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Indoor Comfort as Starting Point for HVAC System Design: What is the Carbon Footprint for Different Systems?

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ABSTRACT

Climatization for human-oriented rooms has always the goal to reach a comfortable indoor climate according to the (ISO 7730 2006) standard or comparable. Additionally, different HVAC components and systems lead to different ventilation and air conditioning strategies. For instance, a fan coil unit installed in the ceiling is mostly used in mixed ventilation mode whereas low velocity air diffusers at the floor result in a displacement flow.

The selection of the appropriate system and airflow strategy in the room is the result of an analysis of the room requirements, architectural and ergonomic possibilities of the building, the source of heat and cooling, and ultimately also the available budget.

However, indoor comfort should be one key factor and could be a starting point for the HVAC design. In this paper we discuss the influence of different systems and components on the efficiency reaching the same comfort levels. The focus is not only the thermal efficiency itself but also interaction with the remaining construction needs induced by the installation setup, e. g. pipe works etc.

The first analyzed system is a fan coil unit installed in a suspended ceiling, inducing a mixed ventilation mode in a standard office room. The other system is a trench cooling system installed in the floor along the facade and establishing a combination of displacement and mixed flow in the occupied zone of the room. Both ventilation strategies are explained and analyzed with CFD. The carbon footprint is calculated by the usage of available environmental product declaration according to the (ISO 14025 2011) standard and construction related considerations as well as energy consumption calculations based on the efficiency findings.

INTRODUCTION

The main purpose of buildings since the stone age is to create or alter the surrounding weather conditions to a more comfortable zone by creating buildings. There are many factors that contribute to his well-being in an enclosed space. There are four main elements to interior comfort. Thermal comfort, a healthy indoor environment, adequate lighting and acoustic comfort. If any of these elements do not meet our (user) expectations, then we cannot speak about the Internal Environment to be a Comfort Zone – which should be the basic function of the building!

Additionally these buildings often have a representative character which can be the more important aspect of design in certain cases. Nevertheless, the majority of buildings have a dominating functional aspect and especially for office buildings the available office space and human comfort levels are most important.

In this article we will discuss to use the indoor comfort as a starting point for designing a building. Hereby we will look at different climatization principles and the influence on the resulting design boundary conditions and parameters with the impact on the carbon footprint. At first the description of a single room with different climatization systems is presented and from this starting point several following aspects are discussed.

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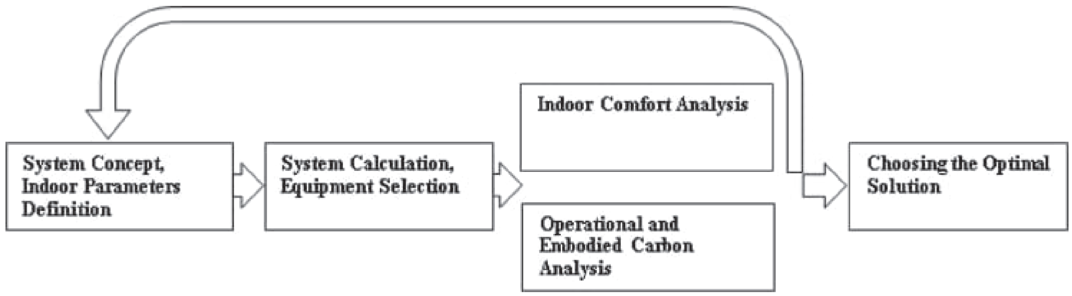

Figure 1: HVAC System selection in room

ISO 7730 AND INDOOR COMFORT CATEGORIES

Quality of the indoor environment has become an important parameter to account for in new and existing buildings due to the increasing number of people spending most of their time indoors. Generally, the design and evaluation of indoor environments in buildings rely on appropriate guidelines and recommendations. The most important contributor was P.O. Fanger (1934–2006), who created a predictive model for general, or whole-body, thermal comfort. Fanger's PMV model is adopted by many (inter)national standards and guidelines for providing an index of thermal comfort (Fanger P.O. 1970, 1988) Standards (ASHRAE 55 2020), (ISO 7730 2006), and (GB/T 50785 2012) present methods for predicting the general thermal sensation and degree of discomfort of people exposed to moderate thermal environments based on indoor thermal environmental factors (i.e., temperature, thermal radiation, humidity, air velocity) and personal factors (clothing level and metabolic rate). While (ISO 7730 2006) and (GB/T 50785 2012) presents three categories for the thermal environment, (ASHRAE 55 2020) does not have indoor environmental categories but defines acceptable thermal environment. (GB/T 50785 2012) presents, in addition to recommendations about temperature and other thermal environmental parameters, requirements for measuring the thermal environment (instruments, parameters, conditions, time and position). (GB/T 50785 2012) is applicable both for residential and public buildings.

