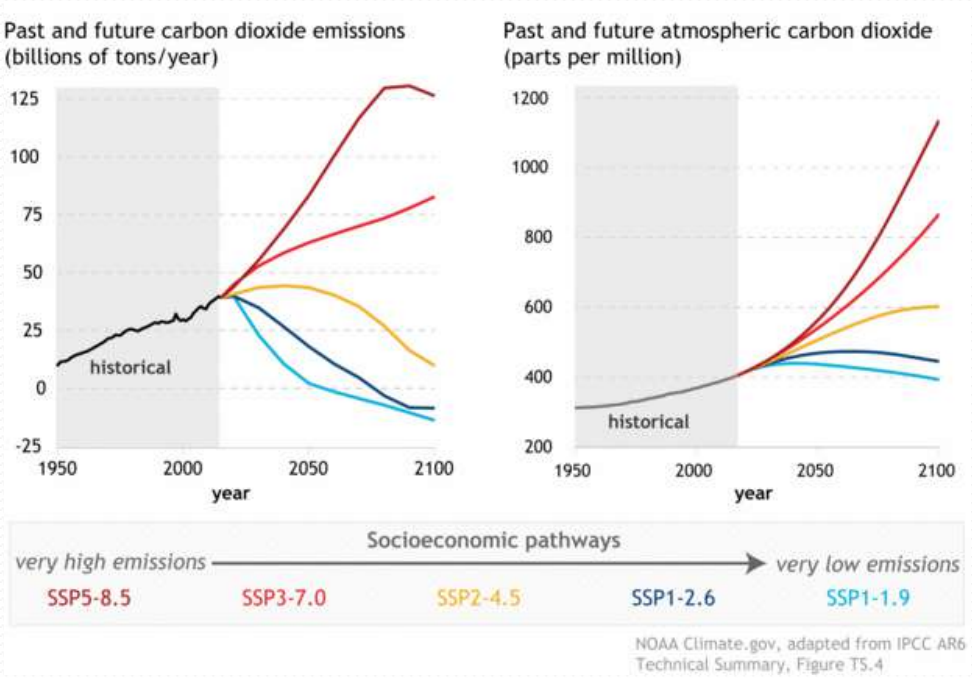
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Total Volume Ventilation (TVV)

- **Environmental Impact:**
  - The high energy consumption associated with TVV contributes to increased greenhouse gas emissions, counteracting efforts to mitigate climate change.

- **The Need for Change:**
  - In light of our current climatic challenges, transitioning to more energy-efficient and adaptive ventilation strategies, such as Personalized Ventilation, can be a solution for the sustainable building design and operation.



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Global and European Legal Constraints on Building Energy Consumption

Global Context:

- Internationally, initiatives like the UN Sustainable Development Goals and the Paris Agreement emphasize the critical need to reduce energy consumption in buildings as a means to lower global carbon emissions.



European Union Regulations:

- **Energy Performance of Buildings Directive (EPBD):** Aims to improve the energy performance of buildings within the EU, requiring Member States to establish and apply minimum energy performance standards for new and existing buildings.
- **Nearly Zero-Energy Buildings (NZEB):** By 2021, all new buildings in the EU must be nearly zero-energy buildings, showcasing the EU's commitment to leading by example in energy-efficient building standards.



Legal Constraints and Objectives:

- These regulations impose legal constraints on energy use in buildings, necessitating the adoption of energy-efficient technologies and designs to meet stringent energy performance criteria.
- The focus is on reducing the operational energy demand of buildings, increasing the use of renewable energy sources, and enhancing overall building efficiency.



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Global and European Legal Constraints on Building Energy Consumption

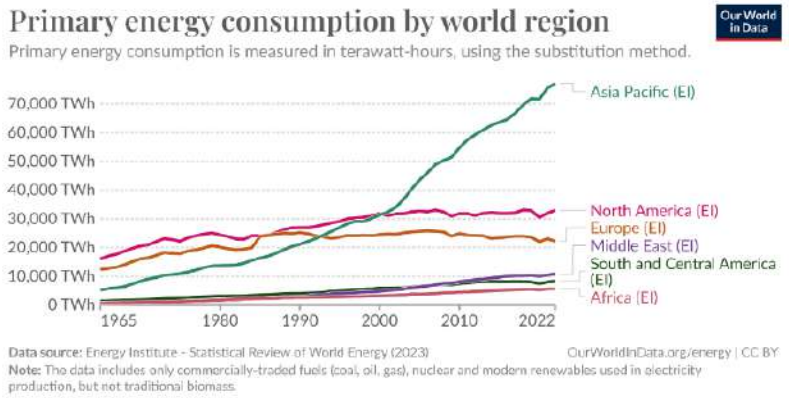
Implications for Building Design and Management:

- Compliance with these legal requirements is driving innovation in building design, construction, and operation, promoting the use of advanced ventilation systems like Personalized Ventilation (PV) to meet energy efficiency targets.
- Building professionals are encouraged to incorporate sustainable design principles and energy-efficient technologies from the outset to achieve compliance and contribute to a reduced carbon footprint.



Global Impact:

- While European regulations are among the strictest, similar trends are emerging worldwide, with countries adopting more rigorous standards for building energy performance to combat climate change.



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Personalized Ventilation (PV)

Definition: An advanced ventilation approach focusing on delivering air directly to the breathing zone of each occupant, tailored to their personal needs.

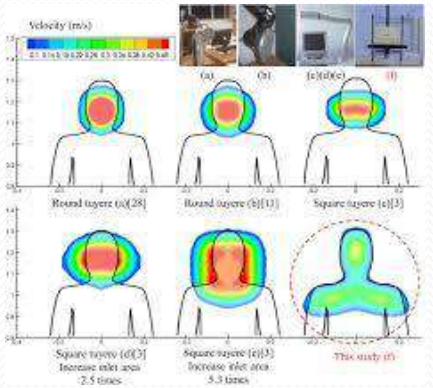
Air Distribution: Utilizes localized diffusers (e.g., at workstations or overhead) to provide fresh air directly to the occupant's breathing zone.

Objective: To significantly improve the individual's inhalation air quality and thermal comfort while potentially reducing overall energy consumption.

Advantages: Offers superior control over air quality and thermal conditions experienced by each occupant; enhances occupant satisfaction and productivity.

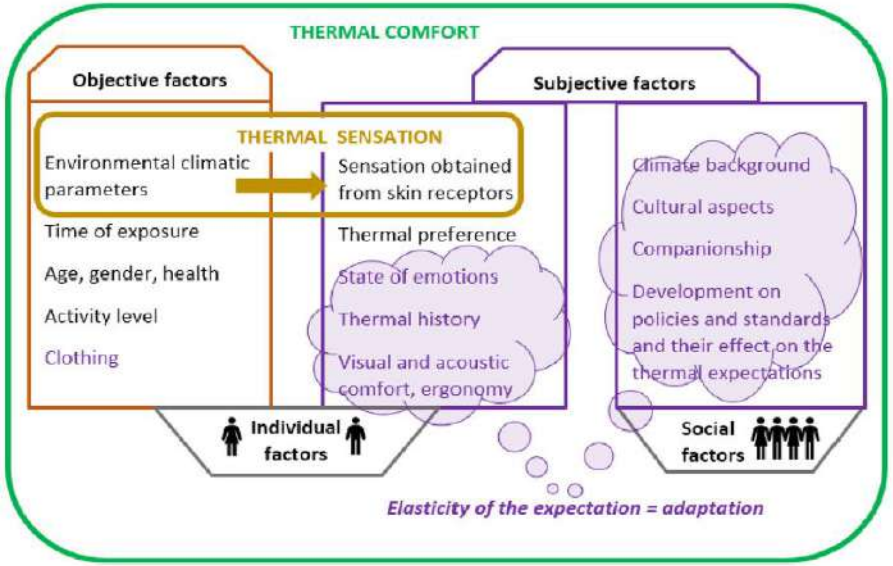






Thermal comfort

- Thermal comfort is very difficult to define.
- Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment, and it's assessed by subjective evaluation[2].



A representation of various factors that are influencing thermal comfort[1]

[1] Ilinca NASTASE, Paul DANCA, Florin BODE, Cristiana CROITORU, Lucian FECHETE, Mihnea SANDU, Costin Ioan COȘOIU, A regard on the thermal comfort theories from the standpoint of Electric Vehicle design — Review and perspectives, Energy Reports, Volume 8, November 2022, Pages 10501-10517, https://doi.org/10.1016/j.egyr.2022.08.186, ISSN 2352-4847, 2022

[2] ANSI/ASHRAE Standard 55-2017, Thermal Environmental Conditions for Human Occupancy

Total Volume Ventilation or Personalized Ventilation?



HVAC engineer often find itself in front of the question:

Energy efficiency or Thermal Comfort?

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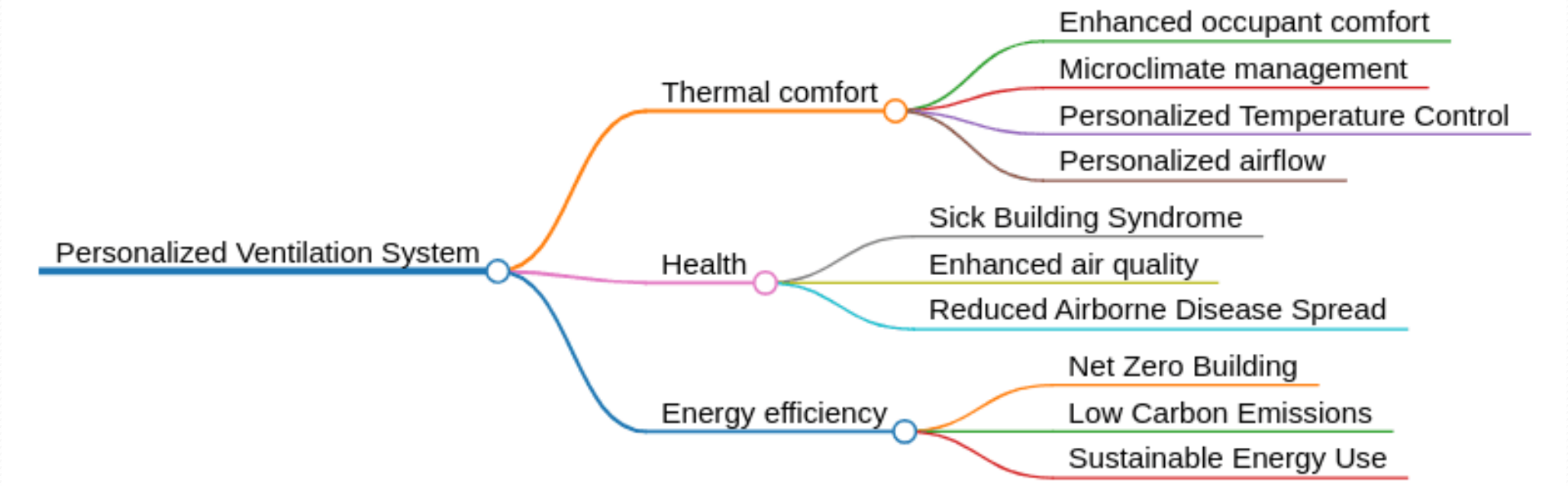
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Personalized Ventilation (PV)



