



**AALBORG
UNIVERSITY**

Master thesis

**Assessment of workstation-specific IEQ performance in
offices - a proof of concept from three selected criteria**

Katerina Dittmerová, Natali Lepsová, Petra Téglás

Department of Built Environment

Faculty of Engineering and Science

Aalborg University

Supervisors:

Lasse Rohde

Rasmus Lund Jensen

Abstract

This paper presents the development of a methodology for an evaluation tool for Indoor Environmental conditions in office buildings. It is based on the principles of IEQ Compass for residential buildings, which emphasises the simplicity of the evaluation, clear communication of the results, and accessibility. The tool strictly focuses on open-plan offices and the evaluation of individual workstations within the room. It is designed to assess office environments and support construction design, renovation proposals, or the change of the workstation layout.

Through the examination of existing frameworks, standards, and regulations, research was conducted to define the parameters for Thermal comfort, Atmospheric comfort, Visual comfort, and Acoustic comfort. The key factors guiding the selection of parameters are well-being and productivity of occupants. A labelling system was developed at the workstation, room, and building levels, ensuring that full traceability from individual workstation conditions to room and building performance. The evaluations of the selected criteria were prepared and tested on three different open-plan office cases. Additionally, the paper presents one renovation case, and one example of a workstation layout change to demonstrate the potential application of the tool.

Keywords: Indoor Environmental Quality, Office building, Open-plan office, Workstations, Local discomfort, View out, Speech transmission index

Table of contents

1.	Introduction.....	6
1.1.	Literature review.....	7
1.1.1.	Purpose and scope of the literature review	7
1.1.2.	Importance of indoor environmental quality in office environments	7
1.1.3.	Existing frameworks, standards and regulations for IEQ assessment	8
1.1.4.	Overview of existing IEQ tools and certification systems.....	9
1.1.5.	Existing IEQ Compass	10
1.1.6.	Identified gaps and the need for workstation-specific IEQ assessment tool ...	11
2.	Methodology	11
2.1.	General framework	11
2.2.	Selection of parameters.....	11
2.3.	Preparation of workstation-specific parameters.....	12
2.4.	Development of the labelling system.....	13
2.5.	Testing process on case study open-plan offices	13
3.	Results.....	15
3.1.	The outline of the tool.....	15
3.1.1.	Tool design.....	15
3.2.	IEQ parameters	15
3.2.1.	Atmospheric comfort	15
3.2.2.	Thermal comfort	17
3.2.3.	Visual comfort	22
3.2.4.	Acoustic comfort.....	27
3.3.	Labelling system	32
3.3.1.	Communication of results	32
3.3.2.	Labelling process	33
3.4.	Application of the method	37

3.4.1.	Case building introduction.....	37
3.4.2.	Application on case buildings.....	37
3.4.3.	Comparison of room specific and the standard method of evaluation.....	46
3.4.4.	Renovation.....	47
3.4.5.	Change of the workstation locations.....	49
4.	Discussion.....	51
5.	Conclusion.....	52
6.	Appendix.....	54
6.1.	Literature review.....	54
6.2.	Selection of parameters.....	55
6.2.1.	General procedure.....	55
6.2.2.	Atmospheric comfort.....	57
6.2.3.	Thermal comfort.....	69
6.2.4.	Visual comfort.....	82
6.2.5.	Acoustic comfort.....	93
6.3.	Tool outline.....	106
6.3.1.	Design – tool structure.....	106
6.3.2.	Labelling system example.....	107
6.4.	Evaluation of parameters.....	111
6.4.1.	Operative temperatures.....	111
6.4.2.	View out.....	117
6.4.3.	Speech transmission index.....	122
6.5.	Application of the tool.....	129
6.5.1.	Case buildings.....	129
6.5.2.	Innovate results.....	132
6.5.3.	FBV results.....	134
6.5.4.	Create results.....	138

6.5.5.	Room-based assessment results	141
6.5.6.	Renovation (view out improvements)-results	142
6.5.7.	Change of layout (STI improvement)-results	144
7.	List of references.....	146

1. Introduction

People typically spend a considerable amount of time at work. Most office-related jobs are performed in modern office buildings. In recent decades, the design of office spaces in these buildings has been evolving, and many office buildings now feature mostly open-plan offices rather than traditional small individual offices. These open-plan layouts accommodate many people in a shared environment, which raises the importance of maintaining proper Indoor Environmental Quality (IEQ) [1].

IEQ balances four different areas: thermal comfort, atmospheric comfort, visual comfort, and acoustic comfort. All of these factors need to be considered in the office spaces. In open-plan layouts, factors such as workstation location and proximity to the façade have been shown to influence occupants' perception of comfort, suggesting that IEQ conditions can vary across different areas of the room [2,3].

Numerous studies highlight the importance of the role that IEQ plays in occupants' well-being and productivity. Well-being is often specified as a combination of health and comfort, reflecting how factors such as lighting, acoustics, air quality, and spatial layout shape occupants' perception of their office environments [1,4]. The office environment can influence workers' productivity and their ability to focus on their tasks, which may differ in certain office settings [5,6]. Improving IEQ and productivity in office spaces benefits both employees and businesses. It leads to greater time efficiency and profitability. Therefore, it is in the best interest of office owners to create an appropriate office environment for their workers [1,5,7].

Currently, the market offers various certification tools for evaluating various conditions in building projects. One such tool is the IEQ Compass, which evaluates the potential IEQ performance. It is a holistic tool designed to evaluate IEQ in residential buildings in Denmark, supporting comfort and well-being of occupants in both new constructions and renovations [8]. There are a few tools, such as DGNB, LEED, and BREEAM, that consider IEQ conditions in office spaces. IEQ evaluation is just a small considerable part of these tools, apart from other aspects [9-11]. Additionally, TAIL evaluates offices and hotels through measurements [12].

However, these tools generally assess IEQ conditions and the office as a whole and do not consider workstations and their layout in the room. This can overlook varying conditions throughout the room, on various workstations. Since workers usually have a dedicated workspace in their office, evaluation of the whole room may not accurately reflect conditions

in different workstations. Therefore, there is a need for a tool that specifically focuses on occupants' experiences in their individual workstations.

This study presents the development of a methodology for an evaluation tool designed for office environments, based on the principles of the IEQ Compass for residential buildings. The tool emphasizes simplicity of evaluation, effective communication, and accessibility. It focuses on IEQ conditions in buildings and supports renovation decisions and construction designs. Occupants' well-being and productivity were key requirements while designing the methodology for this tool, as well as a focus on the workstations. The tool emphasizes numerous IEQ parameters that can be assessed with workstation-specific evaluations. The paper also presents workstation-specific assessment for three different parameters.

1.1.Literature review

1.1.1. Purpose and scope of the literature review

The purpose is to form a theoretical background for the preparation of an IEQ assessment tool for office buildings, with the main focus on workstation location assessment. IEQ is covering thermal comfort, indoor air quality, visual comfort, and acoustic conditions, which all influence how occupants experience the office environment during prolonged periods of sedentary work [13].

This literature review then focuses on existing IEQ assessment evaluations that are relevant to office environments, with a focus on local conditions. Based on this review, gaps in current methods are identified and form the basis for this research paper.

1.1.2. Importance of indoor environmental quality in office environments

Indoor environmental quality plays an important role in office environments. Where occupants typically spend long periods performing sedentary work that requires concentration [1]. A considerable amount of research shows that IEQ affects not only occupants' well-being but also work performance and productivity. This makes it a relevant factor from both human and economic perspective [14].

Thermal comfort, in particular, influences productivity as even small deviations from comfortable temperature ranges may lead to reduced focus and increased dissatisfaction [15]. Similarly, higher levels of indoor air pollutants or insufficient ventilation rates have been linked to decreased cognitive performance and increased errors made in office tasks [16]. Lacking

conditions in visual comfort also shown reduced time of concentration and discomfort that can lead to headaches [17], while a noisy environment can cause distraction and an overall decrease in productivity [18].

Beyond individual comfort, good IEQ also affects organizational performance. Improved IEQ conditions have been associated with reduced absence, lower rates of sick leave, and improved self-reported productivity [19]. From an economic perspective, the potential gains from improved IEQ can outweigh the additional costs of design measures or system optimization long term, as personnel costs typically have a large share of operational expenses [20].

While IEQ is often assessed as one value representative for the whole room, several studies highlight that occupants' experiences are influenced by local conditions at their specific workstations [1]. Variations in thermal comfort, air movement or exposure to noise and glare within the same office can result in different levels of comfort and productivity among occupants [15-18]. This suggests that building or room-level assessment may overlook local factors.

1.1.3. Existing frameworks, standards and regulations for IEQ assessment

Indoor environmental quality is addressed through international standards, Danish regulations and research-based frameworks that define acceptable indoor conditions and assessment methods for thermal comfort, indoor air quality, visual comfort and acoustic performance.

Thermal comfort is commonly evaluated in standards such as ISO 7730, DS 474 and EN 16798, which define comfort criteria based on parameters such as air temperature, mean radiant temperature, air velocity, clothing insulation, and metabolic rate. These standards primarily aim to define acceptable indoor conditions for typical occupants and activities. While they acknowledge the concept of local discomfort, including draught, vertical temperature difference and radiant temperature asymmetry, their application often relies on measured data [13,21,22].

Indoor air quality is addressed mainly through Danish Building Regulations (BR18), DS 7730, DS 447 and EN 16798, which specify ventilation rates, indoor pollutant limits and design principles for healthy indoor environments. These standards typically focus on ensuring sufficient fresh air supply and acceptable pollutant concentration at the room or building level. In general, the standards often overlook the air quality tied to the specific location within the rooms [13,22-24].

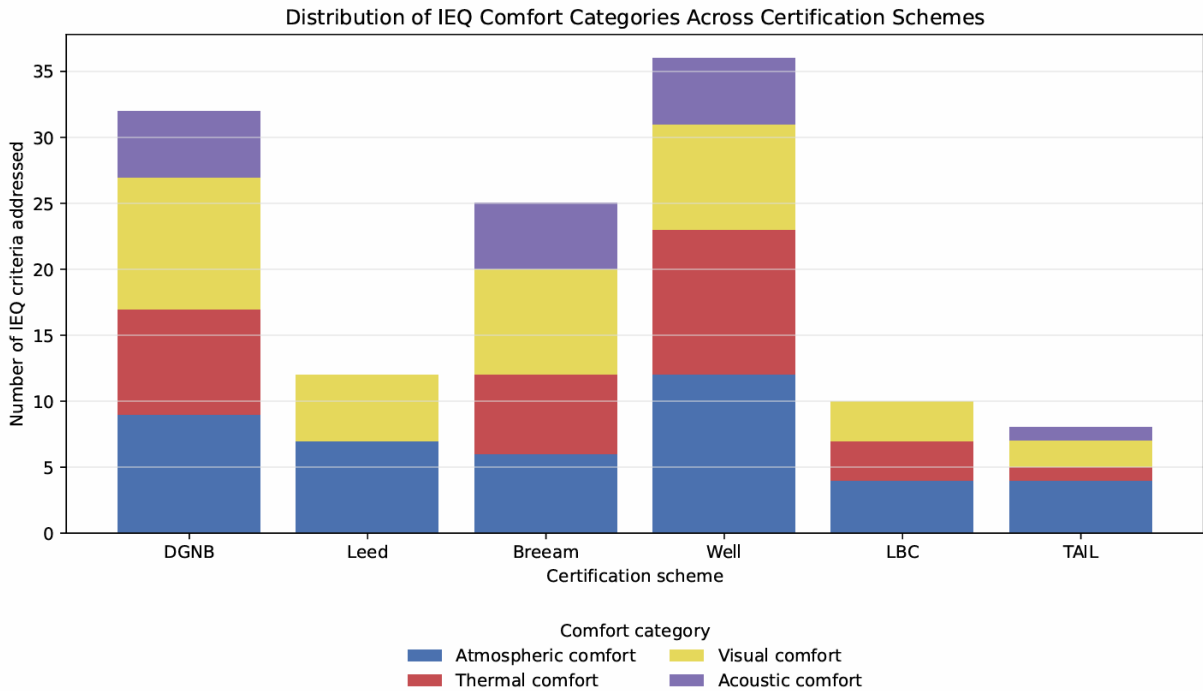
Visual comfort is primarily specified in the standards DS/EN 17037, DS/EN 12464, as well as BR18. The topics mostly cover natural light, sunlight, views, and electric lighting as the main aspects concerning visual comfort. These standards outline requirements and limits for all these elements, while also considering unwanted effects like glare and flickering. Additionally, solar shading plays a significant role in visual comfort, influencing the environment, which is partly covered in standard DS/EN 14501 [25-27].