The (ISO 7730 2006) standard describes the indoor comfort and its necessary input parameters. In short these input can be differentiated in two categories, physical and human centered. The physical parameters are air velocity, air temperature, intensity of turbulence and heat radiation resulting in the draught rate, the stratification and the asymmetry of the radiance temperature. The human centered input parameters include the degree of activities (e.g. sitting, sports or manual work) and the worn clothing. For a general statement from CFD calculations the draught rate is the most significant result because alle other parameters depend on usually unknown or very project specific boundary conditions.

To simplify the information of the before mentioned comfort parameters a category system is additionally introduced by the (ISO 7730 2006) standard. Here the categories reach from A to C with A as the best category available. Category A means that 5 % of the people in the comfort zone are not satisfied with the provided conditions, whereas category C accepts 20 % of unsatisfied inhabitants. The standard comfort level in an office space is category B with 10 % unsatisfied people and this is also the minimum desired category for the later discussed HVAC systems. Multiple or all of the aspects (e.g. draught rate and stratification and so on) can be combined and the worst category counts as the resulting category.

OCCUPANT AREA

When designing an HVAC system in a room, it is important to first define the space in which the user will be located. In the case of the HVAC comfort system, the internal environment should be created for it, and the defined thermodynamic parameters of the air apply only to the zone in which it is located. Appropriate analysis allows for significant savings when not the entire cubic capacity of the room must be subject to the range of HVAC components.

The occupant area (also occupant zone) is the area where the inhabitants remain in a room and is defined according the (EN 16798-3 2017) standard as the room area with a usual gap from indoor climatization units of 1 m and 0.5 m away from the walls. The height of the zone is 2 m from the floor. The area can be extended or reduced by 0.5 m for special purposes and results in the drawback of possible worse comfort categories close to facades or room climatization units.

METHOD AND MODELLING

To get an idea of the resulting comfort in a room the draught rate is deduced from the velocity, temperature and turbulence energy calculated with CFD. The software used to model a standard room of 6 x 4 x 3 m in width, length and height respectively was Hypermesh 2022.3. The calculation was done with the inbuilt solver AcuSolve both from Altair Engineering. The geometry has between 1418781 and 4404790 elements and as turbulence model for the RANS-Steady-State calculations kω-SST was used. The draught rate categories was calculated as shown in the (ISO 7730 2006) standard and the turbulence magnitude according to (Koskela et al. 2001)

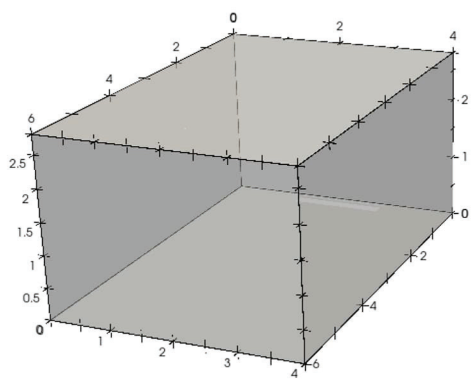

Figure 22: Room dimensions

The room visualised in Figure 2 is divided into three distinct areas. This includes the floor, the walls and the ceiling. Starting from an outside temperature of 30 °C, heat transfer coefficients are imposed on the respective boundary areas to simulate the heat losses across the shell (wall α = 0.35 J/m²sK, ceiling α = 0.33 J/m²sK, floor α = 0.29 J/m²sK). The observed room have a need of cooling for 1200 W to reach a level of 20 °C. This cooling capacity was delivered by different systems:

- Trench Heating unit
- Ceiling installed fan coil
- Wall installed fan coil on railing height
- Wall installed fan coil on ceiling height.

The system description and cooling capacitys are listed in Table 1.
The trench heating unit is a fan coil installed in the floor screed and the railing height fan coil implying both a combination of mixed and displacement flow. The other fan coil units on the other hand are mixed ventilation systems only. To get a valuable comparison between these four different systems concerning the draught rate the occupational zone was rasterized again on the exact same locations with a structured and evenly distributed mesh and the draught rate deduced. This was done because the different cases have different unstructured meshes and the statistics depend on the mesh nots positions and numbers.