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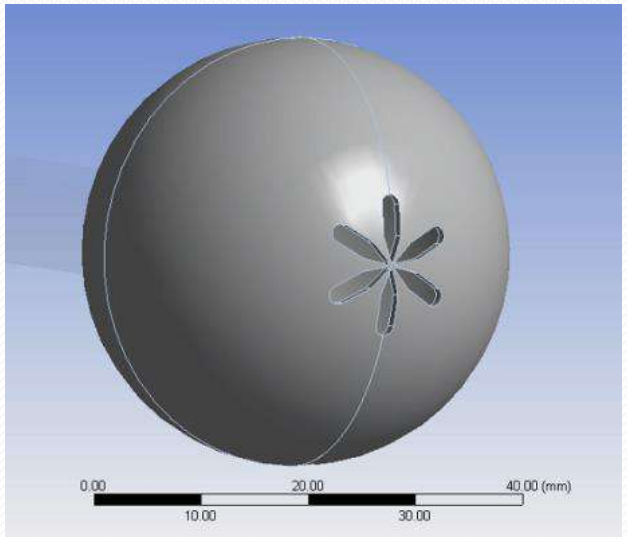
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Material and Methods – Analyzed Case

- The chosen solution resulted from the work carried out in the frame of a few scientific research grants
- Spherical diffuser with low induction lobed orifice for personalized ventilation



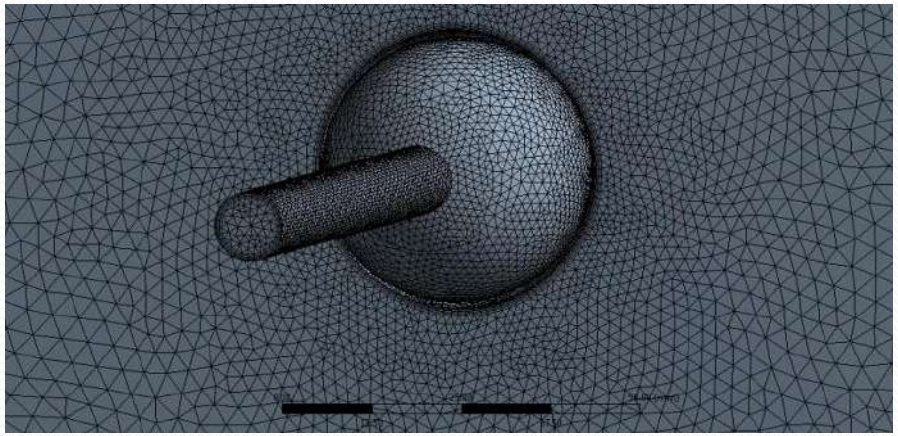
Considered air diffuser geometry



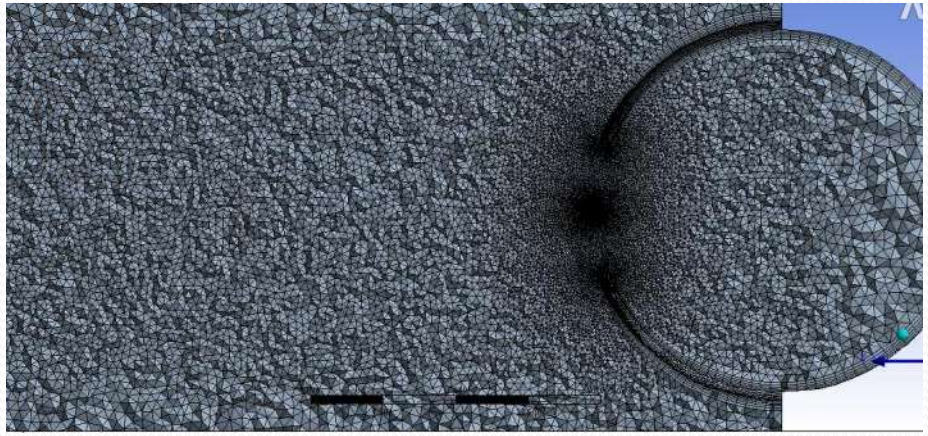
Entire geometry setup

Material and Methods

- The numerical grids setup was performed based of our previous experience.
- A study of solution independence was conducted depending on the number of grid elements used (0.16 million, 0.85 million, 2 millions, 5 millions, 8 millions).
- The numerical grid chosen for the numerical study was that with 5 million elements
- The total airflow rate was 10 l/s (36mc/h)
- Shear-Stress Transport (SST) k-ω turbulence model



Considered air diffuser geometry



Entire geometry setup

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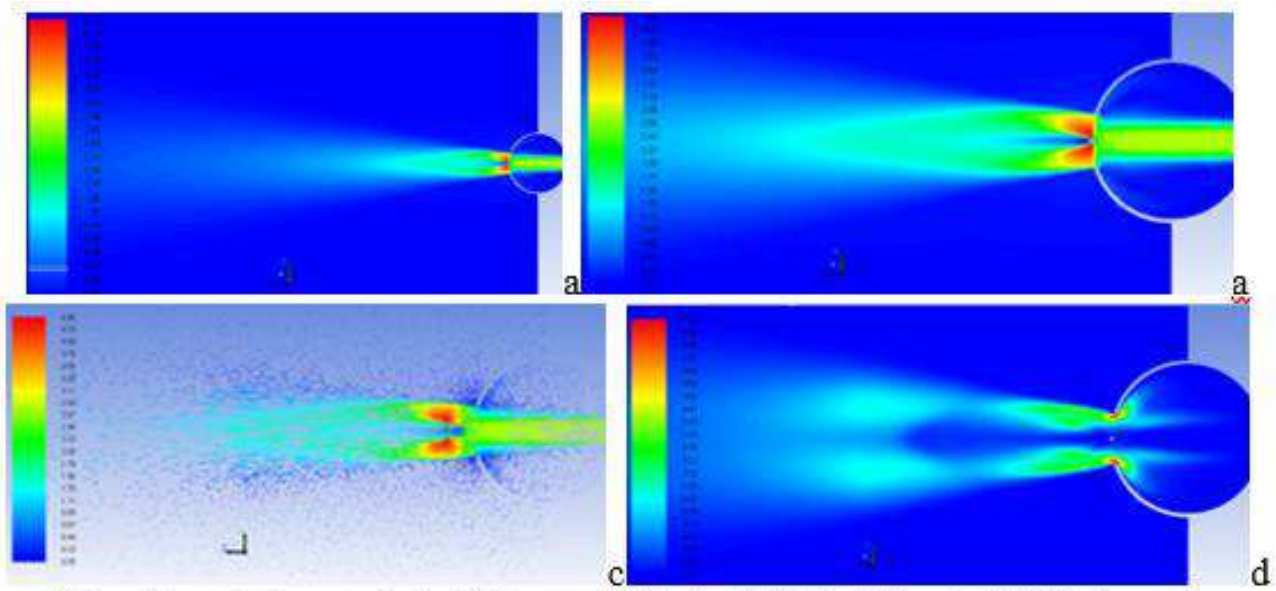
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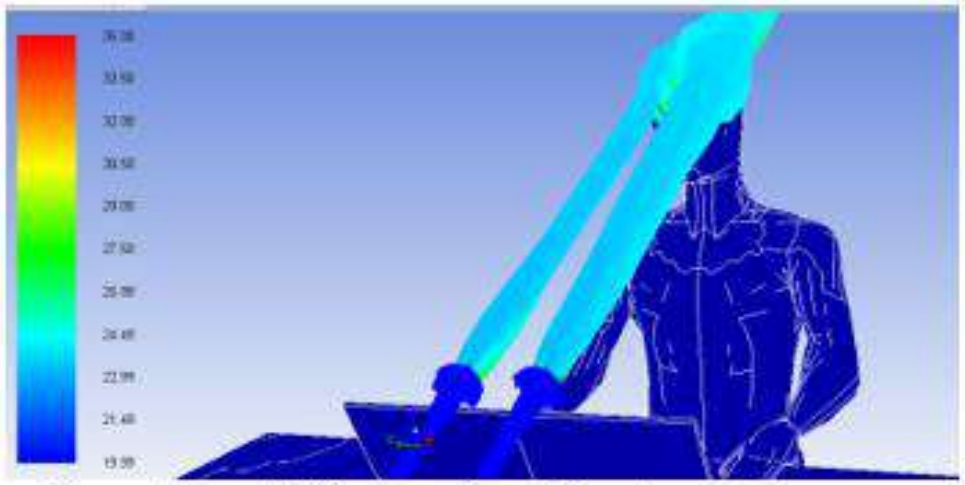
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Results and discussions



Flow through the novel air diffuser a. Velocity field, b. Velocity field (close-up), c. Velocity vectors, d. Turbulent kinetic energy.



Isosurface of 0.3m/s coloured by temperature

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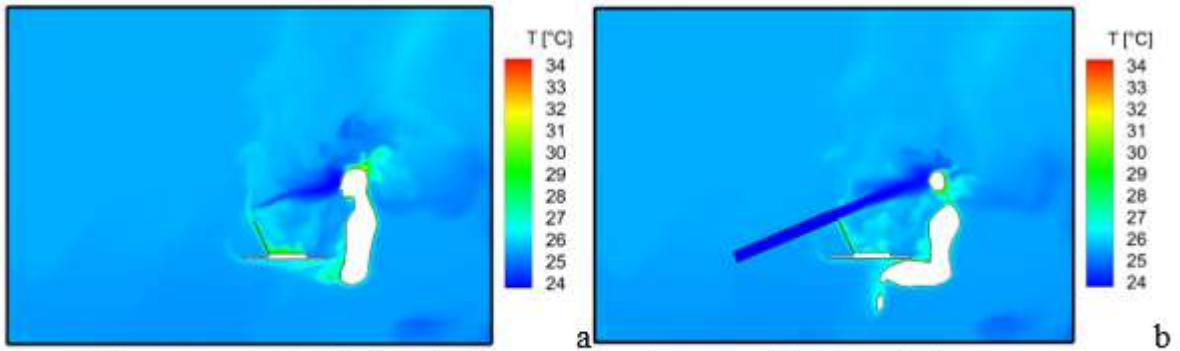
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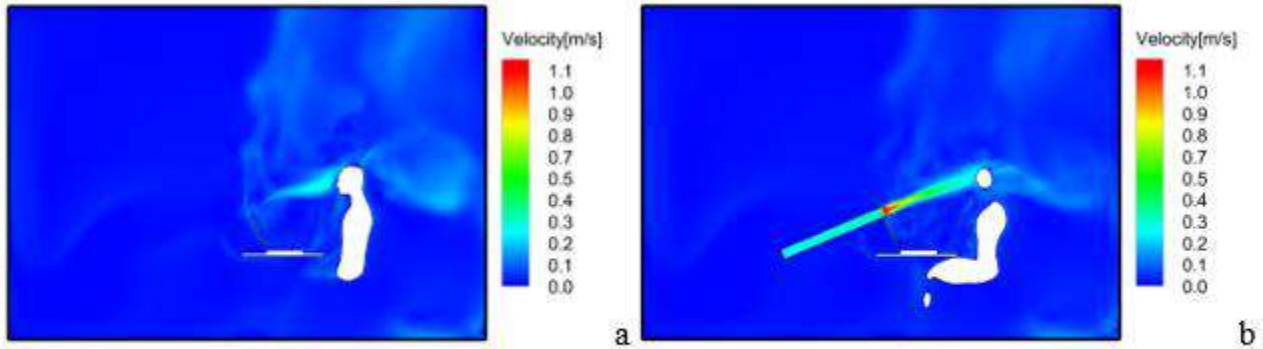
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Results and discussions



Temperature distributions in the room for the personalized ventilation system
a) sagittal plane, b) plane passing through an air diffuser.