Acoustic comfort in office environments is primarily addressed through Danish and European standards, including DS/EN ISO 3382, DS/EN ISO 717, DS/EN ISO 16283, DS/EN 16798-1, and the BR18. These frameworks define requirements for indoor noise levels, sound insulation, and room acoustic conditions. Acoustic comfort generally includes protection against external noise, management of sound transmission between spaces, and control of sound quality in occupied areas. Factors that are considered based on their impact are reverberation, background noise, sound from occupants, as well as technical installations. Speech clarity and sound privacy are also important aspects in office environments, which are generally less documented. [22,23,28-30].

1.1.4. Overview of existing IEQ tools and certification systems

Several building assessment and certification systems, including WELL, DGNB, BREEAM, LEED, TAIL and Living Building Challenge incorporate IEQ as part of a broader evaluation of building performance. In these tools, IEQ is either assessed alongside energy use, environmental impact, materials and management strategies or is solely evaluated through on-site measurements and simulations [9-12,31,32].

The comparison graph shows how much each of the evaluated tools focuses on the IEQ comforts. It is visible that DGNB and WELL certifications address the biggest number of criteria and are generally including significant portion of each comfort. The data for the graph are described in Appendix 6.1.



1. Figure Distribution of IEQ Comfort Categories Across Certification Scheme

As can be seen in Figure 1, some of the frameworks place a stronger focus on the occupants' well-being than others, the IEQ criteria often represent only one component within a larger certification structure. The evaluation is often limited to selected indicators and compliance with requirements, rather than a comprehensive analysis of indoor environmental conditions. In most cases, IEQ assessment is conducted at the building or zone level and is mostly based on documentation, design intention and average performance.

Although some tools like TAIL [12] allow for measurements or after occupancy evaluation, these are typically applied to verify overall performance rather than to assess local conditions experienced by individual occupants.

1.1.5. Existing IEQ Compass

Recent research has introduced a simplified IEQ assessment tool that focuses on residential buildings. This tool aims to simplify complex indoor environmental parameters into a structured assessment that supports design decisions and in general evaluate the IEQ without extensive measurements or simulations [8].

The IEQ Compass for residential buildings uses a scoring system covering thermal comfort, indoor air quality, daylight availability and acoustic conditions. The assessments are often based on design data and standard assumptions regarding occupants' behaviour, making them suitable for early design stages or evaluation of already built buildings [8].

1.1.6. Identified gaps and the need for workstation-specific IEQ assessment tool

The reviewed literature shows the importance of good IEQ in office buildings and that the location-specific assessment is greatly overlooked in most of the standards and the assessment tools. As found, most current approaches assess IEQ either as a small part of broader building analysis or through detailed technical analysis and measurements that are not easily performed, especially in the initial phase of the building design. As a result, the evaluation is often prepared on a whole building or room level, which can overlook significant local variations experienced by occupants.

These identified gaps highlight the need for an IEQ assessment tool focused on office environments with a clear focus on workstation-specific evaluation. Such a tool can support designers, engineers and facility managers in identifying critical IEQ risks, comparing different design solutions and supporting optimal workstation layout for the room.

2. Methodology

2.1. General framework

This study follows a methodological framework consisting of a literature-based research on parameter selection, development of a workstation location-specific IEQ assessment tool and validation using case study office rooms.

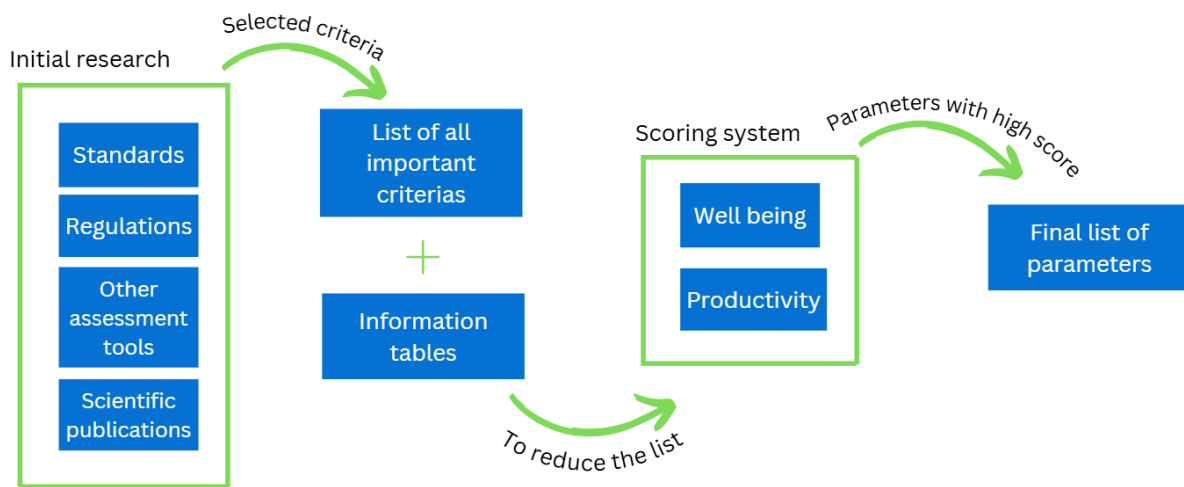
2.2. Selection of parameters

The selection of parameters follows a structured process to identify the factors most relevant for assessing IEQ in office spaces. The aim was to base the tool on parameters that have a clear influence on occupants' well-being and productivity and that can be evaluated using simplified methods without relying on measurements.

First, a gross list of possible parameters was created by reviewing relevant standards, regulations, scientific publications and existing assessment tools. The parameters that were determined as having the highest impact on the occupants, when it comes to workstation-specific location, were included. These parameters were grouped into the four comforts: thermal, atmospheric, visual and acoustic comfort. Each parameter on the list was described to clarify how it could be evaluated using available information and simple procedures. This made it possible to identify which parameters were possible to apply in IEQ assessment of office rooms and open-plan offices with simplified methods.

To narrow the list, a simple scoring system was used where each parameter was rated from 0 (lowest) to 3 (highest) based on its importance for IEQ, specifically impact on productivity and well-being. This tight scale was chosen to keep the process straightforward and to reflect the level of detail typically available in literature and standards.

The final lists for each comfort were then formed into tables, which grouped the parameters according to the source of origin. The resulting set of parameters formed the basis for developing the evaluation methods and labelling system described in the following sections.



2. Figure Diagram shows the parameter selection process

2.3.Preparation of workstation-specific parameters

Three parameters were prepared for detailed evaluation: view out, operative temperatures, and local acoustic conditions. These were chosen because they can be assessed within the outlined framework. At the same time, these are not normally evaluated based on the position in the room, but there is literature that makes it possible to assess them based on spatial location. Together, they provide good proof of concept that criteria can be workstation-specific across the different comfort domains.

The preparation of the evaluation methods relied on relevant standards, regulations, scientific publications, and existing assessment tools. These sources guided how each parameter should be defined and which requirements and considerations needed to be included. The evaluation criteria were developed using relevant equations, clear thresholds and simple categorization. For each parameter, the necessary inputs, such as for example distances, geometry, shading conditions or surface temperatures, were identified. Several simplifications were introduced to

keep the procedures aligned with the overall IEQ Compass approach, meaning they can be applied through calculations and visual assessment rather than simulations and measurements.

2.4. Development of the labelling system

The IEQ labelling system was developed to provide a consistent and scalable way to communicate results across comfort domains, workstations, rooms and building. The structure builds on the scoring system used in the IEQ Compass for residential buildings, where each criterion receives 0-10 points. This range was kept because it is simple, flexible and can easily accommodate future adjustments or additional parameters without changing the whole structure of the tool. For the combined IEQ score, the four comfort domains were given equal importance, each representing 25% of the overall label.

The key part of the process was determining how results should be presented across the three levels of the tool: workstation, room, and building. The main difference from the already established IEQ Compass methodology is that the evaluation is location-specific as opposed to room-specific. This means that a much bigger amount of results is taken into consideration, which aims to not only assess the overall IEQ performance of the room/building, but also to inform the users about the spatial performance within the room, possibly helping to determine optimal workstation locations. The intention was to prepare a method able to capture local variations within open-plan offices while still providing a clear representation of the overall IEQ conditions.

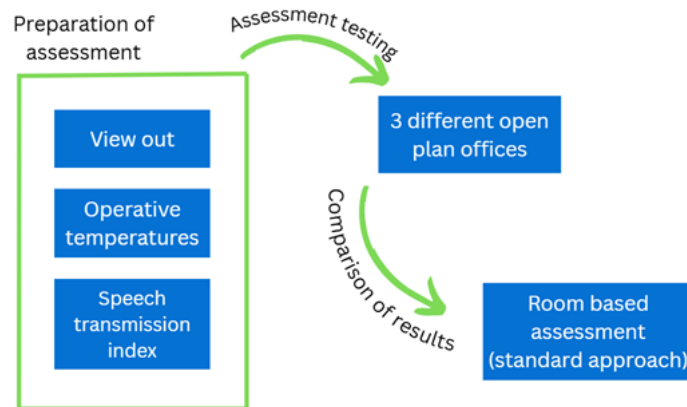
The same procedure was applied when defining how room-level labels should be combined to accurately represent one label for the whole building. The labelling system across all three levels supports the purpose of the tool, identifying suitable workstation location, understanding differences between offices, and providing an overview of the building performance.

2.5. Testing process on case study open-plan offices

The developed IEQ assessment methods were tested for three parameters (view out, operative temperatures and speech transmission index). The methods were applied in three office rooms located in different AAU buildings, allowing variation in geometry, façade conditions, workstation layout and their number.

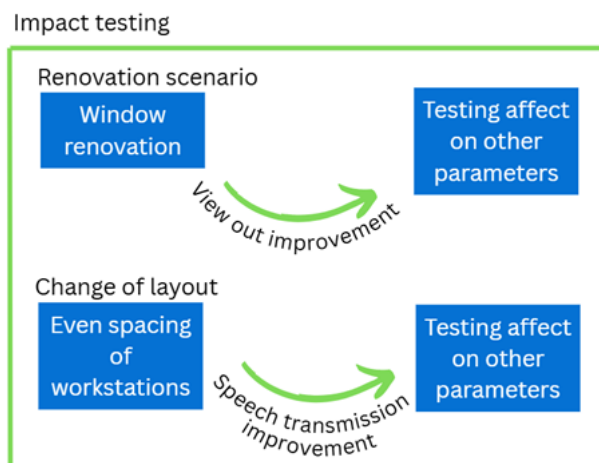
Each parameter was first evaluated at the individual workstation level to assess if the methods capture spatial differences within the office. The results were then compared with a room-based

assessment, representing the approach commonly used in standards, in order to evaluate differences between local and global evaluation.



3. Figure Testing process on case study open-plan offices

To examine interactions between parameters, two modification scenarios were prepared and analyzed in one selected office room. A window size increase was used to improve the view out and assess its impact on operative temperature and speech transmission index, while a change of layout of workstation, which included even spacing between the occupants, was used to improve the speech transmission index and further evaluate the effect on the remaining parameters.



4. Figure Renovation and change of layout proposal testing

Through this process, the evaluation methods were tested on their ability to differentiate spatial variations within the room, identify differences between workstation-level and room-level assessment, and capture interactions between evaluated parameters resulting from design or layout changes.

3. Results

3.1. The outline of the tool

The IEQ Compass for office environments is a methodology that can be used for either renovation projects, in the design of new office spaces, or to assess performance in existing spaces. The focus is on assessing the indoor environment conditions for occupants, especially in relation to their well-being and productivity.

3.1.1. Tool design

This evaluation tool assesses IEQ conditions in office spaces. In its current implementation, it considers only the office rooms in the building, excluding other areas with a different purpose. The tool is designed to easily, with a simple structure, evaluate the conditions in the room without any on-site measurements. The aim is to keep the process simple and time-efficient while providing results that represent the IEQ conditions experienced by the occupants.