Table 1. Climatization systems and cooling capacity

	Trench cooling unit	Ceiling installed fan coil	Wall installed fan coil on railing height	Wall installed fan coil on ceiling height
Cooling Capacity	1200 W	1200 W	1200 W	1200 W
Room Temperature	20,8 °C	19,5 °C	20,3 °C	19,2 °C
Inlet Temperature	12,2 °C	9,9 °C	10,6 °C	9,3 °C
Flowrate	288 m³/h	164 m³/h	189 m³/h	188 m³/h

CFD AND COMFORT RESULTS

In **Fehler! Verweisquelle konnte nicht gefunden werden.**3 the draught risk rate for the above mentioned system is shown. Here can be seen that the trench cooling unit and the railing height fan coil unit establish a bad comfort above the units due to high velocity and low temperatures in the outlet of these units. The location of these outlets is close to the occupational zone of the room and therefore an area of high category comfort levels is found around these units. The resulting definition of occupational zone according to the (ISO 16798 2017) begins with a distance of normally 1 m away from the inner unit perimeter. However at this distance of 1 m the comfort levels are at least in the category B which is the preferred level for office buildings due price/performance ratio. Additionally, in a) it can be seen that the trench cooling unit induces a circulating flow in counter direction of the flow from the outlet region.

The fan coils installed either in the suspended ceiling or in ceiling height show more areas of higher comfort levels due to a higher momentum and a bigger difference between inlet temperature and room temperature. On the other these units are smaller in used space in the room. The larger uncomfortable zone (worse than Cat C) is outside the occupational zone and therefore not found by occupants.

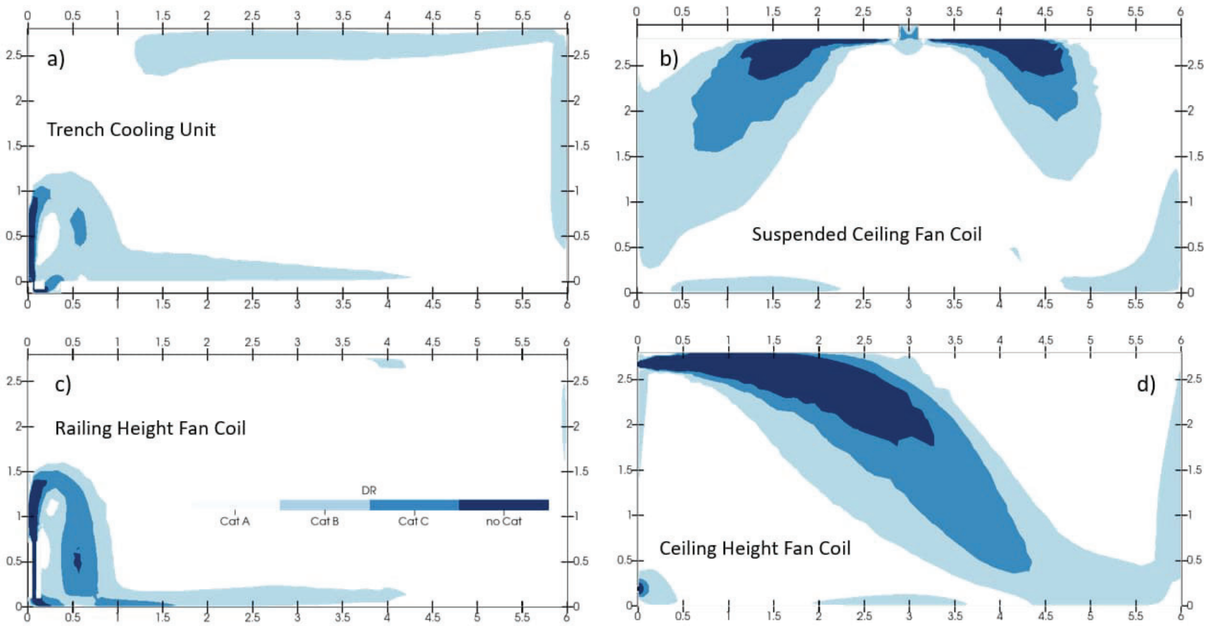

Figure 3 (a) trench cooling unit, b) suspended ceiling fan coil, c) railing height fan coil, d) ceiling height fan coil; draught rate risk in categories from A to C and no category

In Figure 4 the statistics about the occurrence of different draught rate categories is shown. First, all systems establish a sufficient good comfort in the occupational zone. However there are still differences, hence the simple inlet from the smallest unit with a high momentum (ceiling height fan coil) a single direct flow from one side of the room to the other side is not as good as distributing the unit outflow zone and reducing the momentum of conditioned air.