Velocity distributions in the room for the personalized ventilation system
a) sagittal plane, b) plane passing through an air diffuser.

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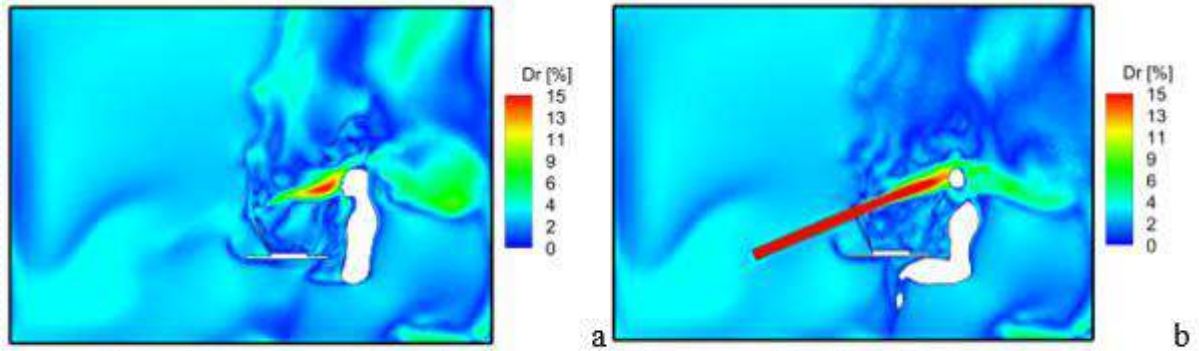
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Results and discussions

$$DR = (t_{sk} - t_a) \times (\bar{v}_a - 0.05)^{0.62} \times (0.37 \cdot Tu \cdot \bar{v}_a + 3.14) \times [1 - 0.013(M - W - 70)]$$

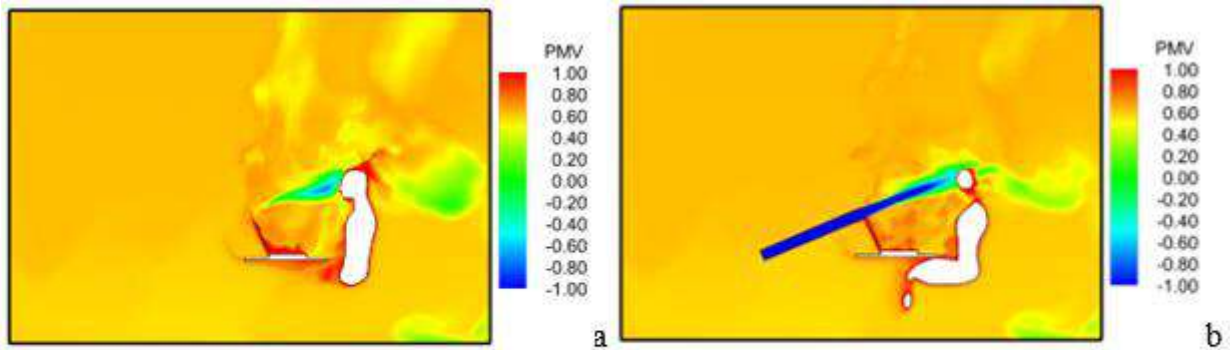
$$t_{sk} = 32.3 + 0.079t_a - 0.019(M - W)$$



Draught rate distributions in the room for the personalized ventilation system
a) sagittal plane, b) plane passing through an air diffuser.

$$\begin{aligned} PMV = {} & (0.303e^{-0.036M} + 0.028)\{(M - W) \\ & - 3.05[5.73 - 0.007(M - W) - p_a] \\ & - 0.42[(M - W) - 58.15] - 0.0173M(5.87 - p_a) \\ & - 0{,}0014M(34 - t_a) - 3{,}96 \\ & \cdot 10^{-8} f_{cl}[(t_{cl} + 273)^4 - (t_{mr} + 273)^4] - f_{cl}h_c(t_{cl} - t_a)\} \end{aligned}$$

$$\begin{aligned} t_{cl} = {} & 35.7 - 0.0275(M - W) \\ & - I_{cl}\{(M - W) - 3.05[5.73 - 0.007(M - W) - p_a] \\ & - 0.42[(M - W) - 58.15] - 0.0173M(5.87 - p_a) \\ & - 0{,}0014M(34 - t_a)\} \end{aligned}$$



PMV distributions in the room for the personalized ventilation system
a) sagittal plane, b) plane passing through an air diffuser.

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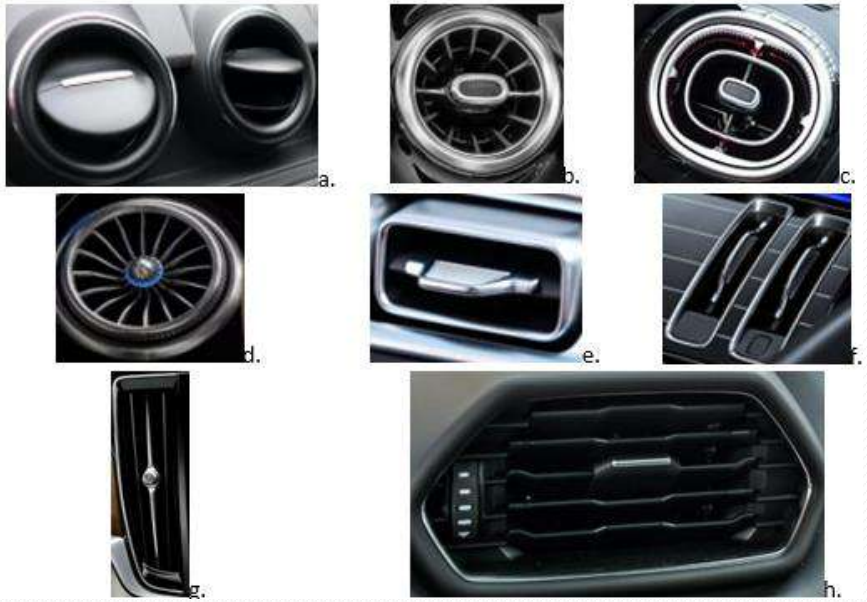
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Material and Methods – Analyzed Case

For example, at this date, the automotive industry did not seem to pay much attention to the mixing of the fresh air introduced through the dashboard air diffusers with the air inside the vehicle in a way to improve the mixing by passive means, and the same conclusion can be draw for the PV case in buildings.





a. Dacia Duster 2022, b. Mercedes clasa A 2022, c. Mercedes clasa C 2022, d. Mercedes EQS 2022, e. Mercedes clasa S 2022 (zona centrtala), f. Mercedes clasa S 2022 (zona laterala), g. Volvo S/V90 2022, h. Lamborghini Huracan Evo 2022, i. Bugatti Chiron 2022, j. Mazda CX5 2022, k. Kia Sportage 2022, l. Rimac Nevera 2022