The whole tool covers all four comforts: thermal comfort, atmospheric comfort, visual comfort, and acoustic comfort, where each is further divided into several parameters and criteria. The tool includes 16 parameters in total, specified for all the comforts.

In the proposed tool methodology, all parameters are weighted equally, however the tool design allows for future implementation of parameter weighting to reflect their varying impact on occupants.

The evaluation process for all parameters is designed to evaluate separate workstations to better specify varying conditions in the room. Each office is evaluated separately to provide a clearer representation of all conditions and separate well-performing and poorly-performing rooms.

3.2. IEQ parameters

The proposed IEQ methodology evaluates each comfort domain through defined parameters that describe the conditions relevant for occupants in the office space. The following sections introduce the parameters proposed for the tool and outline how the selected ones are assessed at workstation level. The detailed description of used method is described in Appendix 6.1

3.2.1. Atmospheric comfort

Atmospheric comfort depends on the amount of pollutants in the indoor air and describes how the air is perceived during use of space. It includes both pollutants that enter from outdoors and those generated indoors by materials, building systems, and occupants. As modern offices are

typically mechanically ventilated, the quality of the supplied air and the pollutant sources inside the room have big role in shaping overall atmospheric conditions [33]. Atmospheric comfort is evaluated through a table of parameters, which address all different groups of pollutant sources that can influence the indoor environment.

1. Table

Atmospheric comfort selected parameters and criteria

	Parameter	Criteria
ATM1	Influence from outdoors	PM _{2.5} / PM ₁₀
		Ultrafine Particles (UFP)
		Radon
ATM2	Impact from building and materials	TVOC (Total Volatile Organic Compounds)
		Formaldehyde
		Moisture in materials / hidden mold
		Microbial contamination (HVAC systems)
ATM3	Impact from the occupants	CO ₂ concentration
		Odor / perceived air freshness
		Relative Humidity (RH)
ATM4	User ability to adjust the indoor climate	Operability of windows
		Local control of ventilation

The ATM1 is a parameter that focuses on the impact of outdoor air quality on the indoor environment. Pollutants such as PM_{2.5} / PM₁₀, UFP and radon mainly originate outside the building and can enter through the ventilation system or infiltration [24]. The assessment reflects how effectively the building envelope and ventilation system prevent or reduce these pollutants from reaching occupied space. This parameter captures conditions that are independent of how the room is used and instead depend on the building's location and outdoor environment.

The second parameter presented in the table considers pollutants that originate from the building itself. These include emissions and off-gassing from construction materials, finishes and furniture, as well as the presence of moisture problems. It also takes into consideration potential microbial contamination within HVAC systems. These sources are often long-term and building-dependent rather than user-dependent.

The ATM3 reflects how occupants themselves can contribute to the atmospheric conditions in the room. This parameter covers CO₂ concentration, odours/perceived air freshness and humidity that increases with activity levels and occupants' density. These criteria reflect how well the ventilation strategy dilutes or removes pollutants generated by people. Unlike the previous parameters, this one varies with the actual use of the space.

The ability to adjust the indoor climate focuses on the ways the atmospheric comfort can be affected by occupants' actions. In this case, the operability of the windows and adjustment of mechanical ventilation are added due to their possibility to improve perceived air quality locally [35].

3.2.2. *Thermal comfort*

Thermal comfort describes how occupants perceive the thermal conditions of the room during use and is determined by the interaction between the indoor environment and human being [13]. Parameters such as air and operative temperature, mean radiant temperature, air movement, and surface temperature are often used for the determination of indoor thermal conditions. The way that heating, cooling, and solar gains are controlled plays important role in the evaluation as well. In office buildings, where thermal conditions are often affected by the mechanical systems, these factors can vary based on the season or the location within the same room [34].

Thermal comfort is assessed through the table of parameters that address both summer and winter conditions.

2. Table

Thermal comfort selected parameters and criteria

	Parameter	Criteria
THER1	Summer comfort	Excessive temperatures
		Operative temperatures for unheated season
		Draught risk from cooling
		Surface temperatures in cooling season
THER2	Winter comfort	Under temperatures
		Operative temperatures for heating season
		Draught risk
		Surface temperatures in heating season
THER3	User ability to adjust thermal comfort	Solar shading control
		Window operability
		Local temperature control

For the summer comfort, the table aims to identify the potential of overheating within the space as well as focus on the local discomfort caused by the solar radiation, draught from the cooling system or the possibility of uncomfortable surface temperatures caused by the design of the cooling system.

The excessive temperatures evaluate the number of hours exceeding comfortable thresholds introduced by BR18 [23]. The main goal is to show how the room functions within the whole year to determine its compliance with the regulations. The operative temperatures for the unheated season focus on the local discomfort risk caused by radiation at different locations within the office. In this case, the solar radiation plays an important role. Further, draught risk from cooling aims to determine local discomfort caused by the draught during summer conditions, which is often linked with the cooling system, and the surface temperatures in the cooling season focus on the cooling system design.

The winter comfort follows a similar evaluation pattern as summer comfort but pays attention to the heating system design more. The under temperatures evaluate the heating system and the construction design and aim to determine the room's ability to keep comfortable temperatures. The operative temperatures focus on the local discomfort through radiation during winter conditions, which depends on the surface temperatures and the occupant's position [35]. As occupants are more sensitive to the draught in colder indoor conditions [13], the draught risk aims to assess the possibility of local discomfort caused by draught. This evaluation should take into consideration the draught caused by the ventilation system and the possibility of downdraught. The surface temperatures in the heating season are centred around the surface temperatures of the heating system design, which could cause discomfort.

The user ability to adjust the thermal comfort mainly focuses on the possibility of local adjustments. Which in this case is the solar shading system that can affect the discomfort caused by direct solar radiation, the window operability that allows mixing of outdoor air with the indoor air which supports adjusting the local indoor temperature with outdoor conditions. The local temperature control centres mostly around the possibility to adjust heating system.

3.2.2.1. Assessment of the operative temperatures

The operative temperatures are used as one of the main indicators in thermal assessment of IEQ for evaluating how occupants perceive thermal comfort since it combines the effect of mean air temperature and mean radiant temperature. Even though the standards, as DS 474, propose to evaluate operative temperature at two locations in the room (the critical location

and the representative location of the occupied zone), such an approach does not necessarily represent the local conditions experienced by the occupants [21].

As previously mentioned, the thermal conditions may vary within the same room, mainly in large open-plan offices. Since the occupants are typically in a sedentary position and remain to one location for longer periods, they might be more sensitive to local thermal effects.

For those reasons, the assessment for operative temperatures for summer and winter conditions was developed. The main objective of this evaluation method is to identify possible local thermal discomfort with a focus on the radiant effects caused by surrounding surfaces and solar exposure.

General approach.

Both summer and winter conditions are assessed as critical but still representative scenarios. This is done by predefined boundary conditions based on the SBI 202, DS 447, where the actual weather data is used or by reference guidance that is used for designing technical systems [24,36] (Appendix 6.4.1).

Even though the overall assessment of both conditions is conducted similarly. The air temperature and mean radiant temperature are used, and the main difference is in the treatment of radiation.

THER1.2 Summer condition-operative temperatures.

The summer condition takes into consideration the solar radiation that heats up the surface exposed to it. This is conducted in a way where the calculation of Sol-air temperature is determined to calculate more representative outdoor air conditions on the element boundary.

The workstations that have a possibility of being directly hit by the solar radiation in the room are identified. For those locations, the calculation is adjusted to account for the effect of direct solar radiation on the workstations. In this case, the shading is taken into consideration as well.

The workstations outside of the lit zone are excluded from this calculation and take into consideration only solar radiation-adjusted surface temperatures. This way, there are clear variations within the room, which highlight the potential risk of local discomfort caused by solar radiation.

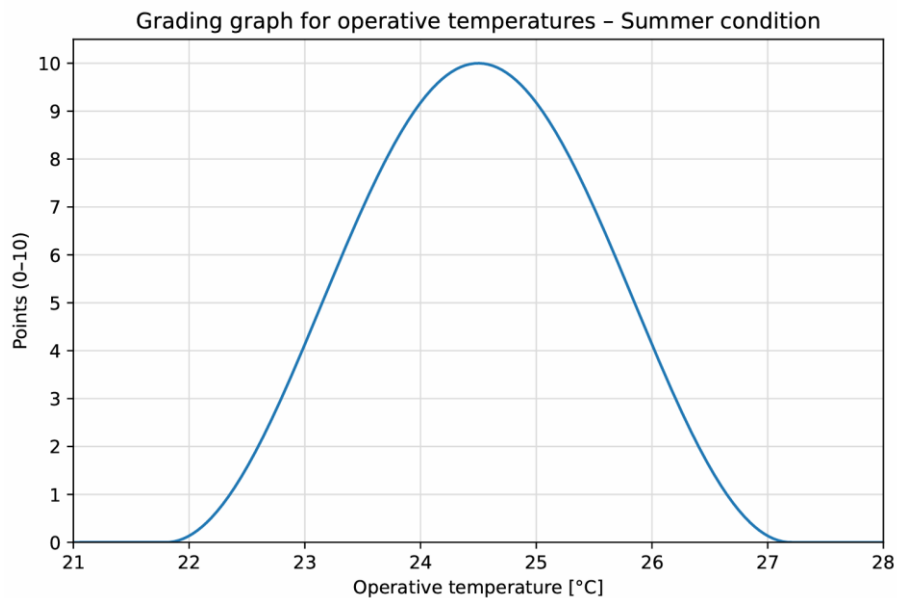
The results for each workstation are assessed on the 0-10 point scale. The points are distributed based on the IEQ categories for operative temperatures from ISO 7730 [13], where the optimal operative temperature for summer in office rooms is:

3. Table

Operative temperature categories and limit values (Summer condition)

Category	Operative temperature
I	24.5±1.0
II	24.5±1.5
III	24.5±2.5

Based on this table, the grading graph was created, which is to be used for the conversion of the resulting operative temperatures into points achieved.



5. Figure Thermal comfort - Grading graph for operative temperature (summer condition)

THER2.2 Winter condition-operative temperatures.

Since the summer and winter conditions aim to assess the critical conditions, the winter evaluation does not include the solar radiation in the calculation process. This calculation represents cold winter conditions with an overcast sky, which is typical for Denmark.

The operative temperatures are calculated from the mean radiant temperature (MRT) and the mean air temperature. The MRT is determined the same way as summer condition with guidance of the ASHRAE fundamentals [35] and the Guidebook Varme og klimateknik Ventilationsteknik [37], through the view factor and the surface temperatures.

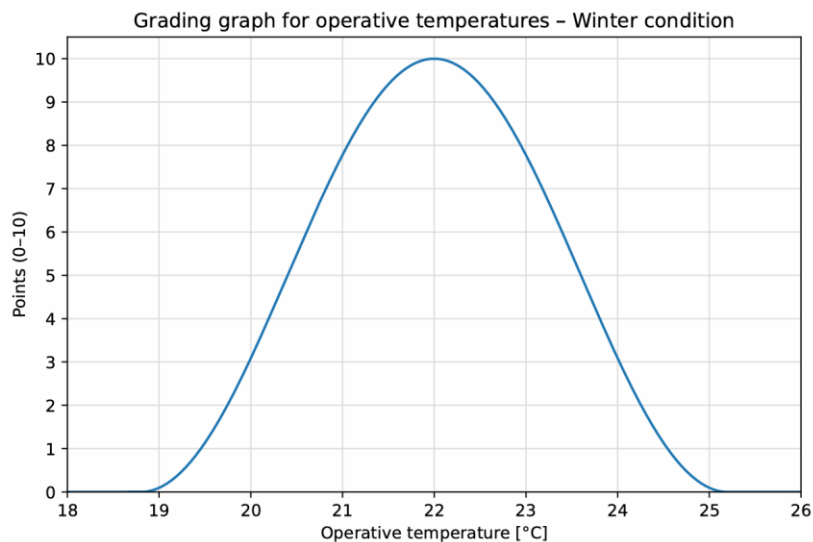
The results for each workstation are assessed on the 0-10 point scale. The points are distributed based on the IEQ categories for operative temperatures from ISO 7730, where the ranges for the heated season in office rooms are:

4. Table

Operative temperature categories and limit values (Winter condition)

Category	Operative temperature
I	22±1.0
II	22±2.0
III	22±3.0

Based on this table the grading graph was created, which is to be used for the conversion of the resulting operative temperatures into points.