The highest amount of category A area can be obtained with units using a combination of mixed and displacement flow like the trench cooling unit and the railing height fan coil. The reason for this is the high comfort category above the unit but this area is very narrow and does not affect the occupational zone in a massive way. However in the remaining room a displacement flow is installed with a high level of comfort.

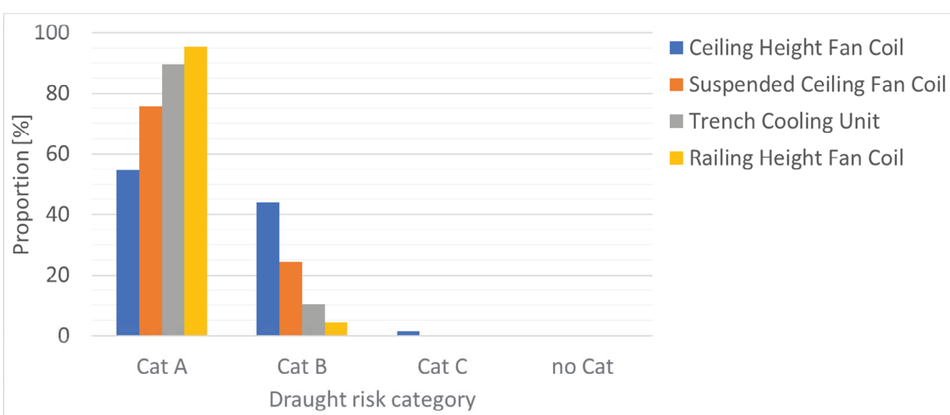

Figure 4 Statistical results from the draught rate calculations. Draught risk by category for different systems.

INDOOR CATEGORIES IN OCCUPANT ZONE

Category analysis in occupied zones allows for a direct comparison between different airflow strategies in a room. The analyzed room is a typical case with medium requirements, therefore each of the presented strategies for introducing air into the room basically meets the requirements of high categories A and B, whose total share in the volume is greater than 95%. However, it is clearly visible on Figure 5 that in cases where quasi-displacement air flow occurs in the occupied zone, the quality of the environment is the highest.