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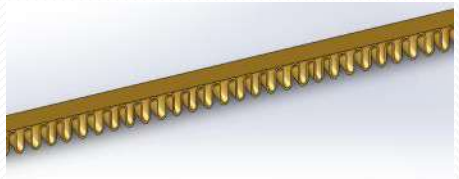
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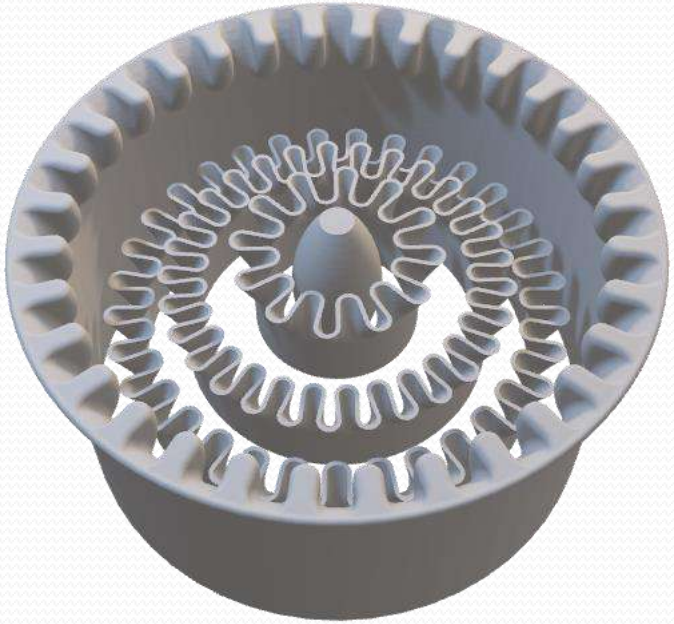
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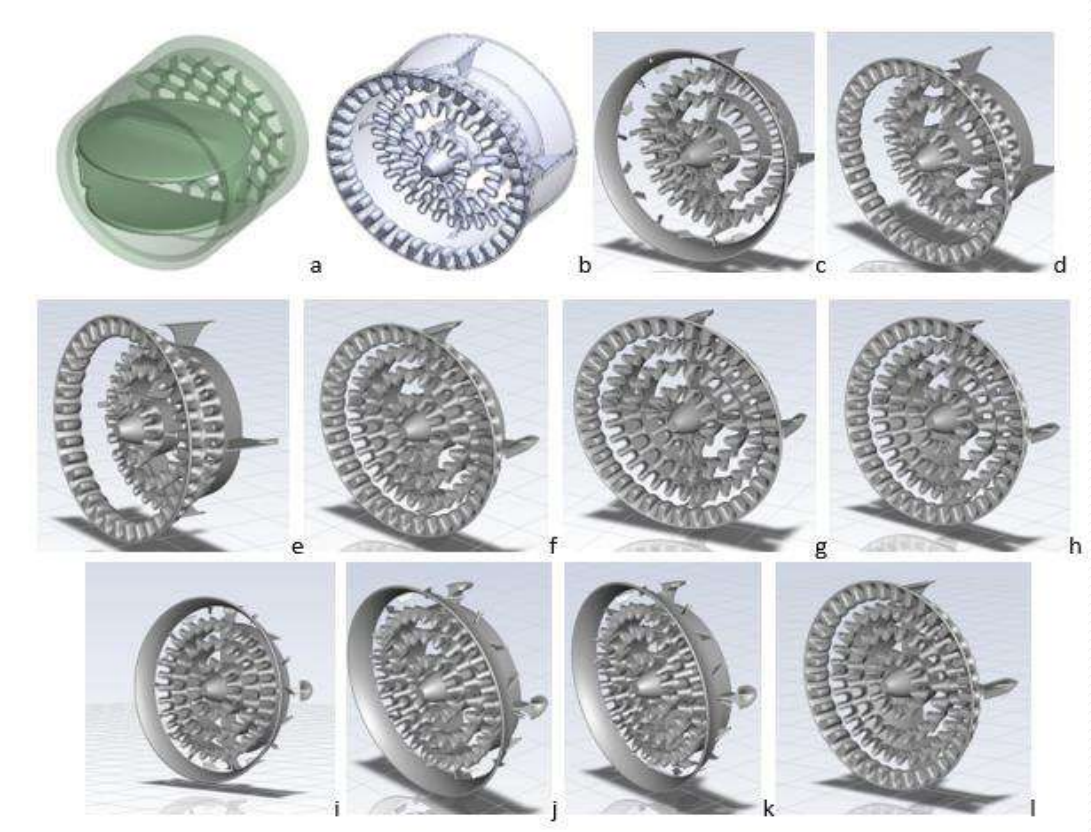
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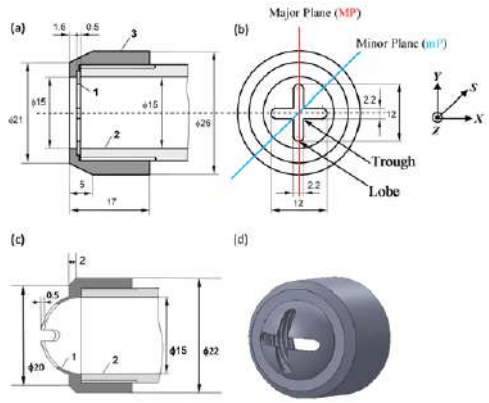
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Material and Methods – Analyzed Case









[1] Kodjovi Sodjavi, Brice Montagné, Pierre Bragança, Amina Meslem, Florin Bode, Magdalena Kristiawan, Impinging cross-shaped submerged jet on a flat plate: a comparison of plane and hemispherical orifice nozzles, Meccanica (An International Journal of Theoretical and Applied Mechanics AIMETA), ISSN 0025-6455, December 2015, Volume 50, Issue 12, pp 2927-2947

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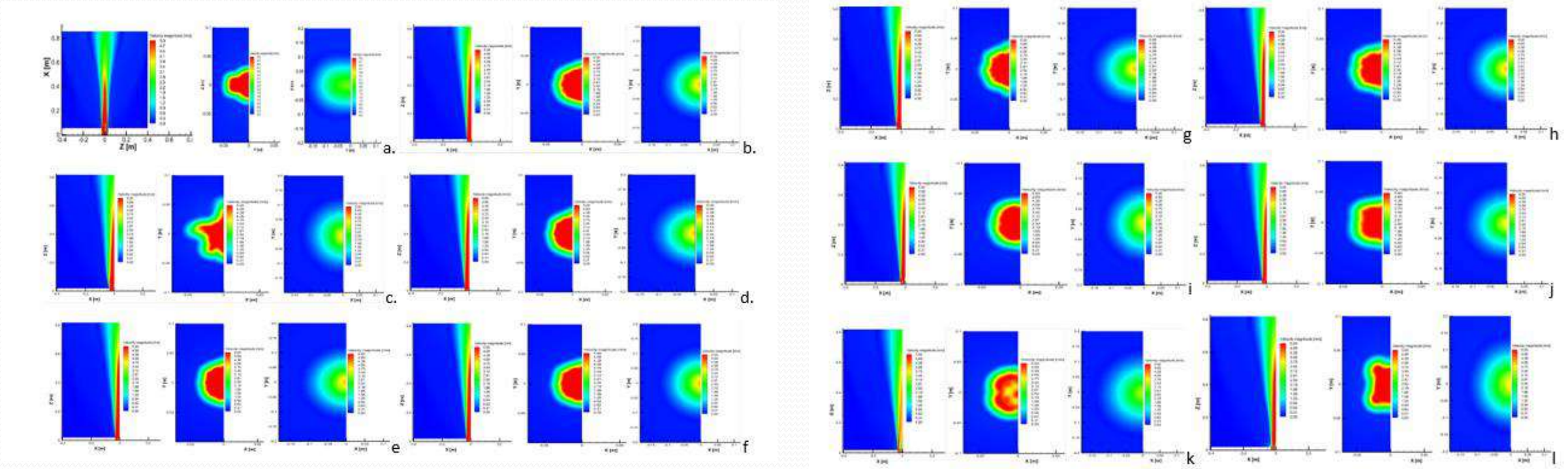
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Numerical results



Velocity field distribution for a part of the air diffusers analyzed: Left – Longitudinal, Middle – Transverse at 100mm from the air diffuser, Right – Transverse at 600mm from the air diffuser.

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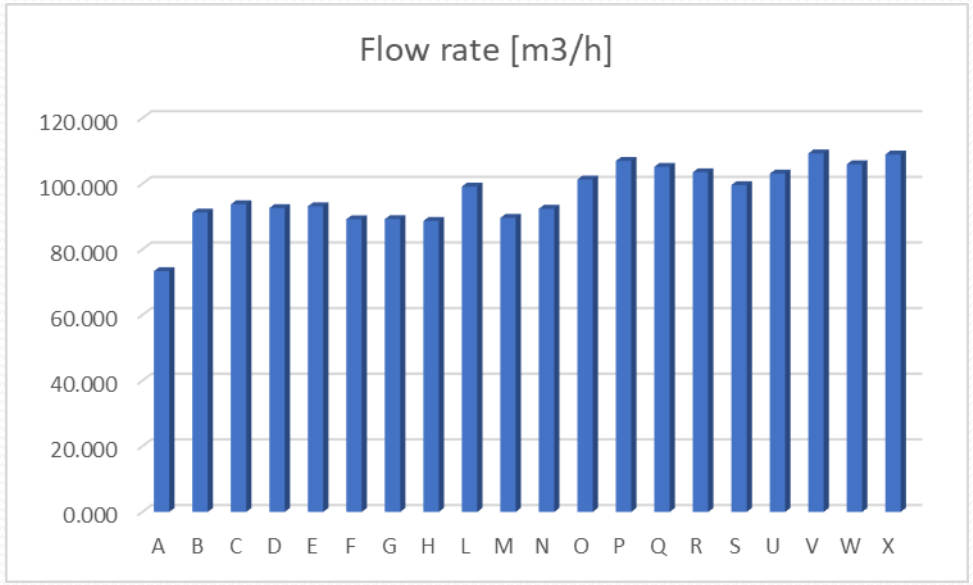
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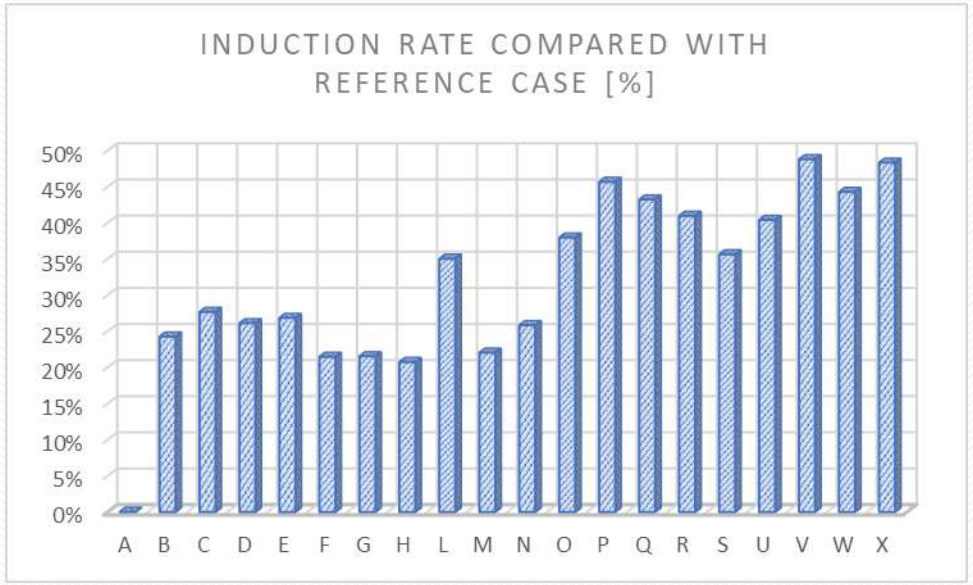
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Numerical results