6. Figure Thermal comfort - Grading graph for operative temperatures (winter condition)

Both evaluations are determined for each workstation placement in the room for sitting position of the occupants. Which means the height of 0.6m is used.

3.2.3. Visual comfort

Visual comfort generally focuses on light produced by various sources, which are both of natural or electrical origin. It examines the performance of the light, how it influences the experience of occupants in the room, and any negative effect that the sources may have. Apart from light distribution and its impact on the environment, visual comfort also includes the views from the room and related properties. All office spaces suitable for work require proper lighting conditions and a view. It is especially important in open-plan offices where the light distribution can vary across different workstations.

Visual comfort is separated into different parameters and criteria, which are outlined in the table. Some parameters vary in different workstations, so the evaluation is workstation-specific.

5. Table

Visual comfort selected parameters and criteria

	Parameter	Criteria
VIS 1	View out	Quality of the view
		Window and obstructions
		Position of the workstation towards window
VIS 2	Daylight	Illuminance from daylight
VIS 3	Sunlight	Glare
VIS 4	Electric lighting	Illuminance
		Colour rendering
		Glare
		Flicker
VIS 5	Control	Sun protection
		Electric lighting

First parameter VIS 1 investigates the view out. The view from the room is an important aspect for the occupants in the room. It provides them with awareness of the weather and time of the day, which contributes to their mental satisfaction [38]. This parameter focuses on the quality of the view, considering the layer of the view, the distance from the building, as well as windows, solar shading, or any fixed obstructions that could be in the way of a clear view. Additionally, the arrangement of workstations and their position in the room is essential for access to the view. Different horizontal sight angles and visible layers are dependent on the different positions.

VIS 2 is parameter daylight. This parameter and its criteria evaluate the amount of daylight that enters and illuminates the room. For the office environment, it is important to assess the daylight distribution through the room and different workstations within. If the area does not meet the threshold of 300 lux for half of the daylight hours, it is unsuitable for work and placement for workstations [23]. The window plays a critical role in the quality of daylight; its size and position on the wall affect, as well as light transmittance and colour rendering of the glass, all these aspects influence the overall lighting quality in the room.

Sunlight (VIS 3) is another parameter supporting visual comfort. While there are no requirements regarding direct sunlight, and it is generally not desirable in office spaces due to the uncomfortable glare it can create, having access to sunlight in the building is usually welcomed with proper solar shading [25]. This parameter does not focus on the availability of daylight in the room but evaluates its negative effect and protection from it. The main drawback considered is glare.

The VIS 4 emphasizes the importance of electric lighting as a key visual aspect in offices. Electric lighting involves the distribution of the light from the source and its illuminance within the space. Different light sources with varying properties can affect the comfort and experience of occupants in the room. One important property apart from illuminance is the colour rendering index. Additionally, artificial light sources can also create issues like glare, especially when combined with bright surfaces, or flickering, which is a disturbing effect and that is considered in the assessment. Placement of the light fixtures in the room affects the distribution over various workstations and their individual performance.

The section on user control (VIS 5) evaluates the potential for occupants to adjust the room conditions to enhance their visual comfort according to their preferences. Within visual comfort, the option is to adjust sun protection and electric lighting. Sun protection considers both external and internal shading of the windows and how they are operated. Additionally, the electric lighting in the room can potentially be adjusted based on the set operation and sectioning of the light fixtures. Having more options for operation and sectioning provides a bigger advantage for user control.

3.2.3.1. *Assessment of view out*

View is an important aspect of visual comfort, as it provides connections with the surroundings, offering information about the weather and supporting better mental health, comfort, and productivity [38,39].

To evaluate the view, multiple factors need to be considered. The quality of the view is evaluated based on a few qualitative aspects (layers) and quantitative (distance outside, horizontal sight angle) aspects. These aspects are separated into three criteria, which helps to make the evaluation process clearer.

VIS 1.1 Quality of the view.

Based on the European standard DS/EN 17037 [25], the quality of the view is evaluated based on the visible layers a person can see through the glazing. These different layers include sky, landscape (which can be urban or nature), and ground.

The tool evaluates the layers in three categories depending on the number of layers. The minimum requirement is having at least a landscape layer in view. Different numbers of layers score different amounts of points.

The visible layers are assessed from a certain workstation, specifically from a seating position towards every window in the room.

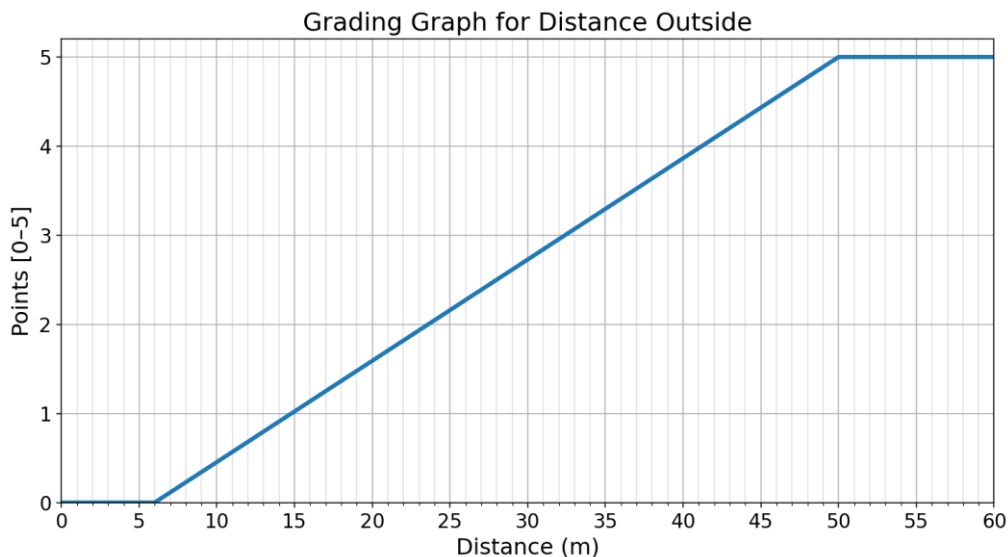
6. Table

Quality of the view - Assigned points for Visible layers and Number of layers

Visible layers	0	1	3	5
Number of layers	0	1 (needs to be landscape)	2 (landscape + one)	all

Another important aspect of view quality is the outside distance of the view. How people perceive the view is also dependent on the minimum distance from the glazing to the first object in the view [40]. The different ranges for this distance are specified in DS/EN 17037 [25].

The evaluation follows a graph with distances and corresponding points. The graph sets the minimum and maximum distances, which are inspired by the requirements from the standard. The minimum acceptable distance is 6 m; anything lower is not considered acceptable. And the maximum is set at 50 m, with any distance beyond this still receiving the maximum of 5 points.



7. **Figure** Visual comfort - Grading graph for distance outside

Evaluate (measure) the distance of the view outside from the window and choose a corresponding range.

VIS 1.2 Windows and obstructions.

Any obstructions in the view can disrupt the quality and accessibility of the view. Obstructions inside are mostly considered fixed objects that cannot be moved. In an office environment, fixed obstructions include any permanent building elements or furniture. Items like computer screens, decorations, or similar are not considered obstructions, as they can be easily moved as needed. Similarly, obstructions outside are also limited to fixed elements.

Solar shading can also disturb the view depending on its type and light transmittance. The quality of visual contact with the outside is evaluated based on how well the solar shading allows external view. The conditions vary throughout the day; however, the standard conditions are assessed based on normal/normal transmittance $\tau_{v,n-n}$ [27].

All the obstructions and solar shading should be evaluated from a specific workstation in a seating position and through every window. Points are awarded based on the designated evaluation Table 7.

7. Table

Visual comfort - Obstruction of view - point system

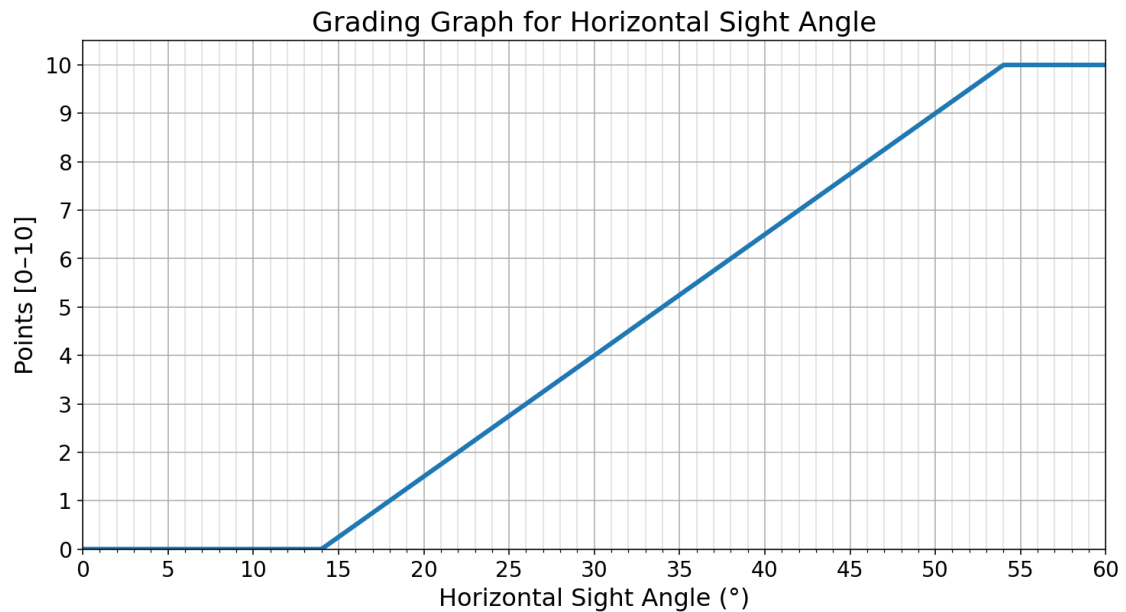
Obstructions of view	0	1	2	3
Inside (fixed)	Yes (completely/mostly blocks the view)	Yes (partially blocks the view)	Yes (there is only a really small disruption to the view)	No
Outside (fixed)	Yes (completely/mostly blocks the view)	Yes (partially blocks the view)	Yes (there is only a really small disruption to the view)	No
Solar shading	No view through the shading	The view outside is possible but disrupted (outside picture is not clear)	Clear view outside	No shading
Extra point	Window has clear glazing and a transmittance of 70 % or more			

The properties of the window play an important role in the view as well. The window needs to offer a clear view with neutrally coloured glass. However, it is important to check the transmittance of the glass. The higher transmittance of glass provides better view quality. One extra point is only rewarded when the glazing of the window performs exceptionally well, reaching a minimum of 70 % of transmittance (Appendix 6.4.2).

VIS 1.3 Position of the workstation

Different positions of the workstations in the rooms offer different visibility of the glass area of the window. This is evaluated and measured using the horizontal sight angle, which indicates which part of the glass area (in width) is visible from a point of measurement. The evaluation follows the minimum and maximum values set by European standards DS/EN 17037 [25]. The minimum angle is 14 degrees, since anything with lower values does not offer a comfortable view. And the maximum angle of 55 degrees or anything higher offers the maximum score, providing a wide view.

The horizontal sight angle should be measured from a given workstation from a seating position towards each window separately.



8. Figure Visual Comfort - Grading Graph for Horizontal Sight Angle

Evaluation of every criterion should be performed from a seating position (1,2 m) from the specific workstation, first considering the position up to a maximum of 95 degrees for a possible view.

3.2.4. Acoustic comfort

Acoustic comfort plays an important role in how individuals experience a space and perform within a building. Evaluating acoustic comfort typically involves assessing the background noise level, which includes traffic noise and technical installations, reverberation time, speech transmission intelligibility, and sound privacy between the workstations. These indicators are influenced by multiple factors, including façade construction, building service system design, building materials, room layout and geometry, material absorption properties, and occupant behaviour. Acoustic comfort is determined by parameters that encompass all relevant noise sources and sound-related factors within the indoor environment.