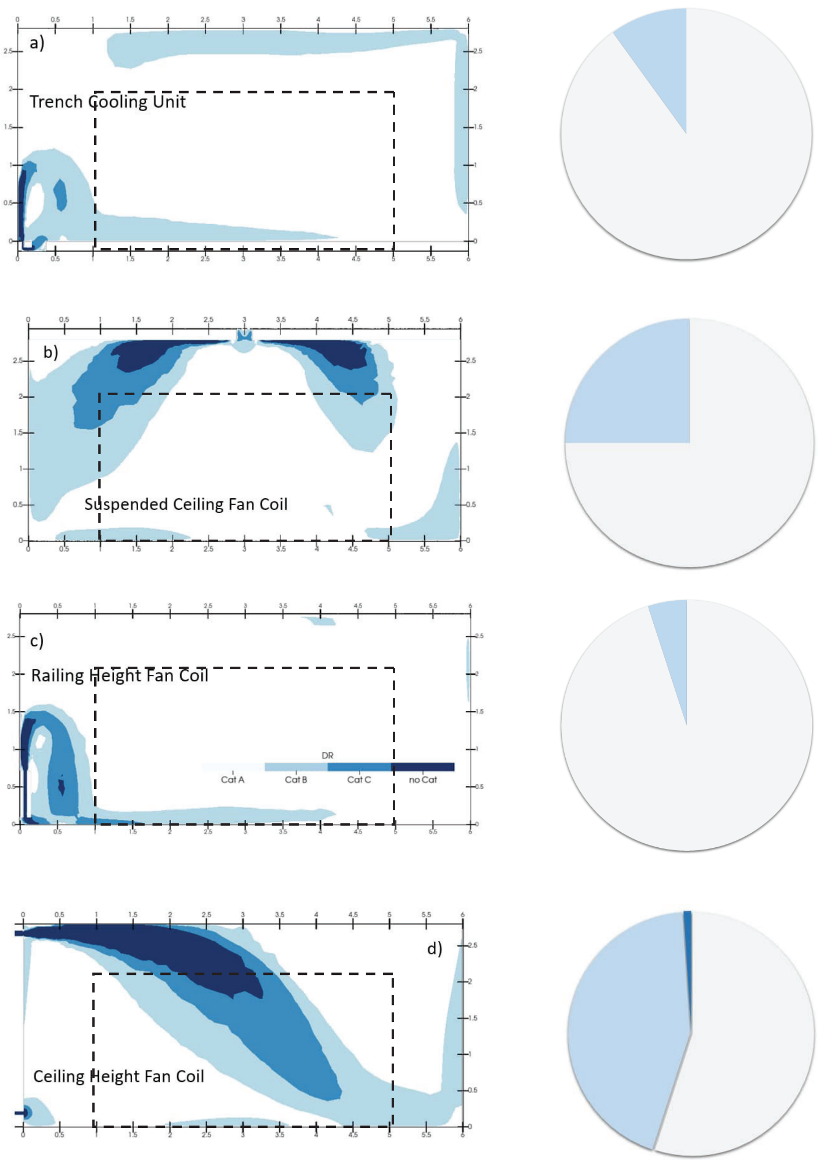

Figure 5 Different air flow strategies and resulting indoor categories in occupant zone according to ISO 7730.
Cat A Cat B Cat C no Cat

HVAC SYSTEM AS A PART OF BUILDING

The occupied zone is interesting for our analysis - not the entire volume of the room. It may sound cliché but it is often not clearly stated: in the HVAC industry there is no golden mean or ideal solution. The final effect can be achieved in different ways and using different systems. But as it happens in life, every choice has different consequences. And so the HVAC system is an element of the building, so it affects its organization, construction and use. Example of this sentence is on figure 6. The drawing is simplified but still true.

When using different end units, it is necessary to adjust them to the room, which may involve lowering or raising the storey. Here you see the same building floors but different net room heights. Currently, the market is observing a trend in new certified buildings to abandon the suspended ceiling and the direction of raw concrete. The issue of design is one thing, but also giving up so many kilograms of substructure, plasterboard, etc. significantly reduces the value of embodied carbon. And of course, as a consequence, we get higher and more attractive storeys, or you can lower them and save additionally on concrete, glass, or get one more storey and in this aspect also improve the building parameters.

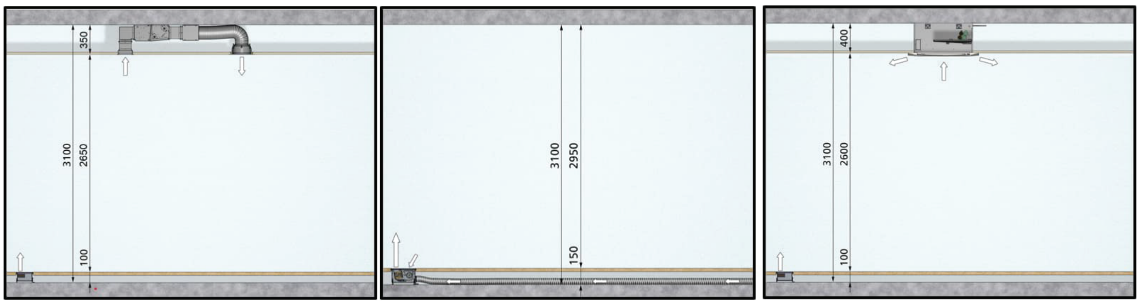

Figure 5 (a) Example cross-sections of stories in a building.

REDUCTION OF CARBON FOOTPRINT

The presented analysis showed that it is possible to achieve comparable categories of indoor environment with the use of various end devices implementing different strategies of air flow in the room. These devices are characterized by different construction, size and, due to the place of assembly, they affect the organization of the internal space between the storeys of the building.

Further analysis of solutions is based on a simplified comparison of Embodied Carbon und den Operational Carbon. In Table 2 below you can see the embodied carbon and the operational carbon as absolute values. For the analysis, it was necessary to adopt specific market applications. Typical devices currently available on the market were taken for analysis and operating points were determined to achieve the assumed cooling power of 1200 W. The analysis relates to a service life of 20 years for all four variants. The operational carbon is calculated using the German electricity mix (CO2 emissions from the German electricity mix).