Crt	Cod	Identificare caz studiat	Debit masic [kg/s]	Debit volumic [m3/s]	Debit volumic [m3/h]	Debit masic inlet [kg/s]	Debit volumic inlet [m3/h]	Rata de antrenare	Adimensionalizare	Cresterea ratei de antrenare fata de etalon
1	*A*	*a. Difuzor aer - Dacia Duster Original*	*0.0245*	*0.020378*	*73.359*	*0.010609*	*31.788*	*2.31*	*1.00*	***0%***
2	B	b. Difuzor lobi concentrici cu lamele de ghidaj la 0 grade	0.0304	0.025343	91.236	0.010609	31.788	2.87	1.24	**24%**
3	*C*	*c. Difuzor Vortex Generators pozitie variabila (unghiulara) a lobilor*	*0.0313*	*0.026041*	*93.748*	*0.010609*	*31.788*	*2.95*	*1.28*	***28%***
4	D	d. Difuzor Lobi concentrici cu lamele de ghidaj la 5 grade	0.0309	0.025722	92.601	0.010609	31.788	2.91	1.26	**26%**
5	E	e. Difuzor Lobi cincentrici cu lamele de ghidaj la 10 grade	0.0311	0.025872	93.138	0.010609	31.788	2.93	1.27	**27%**
6	F	f. Difuzor Lobi concentrici (same plane) cu lamele de ghidaj 0 grade	0.0298	0.024773	89.183	0.010609	31.788	2.81	1.21	**21%**
7	G	g. Difuzor Lobi concentrici (same plane) cu lamele de ghidaj 5 grade	0.0298	0.024788	89.236	0.010609	31.788	2.81	1.22	**22%**
8	H	h. Difuzor Lobi concentrici (same plane) cu lamele de ghidaj 10 grade	0.0296	0.024627	88.657	0.010609	31.788	2.79	1.21	**21%**
9	*L*	*L. Difuzor Unghi variabil I - Lobi concentrici (same plane) cu lamele de ghidaj in unghi variabil*	*0.0331*	*0.027543*	*99.154*	*0.010609*	*31.788*	*3.12*	*1.35*	***35%***
10	M	m. Difuzor Lobi concentrici cu lamele de ghidaj la 0 grade cu margine rotunjita	0.0299	0.024890	89.604	0.010609	31.788	2.82	1.22	**22%**
11	N	n. Difuzor Lobi concentrici cu lamele de ghidaj la 15 grade cu margine rotunjita	0.0308	0.025665	92.392	0.010609	31.788	2.91	1.26	**26%**
12	O	o. Difuzor Lobi concentrici cu lamele de ghidaj in unghi variabil cu margine rotunjita	0.0338	0.028140	101.302	0.010609	31.788	3.19	1.38	**38%**
13	P	p. Difuzor Lobi concentrici cu lamele de ghidaj in unghi variabil cu margine rotunjita la o raza mare	0.0357	0.029712	106.963	0.010609	31.788	3.36	1.46	**46%**
14	Q	q. Difuzor Lobi concentrici cu lamele de ghidaj in unghi variabil cu margine rotunjita la o raza mica	0.0351	0.029214	105.171	0.010609	31.788	3.31	1.43	**43%**
15	R	r. Difuzor- Lobi concentrici cu lamele de ghidaj in unghi variabil cu margine rotunjita la o raza mare + Eleror	0.0345	0.028753	103.511	0.010609	31.788	3.26	1.41	**41%**
16	S	s. Difuzor- Lobi concentrici cu 2 lamele de ghidaj in unghi variabil cu margine rotunjita la o raza mare + Con	0.0332	0.027666	99.598	0.010609	31.788	3.13	1.36	**36%**
17	U	u. Difuzor varianta U	0.0344	0.028636	103.091	0.010609	31.788	3.24	1.40	**40%**
18	V	v. Difuzor - Golden Ratio I	0.0365	0.030350	109.261	0.010609	31.788	3.44	1.49	**49%**
19	W	w. Difuzor - Golden Ratio II	0.0354	0.029426	105.933	0.010609	31.788	3.33	1.44	**44%**
20	X	x. Difuzor - Golden Ratio III	0.0363	0.030253	108.910	0.010609	31.788	3.43	1.48	**48%**

Numerical results





Induction rate for the studied air diffusers at 600 mm from the dashboard

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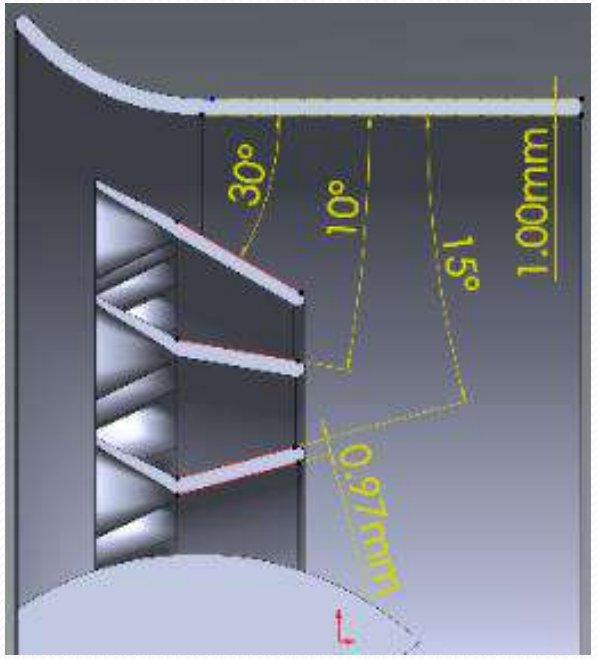
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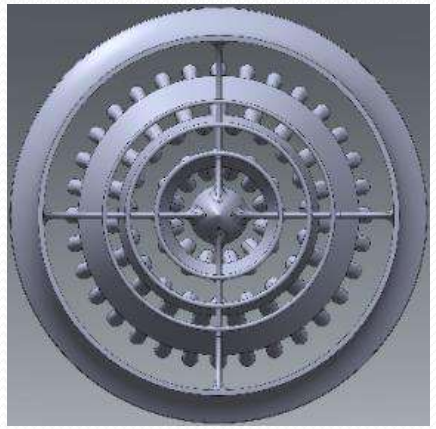
The chosen diffuser for 3D printing





SolidWorks





Air diffuser with 49% induction rate used for 3D printing technologies evaluation

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SLA 3D printing setup and results

Stereolithography








Printing properties for SLA techinque

Slice parameters:		Bottom layers control steps		Normal layers control steps	
Layer thickness [mm]	0.05	Z lift height [mm]	7.5	Z lift height [mm]	2.7
Normal exposure time [s]	4	Z lift step speed [mm/s]	4	Z lift step speed [mm/s]	2
Off time [s]	2	Z retract step speed [mm/s]	4	Z retract step speed [mm/s]	2
Bottom exposure time [s]	30				
Bottom layers	6				

Main capabilities for the DLP and SLA techniques

Types of 3D Printing Technology	Stereolithography (SLA), liquid crystal display (LCD), digital light processing (DLP), micro-stereolithography (µSLA), and more.
Materials	Photopolymer resins (castable, transparent, industrial, biocompatable, etc.)
Dimensional Accuracy	±0.5% (lower limit ±0.15 mm or 5 nanometers with µSLA)
Common Applications	Injection mold-like polymer prototypes and end-use parts,
Strengths	jewelry casting, dental applications, consumer products
Weaknesses	Smooth surface finish, fine feature details

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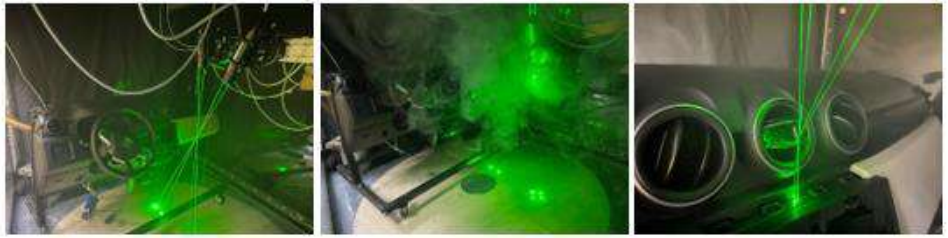
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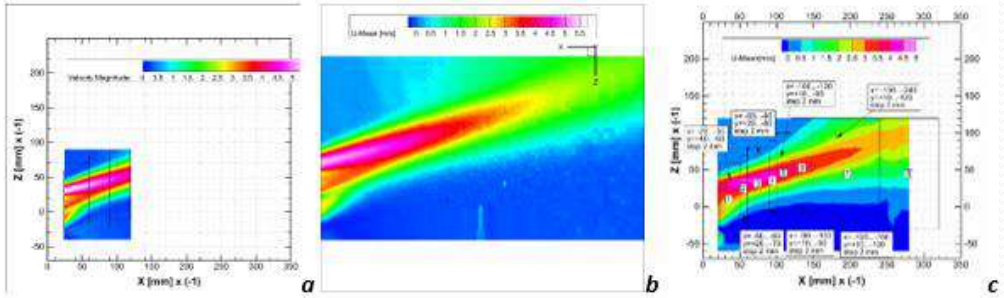
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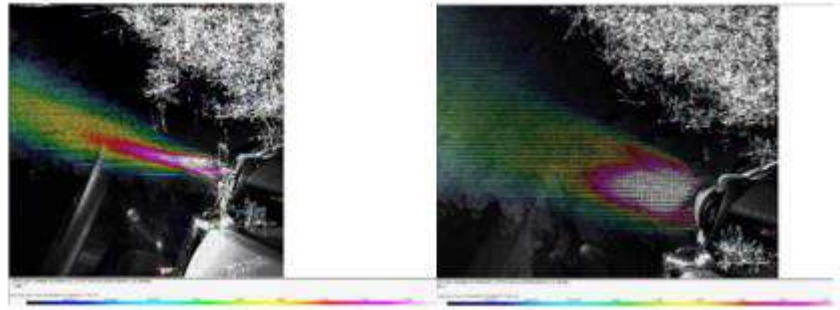
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Experimental results