8. Table

Acoustic comfort selected parameters and criteria

	Parameters	Criteria
ACO1	Noise from outdoors and façade acoustic insulation	Traffic noise
		Façade acoustic insulation level - Airborne
ACO2	Partitions	Airborne- acoustic insulation level - noise from other indoor rooms
		Impact sound from building elements
ACO3	Sound in the office room	Reverberation time in the office
		Noise from people - activities
		Technical installation
		Speech transmission index
ACO4	User control	Internal rules for sound/noise control
		Are there different rooms dedicated to different activities

The first parameter ACO1 represents criteria that are connected to noise from outdoors and the sound-insulating performance of the building façade. External noise, particularly traffic noise, can significantly interfere with performance, concentration, and occupant well-being in office environments [41]. This acoustic parameter includes the evaluation of how effectively the building envelope reduces airborne sound transmission from the exterior before it enters the workspaces. The acoustic performance of the façade is mainly determined by construction characteristics, according to [29]. Guided by the standard, this criterion focuses on whether the façade achieves sufficient sound reduction to maintain indoor noise levels suitable for office work, supporting occupants' well-being. Therefore, the evaluation considers whether the façade design ensures that indoor noise levels stay within recommended thresholds during typical working hours.

ACO2 focuses on the internal partitions, which also provide acoustic separations within the building. In office environments, insufficient sound insulation between rooms can lead to reduced speech privacy and increased distraction [42]. This parameter assesses the airborne sound insulation between offices and indoor spaces, specifically the noise transmission between rooms. The parameter also includes criteria that evaluate the impact sound usually generated by building elements. According to the standard [30], properly designed partition construction limiting both airborne and impact sound transmission, which can highly increase the acoustic comfort between closely located offices, meeting rooms and shared workspaces.

The ACO 3 parameter evaluates sound conditions within the office room itself. One of the main criteria is reverberation time. The reverberation time in an open-plan office is determined by the sound absorption characteristics of the room's surfaces. High reverberation time or low absorption area compared to the floor area can lead to poor acoustic comfort and occupants' dissatisfaction.

ACO3 includes consideration of noise generated by occupants and their activities, such as phone calls and conversations. Noise from technical installations, including HVAC systems, office equipment, and electrical installations, is also evaluated. Continuous background noise can impair concentration in office rooms where workers require high concentration [22]. The criterion speech transmission index (STI) focuses on how clearly speech can be understood in a space. In office environments, STI helps evaluate whether speech conditions support the intended use of a space. Finally, internal rules for sound and noise control, such as guidelines for proper office environment behaviour or designated quiet zones, are considered part of an integrated acoustic strategy [31].

The final parameter, ACO 4, focuses on user control connected to acoustic comfort. This parameter evaluates whether the building provides different rooms or zones dedicated to specific activities, such as quiet work, collaborative tasks, or meetings. According to the WELL Building Standard, access to acoustically appropriate spaces allows occupants to choose environments that match their functional and comfort needs, with this improving satisfaction and productivity [31]. User control here is not limited to technical systems but also includes spatial organisation and functional zoning. Providing spaces for acoustically different office activities reduces conflicts between noisy and quiet workers and supports a more flexible and inclusive office environment.

3.2.4.1. Assessment of Speech Transmission Index (STI)

The Speech Transmission Index (STI) is used to describe how clearly spoken information can be perceived within an indoor space. The index ranges from 0 to 1, where lower values indicate poor speech intelligibility and higher values represent clear and easily understandable speech. Several acoustic factors influence STI, including background noise levels, reverberation time, sound absorption, and the presence of masking sounds. STI is a good indicator of acoustic quality because it is directly connected to communication efficiency, which is very important in an office environment.

The BR18 [23] requires that buildings provide appropriate acoustic conditions for users, but do not specify quantitative criteria for speech privacy in offices. As a result, acoustic assessments typically rely on interpretative use of standards and research-based indicators. ISO 3382-3:2012 [42] defines acoustic descriptors for open-plan offices, such as spatial speech decay (D_2, S), speech level at 4 m ($L_p, A, S, 4m$), privacy distance and distraction distance. Although the standard is a measurement standard without defined performance criteria, its descriptors are widely used as reference indicators for design evaluation. STI, as described in IEC 60268-16, is commonly used as a proxy indicator for speech intelligibility and, by extension, speech privacy [43]. Commonly used thresholds for STI can be found in ISO 9921:2023 [44].

Commonly used thresholds for STI can be found in ISO 9921:2023 [44].

9. Table

Acoustic Comfort - Commonly used threshold for STI (ISO 9921:2023)

Intelligibility rating	STI
Excellent	> 0.75
Good	0.60 to 0.75
Fair	0.45 to 0.60
Poor	0.30 to 0.45
Bad	<0.30

The purpose of the created Excel tool, based on the following described evaluation method, is to provide a planning-level, workstation-specific evaluation of speech privacy in open-plan offices, based on the Speech Transmission Index (STI) interpreted in accordance with the intent of ISO 3382-3, ISO 60268-16, ISO 9921:2023 and Danish acoustic practice [42-44]. The Excel tool is implemented as a transparent, auditable spreadsheet model, allowing explicit control of assumptions and direct interpretation of results (Excel file-Danish Open Office STI). The calculation for STI in Excel is based on pairwise evaluation of speech intelligibility between all workstation combinations in an open-plan office. The Excel tool uses an STI matrix to show all results for talker-listener workstation pairs. The method combines geometric spreading, background noise, speech directivity, line-of-sight conditions, and screen attenuation into a single effective signal-to-noise ratio (SNR), which is subsequently converted into Speech Transmission Index (STI). The assessment is based on the principle that speech privacy is dependent on the listener. The disturbance experienced at a workstation depends on which

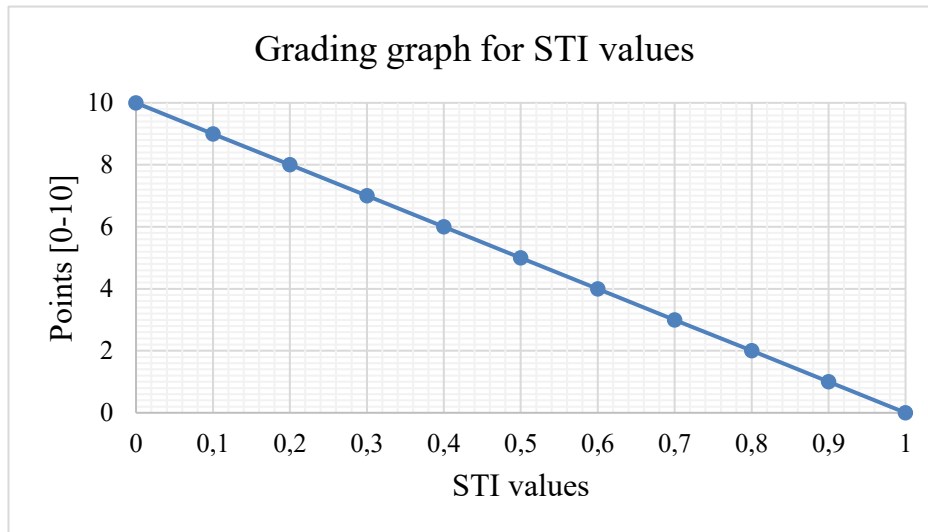
talkers are present, their relative positions, and the local acoustic environment. Averaged room-level metrics, therefore, provide limited insight into individual workstation conditions.

The calculation uses input data from standards or published Danish practice design values, including workstation positions and distances, background noise level, spatial speech decay ratio, desk screens or partitions insertion loss, line-of-sight conditions, and talker orientation. Speech propagation is modelled using a planning-level approach inspired by ISO 3382-3 [42], where the spatial decay rate represents the combined effect of room absorption, ceiling treatment, and layout. Local acoustic effects are accounted for. Desks, screens and partitions between workstations are represented through an effective insertion loss, dependent on screen type, height, and line-of-sight conditions.

Values and limits are applied to reflect measured performance in real office environments. The relative orientation of talker and listener is included as a source-related correction. To reflect the reduced importance of directivity at larger distances, the orientation effect is weighted by distance, ensuring a physically plausible transition toward diffuse-field behaviour. The final signal-to-noise ratio for each talker–listener pair is obtained by combining the base SNR with orientation-related corrections and subtracting effective insertion loss due to screening and line-of-sight blocking. All physical effects are treated separately and applied once to avoid double-counting (See Appendix 7.4.3 for detailed explanation of calculation method).

The final graded STI values for each workstation were 90th-percentile STI (STI_P90), which represents the speech intelligibility level that is exceeded by only 10 % of potential speech sources at a workstation, providing a robust indicator of typical worst-case speech exposure.

The workstation-specific STI_P90 values are converted to points. The privacy score for STI evaluation ranges from 0 to 10; the higher the points the workstation gets, the lower the privacy and comfort can be experienced at that workstation.



9. Figure Acoustic comfort - Grading Graph for STI values

3.3. Labelling system

Ensuring good indoor environmental quality in office buildings requires assessment methods that can represent both the local working conditions experienced by individual occupants and the overall conditions. Therefore, the tool will provide an Indoor Environmental Quality (IEQ) label for the entire building. However, the tool now only proposes open open-plan office evaluation. Additionally, it will offer separate IEQ results for each evaluated room and workstation. The purpose of this labelling system is not only to label the building and rooms, but also to address critical areas within each room visually in a comprehensible way.

3.3.1. Communication of results

The tool uses both labelling by a letter ranking and colour code, similar to the energy labels found in the European energy performance certificates for buildings [45]. It assigns an overall class to the building while also providing results for the four individual IEQ comforts on the room and workstation level. This distinction helps to identify the most critical areas that need attention across all three levels.






















The aim is to use the results for overall assessment of IEQ, more efficient design processes for new constructions or for renovation projects, similarly to the IEQ compass for residential building: Class C corresponds to the baseline indoor environmental quality level required for

new buildings under the 2018 Danish Building Regulations. Higher ratings, such as classes A and B, are awarded only when performance criteria go beyond these minimum requirements and demonstrate enhanced IEQ conditions. To prevent any shortcomings from being overlooked, the overall final rating is limited to a maximum of two class levels above the lowest-rated IEQ domain [8].

To make it easier for the users to orientate in the results, each labelling level is represented in a different shape.

10. Table

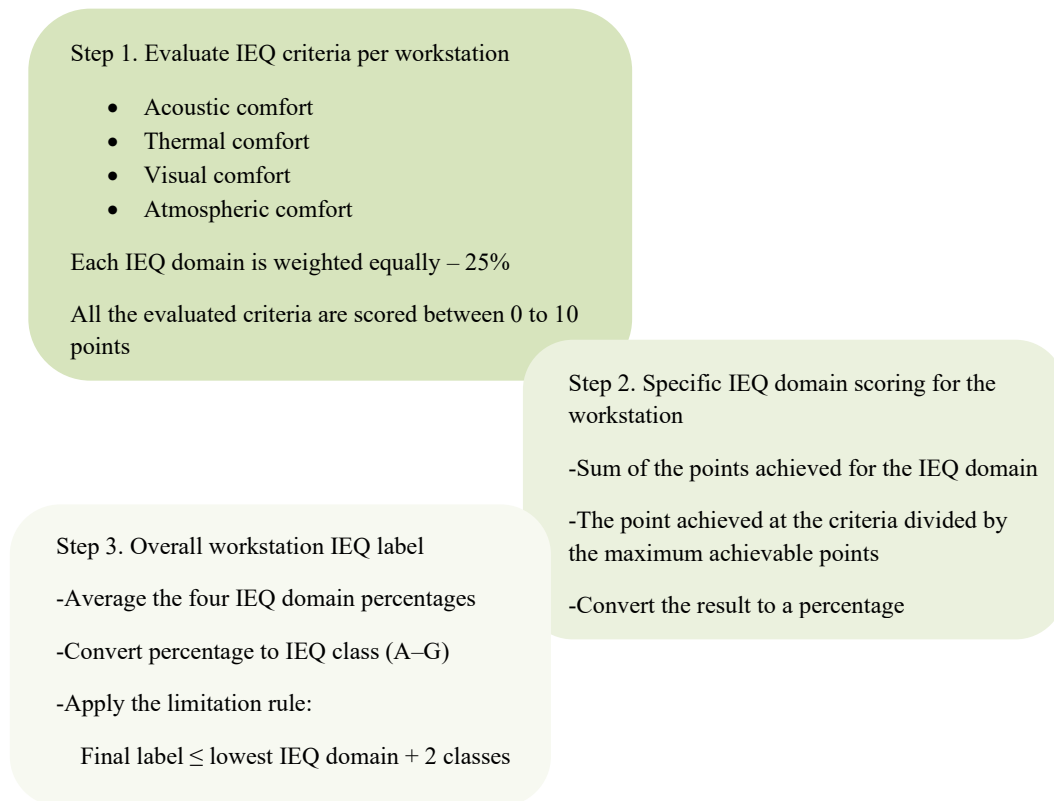
Labelling - Letter and colour ranking of the IEQ compass, Score intervals, Label representations at Workstation level, Label representations at Room level, Label representations at Building level

Letter and colour rank of the IEQ compass	Scores	Workstation level	Room level	Building level
A	$85\% \leq \text{score} \leq 100\%$			
B	$75\% \leq \text{score} < 85\%$			
C	$65\% \leq \text{score} < 75\%$			
D	$55\% \leq \text{score} < 65\%$			
E	$45\% \leq \text{score} < 55\%$			
F	$35\% \leq \text{score} < 45\%$			
G	$0\% \leq \text{score} < 35\%$			

3.3.2. Labelling process

Each IEQ parameter table defines all criteria at the workstation level. Therefore, each one of the criteria is expected to be evaluated individually for each workstation. This leads to a labelling process that starts at the workstation level.