Table 2. Comparison of Embodied Carbon und den Operational Carbon for commercial application

	Fan Stage	Embodied Carbon - 20 years [kg CO2 eq.]	Operational Carbon - 20 years [kg CO2 eq.]
Trench cooling unit	5,8 V	128,22	160,57
Wall installed fan coil on ceiling height	5,6 V	162,16	95,26
Ceiling installed fan coil	5,4 V	150,98	95,26
Suspended Ceiling fan coil	2 V	164,14	68,04

The indicated impact of the HVAC system on the organization of the building can also be analyzed in terms of possible carbon footprint reduction. The schematically shown possibility of reducing the height of the storey with the right selection of HVAC devices can be of significant importance for the material savings of the building. The floor system has a significantly distributed air supply area so as to introduce linear circulation air along the façade. Thanks to this assumption, the solution is shallow and it is possible to resign from the suspended ceiling at the same time. This is shown schematically in Figure 6.

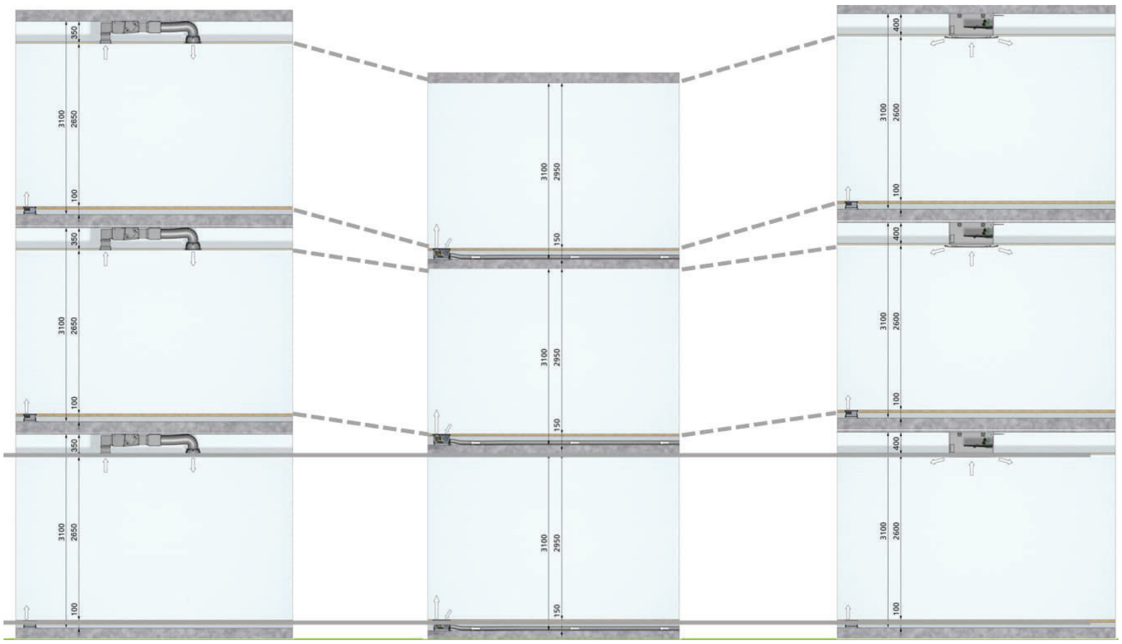

Figure 6 Example cross-sections of a building.

Depending on the building, it is possible to individually estimate the existing savings in construction and façade material and the resulting reduction of Embodied Carbon. Of course, yes, and the above analysis is carried out for each case individually and the presented numbers are only an example to show certain dependencies and relationships.

Table 3. Embodied Carbon

Product	Embodied Carbon - 20 years [kg CO2 eq.]
Construction concrete (C20/25)	172,69
Glass facade (insulating glass, double glazing)	24,48
Glass facade (insulating glass, triple glazing)	37,05

CONCLUSIONS

Analyzed was the comfort room for the summer case with medium requirements. For the room, four different strategies for bringing of circulating air into the room were analysed. The CFD analysis showed differences in the indoor environment categories achieved in the occupied zones. The data presented in this way enable comparison and evaluation between different HVAC system implementation scenarios. This study also shows that the final choice of the HVAC system affects the architectural organization of the room and may also affect the size of the storey. The interaction of the HVAC system and the building also enables the analysis of the carbon footprint and the search for the most optimal solution in terms of carbon footprint.

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