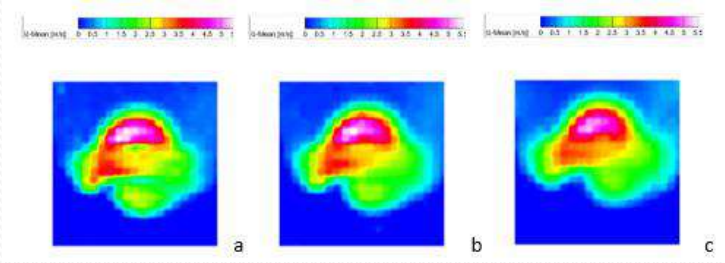




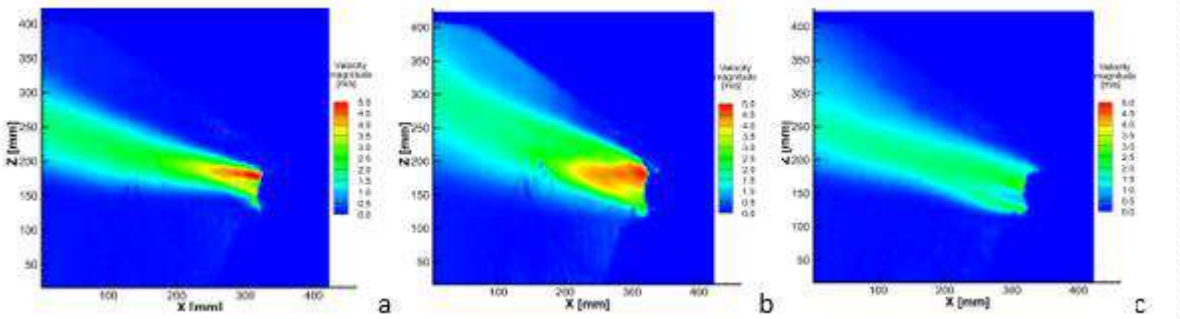




PIV



LDV



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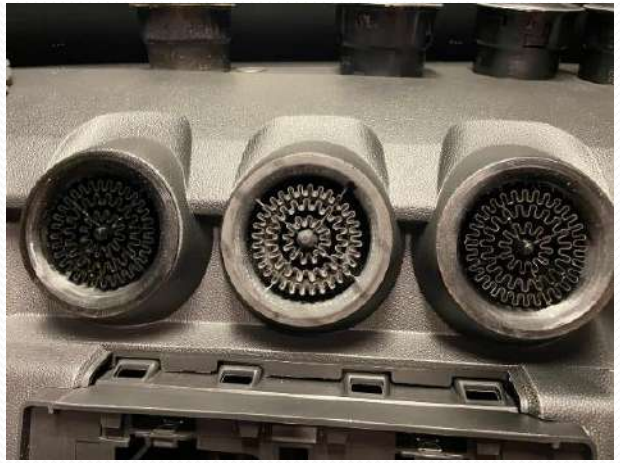
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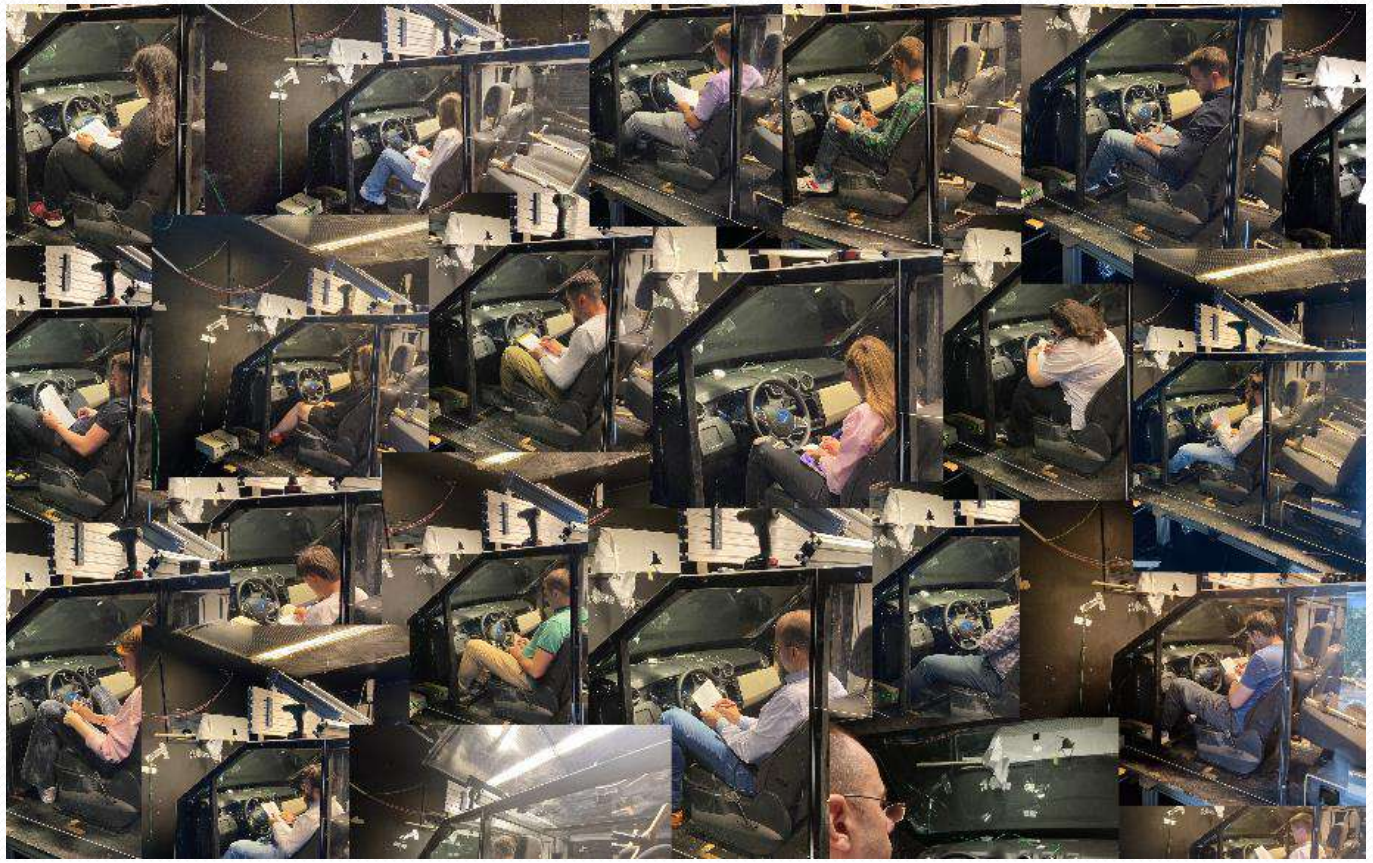
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Experimental evaluation







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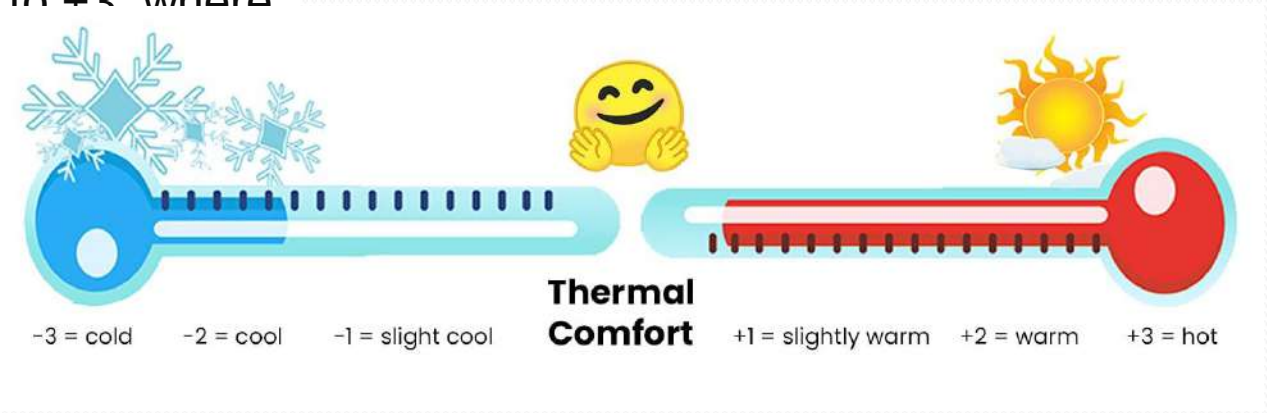
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Experimental evaluation

The "thermal sensation vote" (TSV) is a metric used in the study of thermal comfort, reflecting the subjective assessment of the thermal environment by individuals within a space. Typically, it is measured using a seven-point scale ranging from -3 to +3, where:

- -3 stands for cold,
- -2 for cool,
- -1 for slightly cool,
- 0 for neutral,
- +1 for slightly warm,
- +2 for warm,
- +3 for hot.



This scale allows individuals to express how they feel about the temperature of their surroundings, which can be crucial for studies on building climate control, ergonomics, and environmental psychology. The TSV is valuable for optimizing indoor environments to suit the preferences and comfort of the occupants, which can also impact energy consumption in heating and cooling systems.

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Experimental Sound Evaluation

Speed	Flowrate [m3/h]
V1	23.90
V2	33.60
V3	45.47

- **Fan Model:** Ruck MPS-250EC
- **Ducting Configuration:**
  - **Flexible Tube:** 12m length, 200mm diameter
  - **Reducer:** 1m length, 100mm diameter
  - **End Attachment:** Air diffuser
- **Silencer Integration:**
  - **Type:** Inserted into a silencer
  - **Dimensions:** 1m length, 315mm diamete
- **Sound Measurement:**
  - **Location:** 1m from the air diffuser



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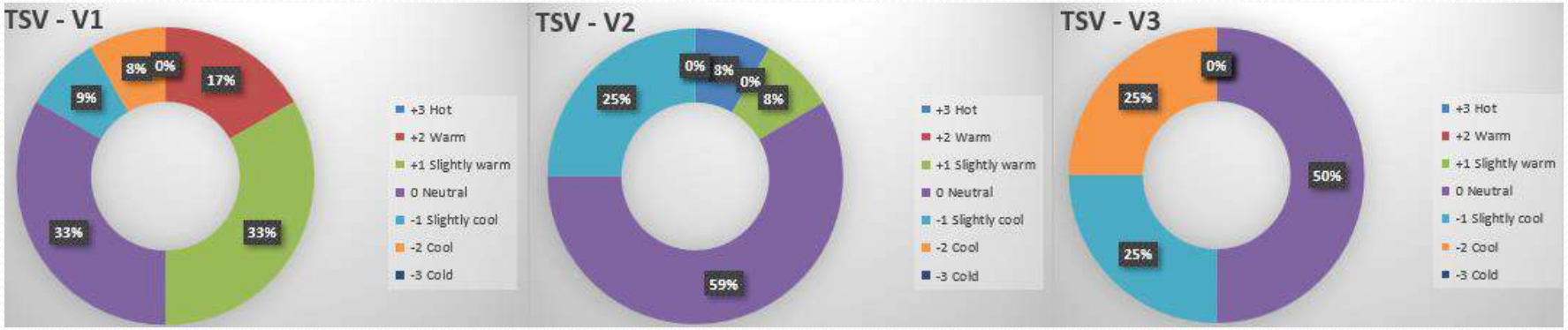
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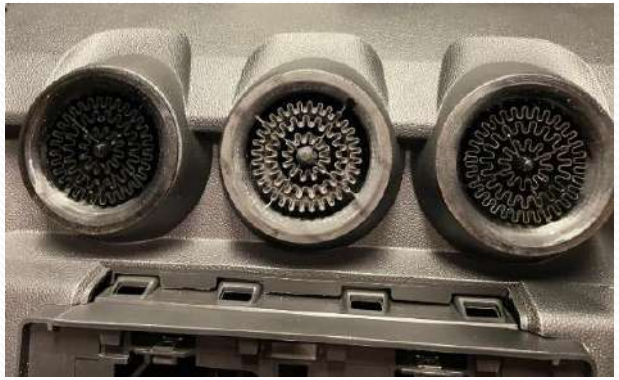
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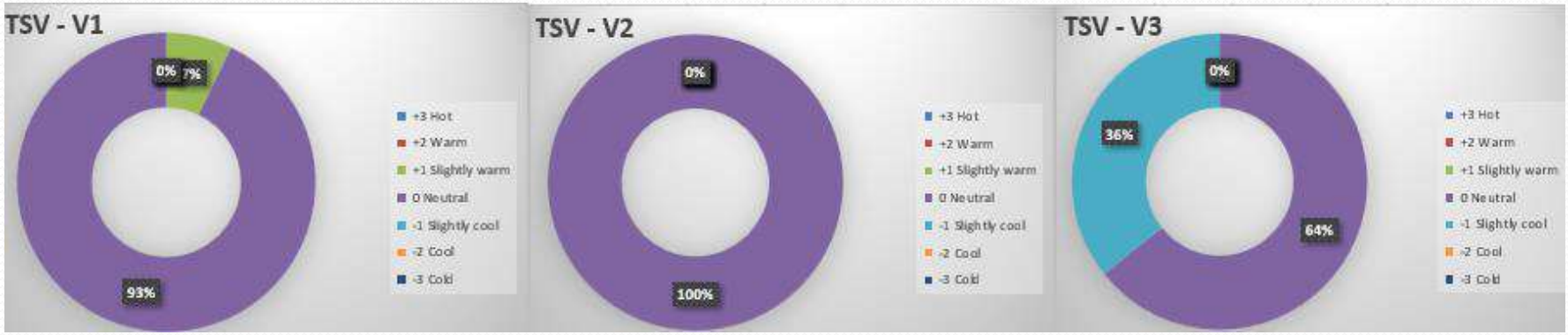
Experimental evaluation