3.3.2.1. Workstation-level labelling process



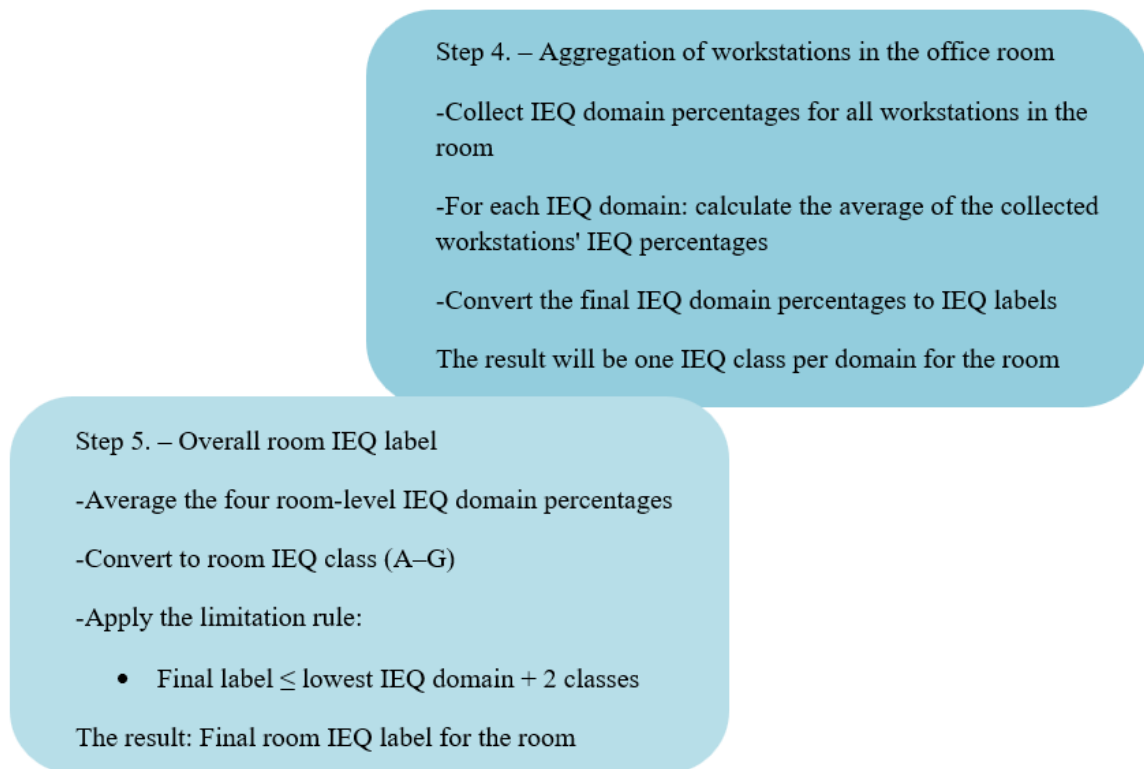
10. Figure Workstation level labelling process

At the workstation level, each workstation is individually assessed for the four IEQ comfort domains: acoustic, thermal, visual comfort, and atmospheric comfort. Each criterion is scored on a standardised point scale from 1 to 10 points, converted into comfort-specific percentages.

The overall workstation label is calculated as the average of the four comfort percentages, with the restriction that the final label cannot exceed the lowest-performing domain by more than two classes (See Appendix 7.3.2, the discussion about determining the most accurate final label).

The label assigned to each workstation shows where good areas are to place workstations in the room and which areas can be uncomfortable for occupants. The final overall IEQ label for the workstations can have similar results; however, the specific IEQ parameter performance of the workstations can differ. Therefore, even if two workstations have the same final IEQ score, it does not necessarily mean they perform identically across all four IEQ parameters.

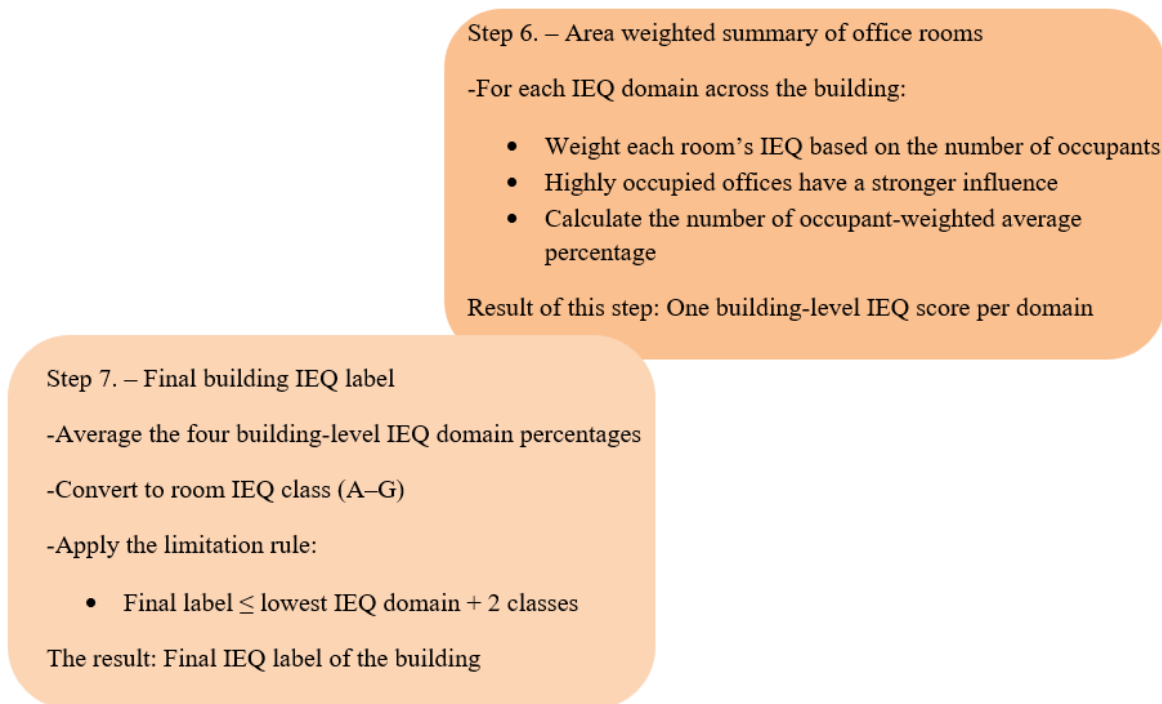
3.3.2.2. *Room-level labelling process*



11. Figure Room level labelling process

The next labelling level is the room-level. Here, the workstation results within the same open-plan office are aggregated. For each IEQ domain, the average percentage across all workstations is calculated and converted into a room-level IEQ class. The four room-level domain results are then combined to determine the overall room label, again applying the same limitation rule.

3.3.2.3. *Building-level labelling system*



12. Figure Building level labelling process

The final labelling level is the building level, where the IEQ performance of all evaluated rooms is aggregated using the number of occupants the room is designed for. This is mainly implemented to make sure that the final score takes into consideration the number of occupants in the building experiencing the IEQ conditions varying between rooms as opposed to the room area.

Further, for each IEQ domain, a building-level score is calculated and combined to determine the final building IEQ label, again respecting the class limitation rule.

If a weighting approach is introduced at a later stage, the relative influence of individual criteria on the overall outcome can be adjusted accordingly, but in this stage of the methodology, all the IEQ parameters have the same weight, contributing to the final results. When it comes to all 4 IEQ comforts, they are weighted equally at the final labels, so each accounts for 25% of the final label. For a better understanding of the labelling method, there is an example of the process in the Appendix 7.3.2.

3.4.Application of the method

In this section, the previously proposed method is tested on three case office rooms. The purpose is to test all three prepared evaluation methods for the selected parameters to ensure the practical applicability in a real building context.

3.4.1. Case building introduction

For the evaluation process, three open-plan offices in different case buildings at Aalborg University campus were selected, ensuring a variation of conditions was introduced for the testing process.

One of the offices selected for evaluation is at Fredrik Bajers Vej 1 in Aalborg, Denmark. The building is surrounded by a neighbouring building, a parking plot, and a lake. The chosen open-plan office is situated on the second floor, facing east with a view of the parking lot. The room has 24 workstations, and it has windows across the whole room.

The second building under review is Create, a university building assigned to teaching, group and office work purposes in Aalborg. This building is closely surrounded by other buildings, while one of its façades offers a view of the fjord, however, the open spaces and teaching rooms benefit from the Fjord view, not the offices. The windows' shape and placement are architecturally unique on the building façade. The tested office room is on the second floor, facing north-east. This L-shaped office accommodates 13 workstations, which are arranged asymmetrically, and systematic use of acoustic panels is not implemented.

The last office that was evaluated is another university building Innovate, located in Aalborg. It is a relatively new building with curtain walls and fixed wooden solar shades. The surrounding area includes university buildings and a lake, with one of the façades facing a parking lot. The open-plan office being tested in this building is a corner room that offers a view of the lake. The room orientation is southwest, with installed sound panels on the walls, accommodating 6 workstations.

The layouts, building envelope thermal performance can be found for the buildings in the Appendix 7.5.1.

3.4.2. Application on case buildings

All the suggested evaluations were implemented on the three different office cases. Their potential performance in operative temperatures, view, and speech transmittance index was evaluated for their current workstation layout. For all separate assessments, the calculation

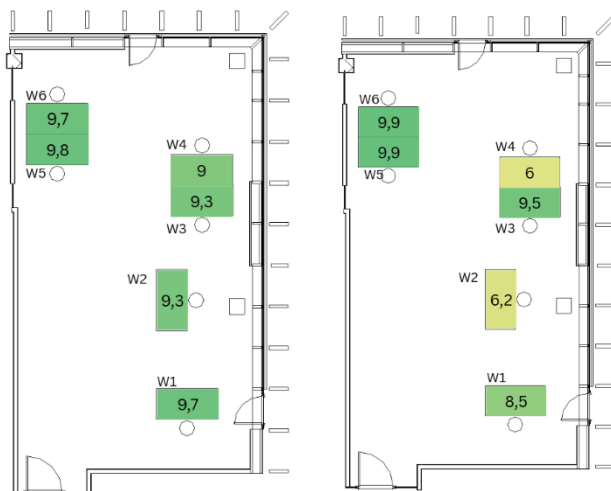
Excel sheets with the whole evaluation process for each case were created (Excel file evaluations).

3.4.2.1. Innovate office

Operative temperatures.

The calculation of the operative temperatures in the winter case shows generally good local thermal comfort for all workstations. This is mainly due to the relatively new construction of the building, where the low U-values result in internal surface temperatures that are close to the indoor air temperature.

In contrast, the summer assessment highlights potential local discomfort at Workstations 2 and 4. These workstations are identified as being potentially exposed to direct solar radiation caused by their position to the windows. This exposure may lead to local discomfort for the occupants at the set location.



13. Figure Office at Innovate - Points for operative temperature (Winter condition)

14. Figures Office at Innovate - Points for operative temperature (Summer condition)

View out.

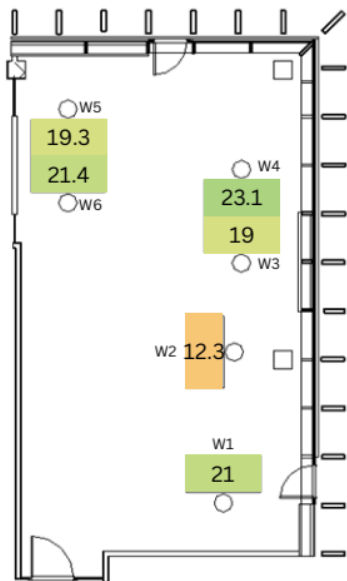
This office in the Innovate building provides wide, clear view, scoring generally well over most workstations. This is primarily due to the large glazing areas created by curtain walls on two different façades. These curtain walls provide quite large horizontal sight angles and visibility of many layers of the view. However, there are various obstructions inside and outside that

11. Table

Office at Innovate - Result and achieved points for Operative temperature (both summer and winter condition)

	Winter		Summer	
	Top(°C)	Points	Top(°C)	Points
W1	21.6	9.7	25.2	8.5
W2	21.4	9.3	25.4	6.2
W3	21.4	9.3	24.8	9.5
W4	21.3	9	25.5	6
W5	21.7	9.8	24.5	9.9
W6	21.6	9.7	24.5	9.9

disrupt the view. Of all the workstations, Workstation 2 performs the poorest due to its placement and rotation.



12. Table

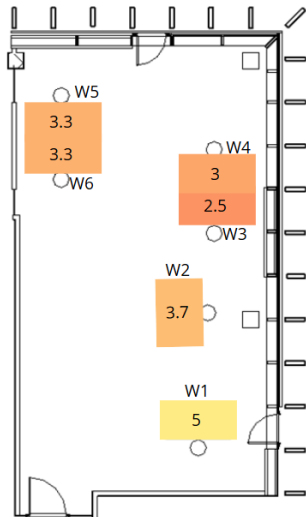
Office at Innovate - Results of view out assessment for each criteria and achieved points for view out

Workstation	Criteria			Score
	VIS 1.1	VIS 1.2	VIS 1.3	
W1	10	6	5	21
W2	6	5	1.3	12.3
W3	8	5	6	19
W4	10	6	7.1	23.1
W5	10	6	3.3	19.3
W6	10	6	5.4	21.4

15. Figure Office at Innovate - Points for view out

Speech transmission index.

The STI result for this office is primarily driven by distance, orientation, and lack of acoustic separation. Although the room has absorptive wall panels, there are no acoustic screens between workstations, and a direct line of sight exists between all desks. Several workstations are placed face-to-face and close together, increasing speech transmission. Differences in performance are therefore caused by relative position to neighbours, not mainly by the room absorption. Workstation 1 performs best acoustically because it is furthest from other desks. Workstation 3 performs the worst due to multiple close neighbours and face-to-face orientation. The remaining workstations show similar STI values. Overall, most workstations are rated “Good” speech intelligibility, indicating high disturbance and low privacy.



16. Figure Office at Innovate - Points for STI

13. Table

Office at Innovate - Results of STI assessment and achieved points

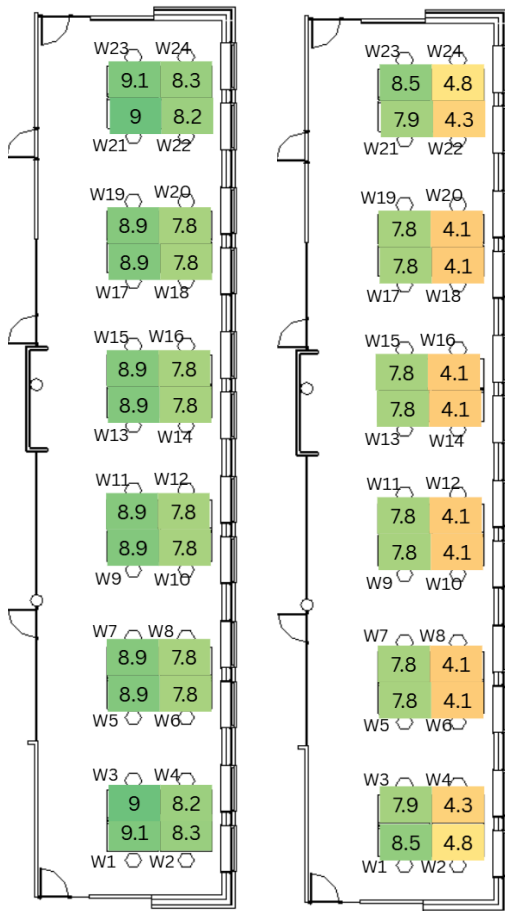
Workstation	STI_P90	IEQ criteria score (STI_P90)
W1	0.5	5
W2	0.6	3.7
W3	0.8	2.5
W4	0.7	3
W5	0.7	3
W6	0.7	3

3.4.2.2. Frederik Bajers Vej office

Operative temperatures.

The evaluation shows that the FBV office in winter performs well, with the lowest points at 7.8. The workstations located close to the external wall with windows, perform slightly worse than the row positioned further due to their proximity to the glazing area, which influences the view factor.

Under summer conditions, all workstations along the external wall are highlighted as being at risk of direct solar radiation caused by their proximity to the windows and limited shading options. This exposure may lead to increased local discomfort at this location.



17. Figure Office at Frederik Bajers Vej - Points for operative temperature (Winter condition)

18. Figure Office at Frederik Bajers Vej - Points for operative temperature (Summer condition)

14. Table

Office at Frederik Bajers vej - Result and achieved points for Operative temperature (both summer and winter conditions)

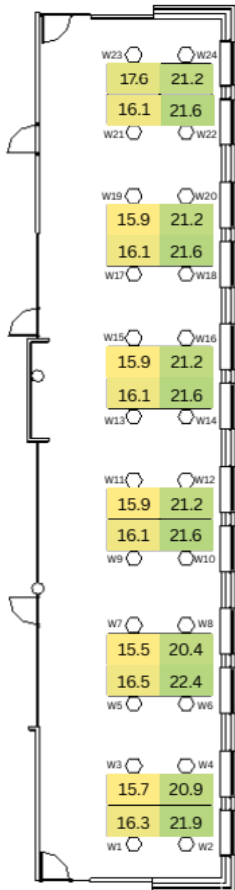
	Winter		Summer	
	Top(°C)	Points	Top(°C)	Points
W1	21.1	8.3	25.1	8.5
W2	21.4	9.1	25.8	4.8
W3	21.1	8.2	25.3	7.9
W4	21.4	9	25.9	4.3
W5	21	7.8	25.3	7.8
W6	21.3	8.9	26	4.1
W7	21	7.8	25.3	7.8
W8	21.3	8.9	26	4.1
W9	21	7.8	25.3	7.8
W10	21.3	8.9	26	4.1
W11	21	7.8	25.3	7.8
W12	21.3	8.9	26	4.1
W13	21	7.8	25.3	7.8
W14	21.3	8.9	26	4.1
W15	21	7.8	25.3	7.8
W16	21.3	8.9	26	4.1
W17	21	7.8	25.3	7.8
W18	21.3	8.9	26	4.1
W19	21	7.8	25.3	7.8
W20	21.3	8.9	26	4.1
W21	21	7.8	25.3	7.9
W22	21.3	8.9	25.9	4.3
W23	21	7.8	25.1	8.5
W24	21.3	8.9	25.8	4.8

View out

All the workstations in this office perform quite similarly in terms of view out. The room's geometry, workstation layout, and the identical windows support the similarity of the score. The score differs mainly by rows: the workstations closer to the windows receive higher points due to the better visibility of the view that includes all layers and wide horizontal sight angles. In contrast, the distant row can only see two layers of view. Overall, the room does have a few obstructions inside blocking the view only partly.

15. Table

Office at Frederik Bajers Vej - Results of view out assessment for each criterion and achieved points for view out

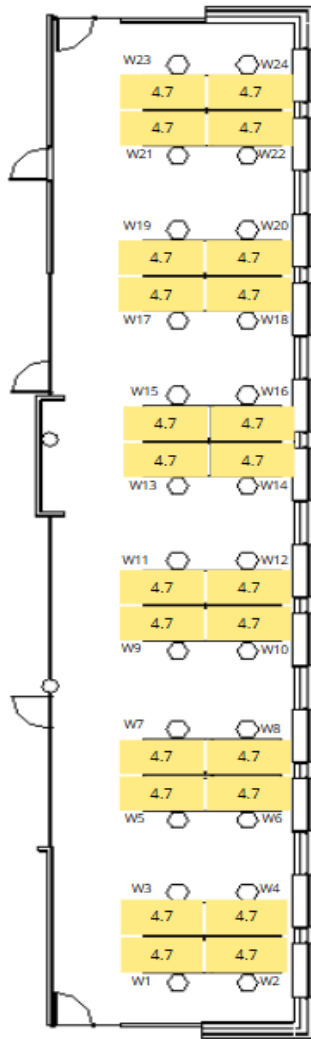


19. Figure Office at Frederik Bajers Vej - Points for view out

Workstation	Criteria			Score
	VIS 1.1	VIS 1.2	VIS 1.3	
W1	8	7	1.3	16.3
W2	10	7	4.9	21.9
W3	8	7	0.7	15.7
W4	10	7	3.9	20.9
W5	8	7	1.5	16.5
W6	10	7	5.4	22.4
W7	8	7	0.5	15.5
W8	10	7	3.4	20.4
W9	8	7	1.1	16.1
W10	10	7	4.6	21.6
W11	8	7	0.9	15.9
W12	10	7	4.2	21.2
W13	8	7	1.1	16.1
W14	10	7	4.6	21.6
W15	8	7	0.9	15.9
W16	10	7	4.2	21.2
W17	8	7	1.1	16.1
W18	10	7	4.6	21.6
W19	8	7	0.9	15.9
W20	10	7	4.2	21.2
W21	8	7	1.1	16.1
W22	10	7	4.6	21.6
W23	8	7	2.6	17.6
W24	10	7	4.2	21.2

Speech transmission index.

The even STI performance is due to high acoustic absorption and strong workstation separation in this evaluated open-plan office room. The office includes absorptive ceiling, acoustic wall panels, carpet flooring, and high acoustic partitions. Workstations are symmetrically arranged in groups, with full acoustic blockage between groups by tall acoustic boards, significantly reducing speech transmission. Because of the symmetric office layout, all workstations achieve the same STI_P90 value, rated as “Fair” speech intelligibility. While STI values are still above the recommended 0.30, the room provides balanced and controlled acoustic conditions.