Speed	Flowrate [m3/h]
V1	23.90
V2	33.60
V3	45.47









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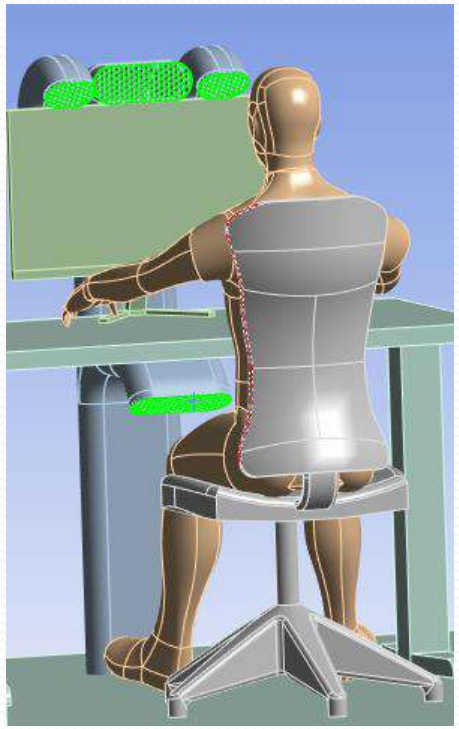
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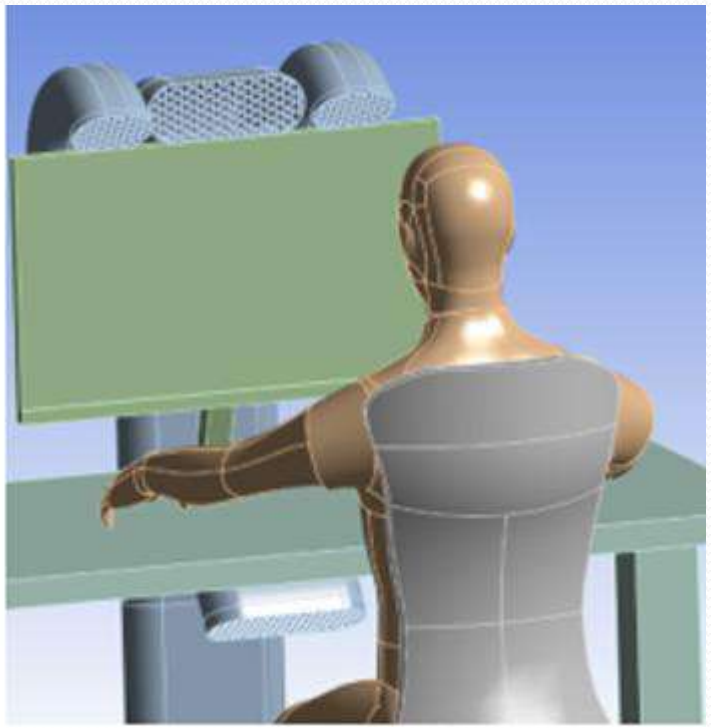
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Future direction







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Thermal alliesthesia

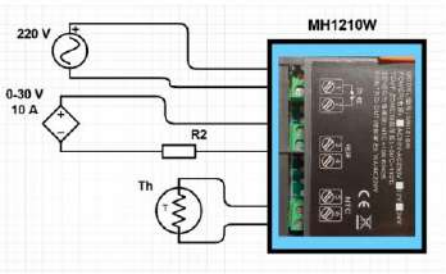
- The brain has a selective mechanism which allows it to “select” the thermal signal that allows it to achieve thermal comfort [1]
- As a result, it is enough to stimulate specific receptors (heat or cool) of the body for the brain to perceive thermal comfort for the entire body
- For office applications, this means that ensuring the thermal comfort does not require to heat or cool the entire bureau

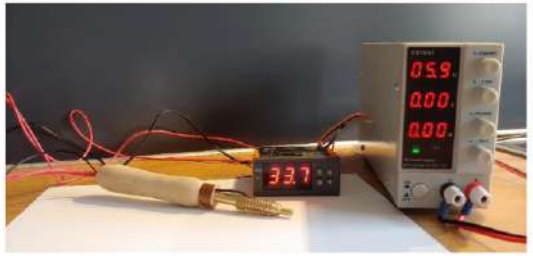


[1] Parkinson T, de Dear R, Candido C. Thermal pleasure in built environments: alliesthesia in different thermoregulatory zones. Building Research & Information 2015;44:20–33.

Human skin thermal sensitivity map [1]

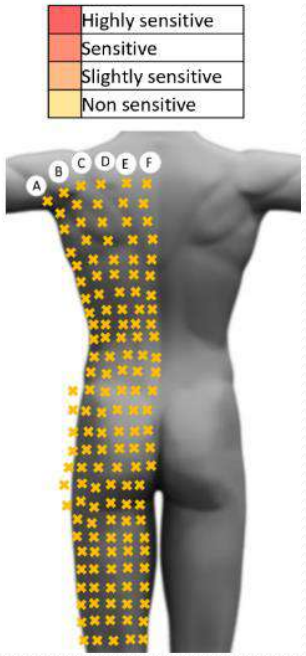
- Design and build of a thermal sensitivity test device
- Experimental determination of the human skin thermal sensitivity map







	A	B	C	D	E	F	Average
1	3	3	3	2	3	3	2	3
2		3	3	2	2	3	2	2
4		4	4	1	2	2	2	2
6		5	5	2	3	1	2	3
8		2	2	3	5	2	4	3
9		3	3	3	4	1	2	3
10		2	2	1	2	3	3	2
11		1	1	2	4	2	5	3
12		5	5	2	4	3	4	3
13	4	4	4	2	4	3	4	4
14	2	2	2	1	1	3	4	2
15	5	2	2	3	1	2	3	3
16	5	2	2	2	1	2	3	2
17	2	3	3	5	2	4	3	2
18	3	3	3	4	1	2	3	2
19	2	1	2	2	3	3	2	2
20		3	3	5	2	4	3	3
21		3	4	4	1	2	3	3
22		1	2	2	3	3	2	3
23		1	2	2	3	3	2	3
24		1	2	2	3	3	2	2
25		1	2	2	3	3	2	3
26		1	2	2	3	3	2	3
27		1	2	2	3	3	2	4



[1] Florin Bode, Nicolae Vlad Burnete, Lucian Fechete Tutunaru, Ilinca Nastase, Improving electric vehicle range and thermal comfort through an innovative seat heating system, submitted to Applied Sciences, 2022

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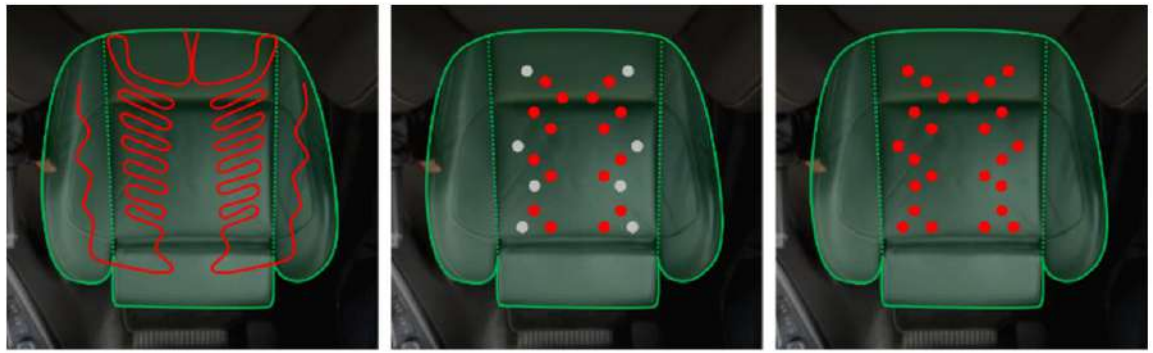
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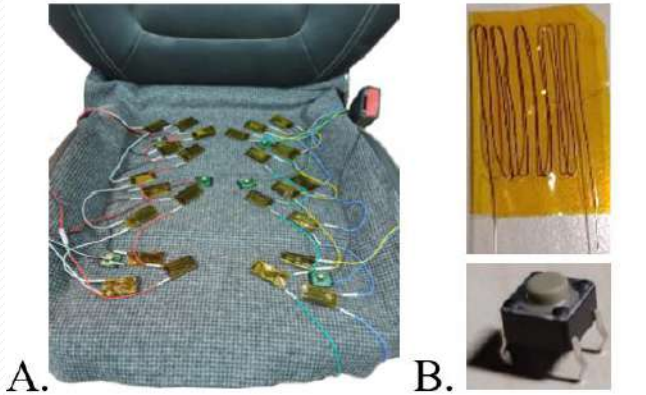
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Seat With Integrated Heating Elements

The alliesthesia hypothesis suggests that nonuniform stimulus that manifest as localized differences in skin temperature can create a conscious experience of thermal pleasure.



Seat with classical heating (left) and seat with targeted heating elements for persons with low body mass – red dots (grey inactive) – and persons with high body mass – red + grey dots (right) [1]



Car seat used in experiments [1]
(A) Positioning of the heating resistances
(B) An example of a heating resistance and a pressure switch used for the experimental setup

[1] Florin Bode, Nicolae Vlad Burnete, Lucian Fechete Tutunaru, Ilinca Nastase, Improving electric vehicle range and thermal comfort through an innovative seat heating system, submitted to Applied Sciences, 2022

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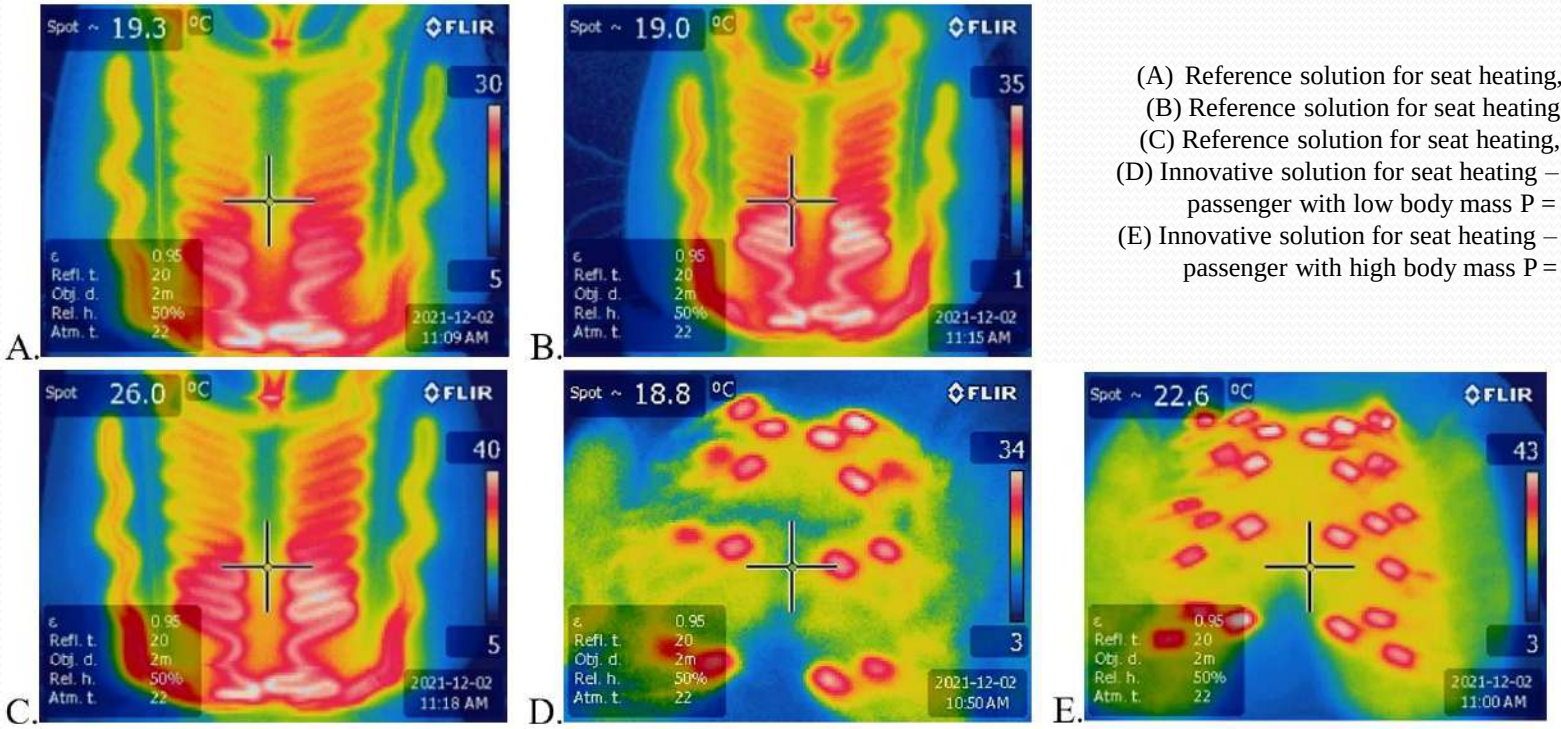
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Seat With Integrated Heating Elements – Results (1)



(A) Reference solution for seat heating, P = 48.6 W,
(B) Reference solution for seat heating, P=66.0 W,
(C) Reference solution for seat heating, P = 85.0 W,
(D) Innovative solution for seat heating – adjustment for passenger with low body mass P = 29.4 W,
(E) Innovative solution for seat heating – adjustment for passenger with high body mass P = 43.4 W [1]

[1] Florin Bode, Nicolae Vlad Burnete, Lucian Fechete Tutunaru, Ilinca Nastase, Improving electric vehicle range and thermal comfort through an innovative seat heating system, submitted to Applied Sciences, 2022

Seat With Integrated Heating Elements – Results (1)

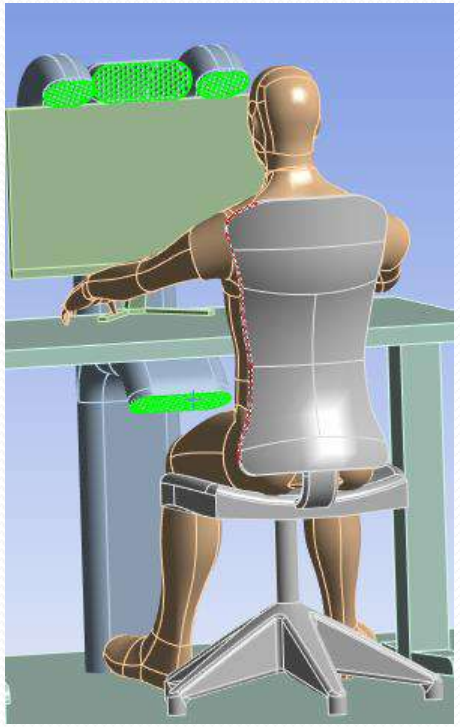
	A	B	C	D	E
Power consumption [W]	48.6	66.0	85.0	29.4	43.4
Male, 42	0	2	3	2	3
Male, 47	1	2	3	2	3
Female, 26	1	2	2	2	3
Male, 56	2	2	3	0	3
Male, 64	2	2	3	0	2,5
Male, 36	1	2	2	0	3
Male, 37	1	2	2	0	3
Male, 29	2	2	2	0	3

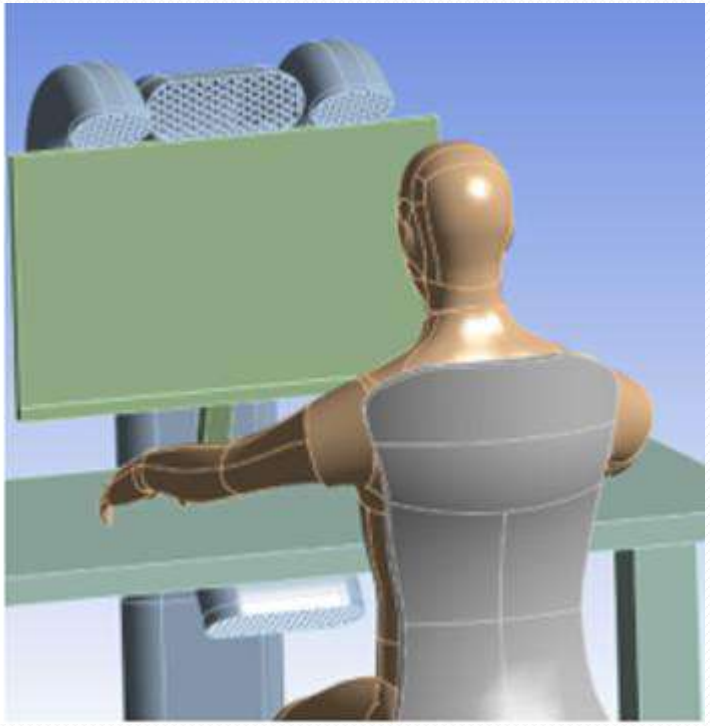
-3	-2	-1	0	+1	+2	+3
Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot

Preliminary results for human subjectivity tests (gender and age)[1]

[1] Florin Bode, Nicolae Vlad Burnete, Lucian Fechete Tutunaru, Ilinca Nastase, Improving electric vehicle range and thermal comfort through an innovative seat heating system, submitted to Applied Sciences, 2022

Future direction





Embracing personalized ventilation and other innovative technologies is not just about improving indoor air quality; it's about taking a responsible step towards a more sustainable and health-conscious future.

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Conclusions

Efficiency	• In contrast to traditional ventilation systems, where as little as 5% of supplied air reaches the occupant, PV systems can deliver a substantial 50% or more of the supply air directly to individuals in the space.
Reassessing Ventilation Strategies	• The comparison between TVV and PV underscores the necessity of evolving our approach to indoor air management, prioritizing both occupant health and energy efficiency.
Advantages of Personalized Ventilation	• PV offers a targeted approach, delivering air directly to the breathing zone and significantly enhancing air quality and thermal comfort for individuals, while also being more energy-efficient than TVV.
Energy Efficiency & Sustainability	• The current climatic challenges demand that we shift towards more energy-efficient systems. PV represents a step forward in reducing energy consumption and minimizing environmental impact.
What to do next?	• Architects, engineers, and facility managers are encouraged to integrate advanced ventilation solutions, like PV, into new and existing buildings to meet future sustainability and wellness goals.
Research & Innovation	• Continued research and technological innovation are crucial in developing even more efficient and adaptive ventilation systems, ensuring that indoor environments remain healthy, comfortable, and environmentally friendly.

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ACKNOWLEDGEMENT

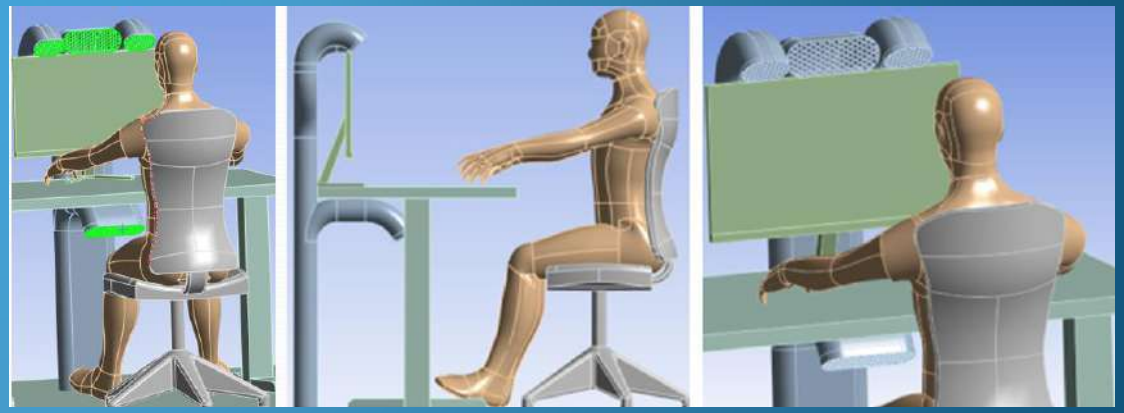
This work was supported by a grant of the Ministry of Research, Innovation and Digitization, CCCDI - UEFISCDI, project number PN-III-P2-2.1-PED-2021-0559, within PNCDI III, -

Innovative high induction air diffusers for improved indoor environmental quality in vehicles and by EU-CONEXUS mobility programme

Innovations in Energy and Environment



Thank you!



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