20. Figure Office at Frederik Bajers Vej - Points for STI

16. Table

Office at Frederik Bajers Vej - Results of STI assessment and achieved scores

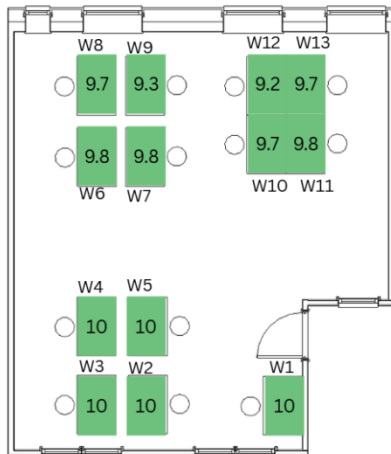
Workstation	STI_P90	IEQ criteria score (STI_P90)
W1	0.5	4.7
W2	0.5	4.7
W3	0.5	4.7
W4	0.5	4.7
W5	0.5	4.7
W6	0.5	4.7
W7	0.5	4.7
W8	0.5	4.7
W9	0.5	4.7
W10	0.5	4.7
W11	0.5	4.7
W12	0.5	4.7
W13	0.5	4.7
W14	0.5	4.7
W15	0.5	4.7
W16	0.5	4.7
W17	0.5	4.7
W18	0.5	4.7
W19	0.5	4.7
W20	0.5	4.7
W21	0.5	4.7
W22	0.5	4.7
W23	0.5	4.7
W24	0.5	4.7

3.4.2.3. Create office

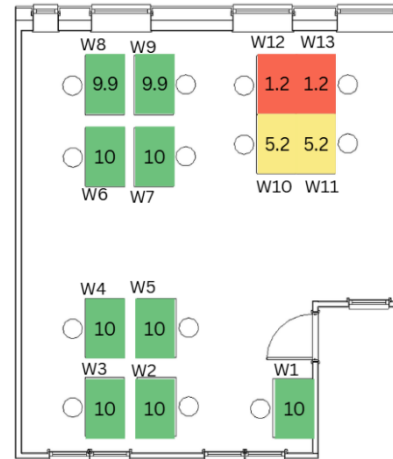
Operative temperatures.

Similarly to the Innovate office room, the winter condition shows nearly optimal results due to buildings construction. There is slight variation in the results the closer the workstation is to the external wall.

The summer condition assessment reveals a high risk of direct solar radiation and elevated operative temperatures, mostly for occupants at Workstation 12 and 13. Since its direct location in front of the window and the windows height, these workstations are expected to be exposed to the direct solar radiation. Workstations 10 and 11, which are located slightly further away from façade, show a lower but still noticeable risk of solar exposure.



21. Figure Office at Create - Points for operative temperature (Winter condition)



22. Figure Office at Create - Points for operative temperature (Summer condition)

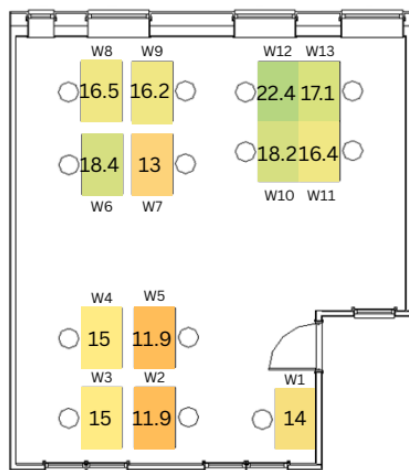
17. Table

Office at Create - Result and achieved points for Operative temperature (both summer and winter conditions)

	Winter		Summer	
	Top(°C)	Points	Top(°C)	Points
W1	22	10	24.5	10
W2	22	10	24.5	10
W3	22	10	24.5	10
W4	22	10	24.5	10
W5	22	10	24.5	10
W6	21.8	9.8	24.5	10
W7	21.8	9.8	24.5	10
W8	21.6	9.7	24.6	9.9
W9	21.4	9.3	24.6	9.9
W10	21.6	9.7	25.8	5.2
W11	21.8	9.8	25.8	5.2
W12	21.4	9.2	26.6	1.2
W13	21.6	9.7	26.6	1.2

View out.

The workstations in this office each have varying access to the view out, which affects their quality and score. It is dependent on the location of the workstation in the room. A group of workstations with close proximity to the larger windows supports a clear view. The group of worst performing workstations (Workstation 2, 3, 4, 5) is affected by a greater distance to the façade and limited access to the view under narrow horizontal angles. Most of the rooms in general do not receive a high evaluation score due to several factors: large depth of the room, small windows that are unevenly positioned in the façade, and the presence of obstructions blocking the view.



23. Figure Office at Create - Points for view out

18. Table

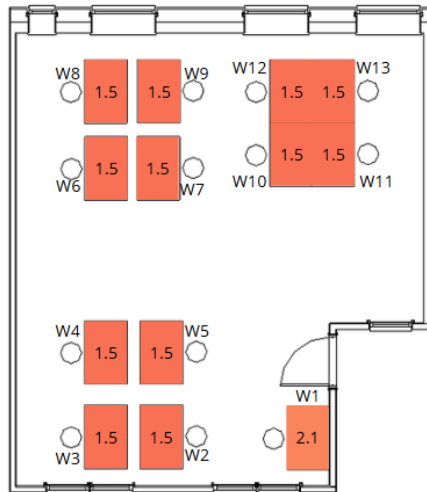
Create - Results of the view out assessment for each criterion and achieved points for view out

Workstation	Criteria			Score
	VIS 1.1	VIS 1.2	VIS 1.3	
W1	8	6	0	14
W2	4.9	7	0	11.9
W3	8	7	0	15
W4	8	7	0	15
W5	4.9	7	0	11.9
W6	10	7	1.4	18.4
W7	4.9	7	1.1	13
W8	4.9	7	4.6	16.5
W9	6.9	7	2.3	16.2
W10	10	6	2.2	18.2
W11	10	6	0.4	16.4
W12	10	6	6.4	22.4
W13	10	7	0.1	17.1

Speech transmission index

The high STI value results in this room are caused by low room absorption, minimal acoustic screening, and an unstructured room layout. Most workstations have a direct line of sight (there are no blocking obstacles), short distances between each other, and no separating acoustic panels. The L-shaped geometry and dense furniture provide only limited attenuation, while workstation orientations do not sufficiently reduce speech propagation. All workstations show very high STI_P90 values, rated as “Excellent” speech intelligibility, which in this context means very poor acoustic privacy. Only one workstation performs slightly better due to

increased distance and favourable orientation. Based on the results, the office performs poorly in terms of concentration and privacy.



24. Figure Office at Create - Points for STI

19. Table

Office at Create - Results of STI assessment and achieved points

Workstation	STI_P90	IEQ criteria score (STI_P90)
W1	0.8	2.1
W2	0.9	1.5
W3	0.9	1.5
W4	0.9	1.5
W5	0.9	1.5
W6	0.9	1.5
W7	0.9	1.5
W8	0.9	1.5
W9	0.9	1.5
W10	0.9	1.5
W11	0.9	1.5
W12	0.9	1.5
W13	0.9	1.5

3.4.3. Comparison of room specific and the standard method of evaluation

This section describes the comparison between the proposed method of evaluation with the standard assessment method defined by standards. The results from this comparison can be seen in Appendix 7.5.5.

3.4.3.1. Operative temperatures

The standard evaluation of the operative temperatures from DS 474 [21] mentions that the operative temperatures for the room should be assessed at the critical location and at the representative location of the occupied zone. Even though this method is able to discover critical conditions in the room, the proposed workstation-specific method shows a whole range of results, helping to determine actual conditions experienced at different workstation locations.

3.4.3.2. View out

The evaluation of the view out for the whole room is analyzed through one reference point. This reference point should be positioned in the most representative location within the occupied zone, typically at the centre of the glazing area of the façade. The view from the

reference point is not representative for every workstation or location in the room, since most of the criteria are dependent on its relation to the windows.

3.4.3.3. Speech transmission index

By using the Bradley calculation for STI estimation in the room (Bradley calculation described in the Appendix), the result for the office rooms will not differ. Bradley showed that STI can be reasonably approximated from the signal-to-noise ratio (SNR) at the listener position, assuming moderate reverberation control. Since the values used in the equation are assumed, since it is not measured values, therefore the assumption for all the tested office rooms for these values would be the same. This would result in identical outcome for the tested office rooms.

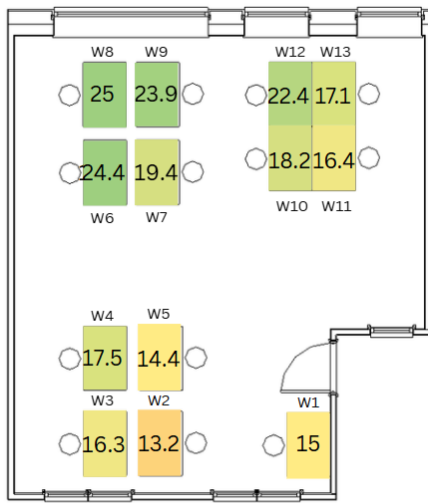
3.4.4. Renovation

The office room in Create was suggested and tested for renovation, which tests how the evaluation methodology is able to point to problematic areas within the room, and if improved critical area reflects on the results.

The renovation is focusing on the improvement of view out. The proposal is to replace two smaller windows on the left side with one larger window. The main goal of this renovation was to improve the most critical workstations in the room, while keeping the renovation scenario realistic. This is why other windows were not included in the renovation plan. However, if the aim was to improve the view for other workstations as well, even greater glazing area could be implemented.

Two smaller windows were exchanged for one larger, enhancing the glazing area by 3.25 m². This change improved the view for most of the workstations. It particularly benefits the workstations furthest in the room, as well as the group on the left side. One group of workstations (10, 11, 12, 13) remained unchanged since their view is evaluated through the windows that were not renovated. These workstations already offered a clear view before the renovation, so they were not prioritized for improvement.

Due to the depth of the room and the size of the windows, a further group of workstations was not performing well in terms of offering a great view even after the renovation.



25. Figure Points after Renovation - Office room at Create - Focus on view out improvements

20. Table

Office at Create - Results of the view out assessment for each criterion and achieved points for view out after Renovation

Workstation	Criteria			Score
	VIS 1.1	VIS 1.2	VIS 1.3	
W1	8	7	0	15
W2	4.9	7	1.3	13.2
W3	8	7	1.3	16.3
W4	8	7	2,5	17.5
W5	4.9	7	2.5	14.4
W6	10	7	7.4	24.4
W7	4.9	7	7.5	19.4
W8	8	7	10	25
W9	6.9	7	10	23.9
W10	10	6	2.2	18.2
W11	10	7	2	16.4
W12	10	6	6.4	22.4
W13	10	7	5.5	17.1

3.4.4.1. Effect on other parameters

Operative temperatures.

The window enlargement caused slightly worse operative temperatures under winter condition, especially in close proximity to the new window. This is mainly caused by the increase view factor of the glazed area, which has lower surface temperature compared to the surrounding surfaces.

The summer condition also worsens due to the renovation, mostly for the Workstation 8 and 9. The increased window area, combined with the unchanged layout, results in the workstations being positioned directly in front of the window, leading to higher local discomfort caused by direct solar radiation.

Speech transmission index.

The suggested renovation for the office room in Create does not affect the acoustic performance in the room significantly. While the renovation may slightly reduce the absorption area, this change will not have a substantial effect. Now, the value included in the STI evaluation, which is connected with room absorption, is the spatial decay ratio, and is assumed based on a

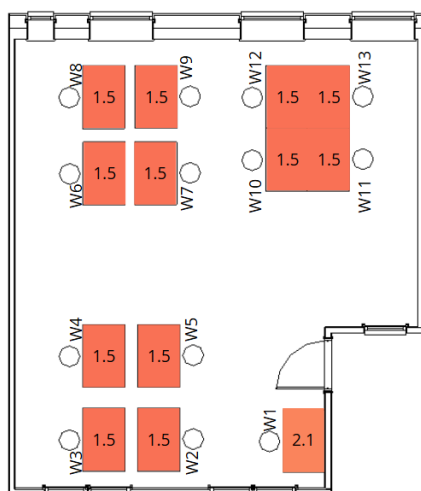
standard range. If, in the future, the tool can assess a more accurate room absorption area, that result could be incorporated for a more precise STI calculation.

3.4.5. Change of the workstation locations

A change of the workstations' position was suggested in the open-plan office room in Create. This implementation was included to test the ability of the methodology to optimise IEQ conditions perceived by occupants with only layout modification.

The focus was on the optimisation of acoustic comfort, without using any acoustic partitions between the workstations. The aim is to demonstrate that simply reorganising the workstations, by altering the talker-listener orientation and increasing the distance between them, can result in a more acoustically balanced office environment. The objective is to rearrange the existing workspace in a way that reduces the need for acoustic panels, as there is currently only one workstation in the room that utilises acoustic panels and one workstation which is blocked with a movable writing board. To achieve this, the room has been reorganised so that most workstations are positioned back-to-back, creating as much distance between them as possible.

The workstation score is based on the 90th-percentile STI value, representing typical worst-case speech intelligibility, so the result for reorganisation does not show a big change in the STI_P90 values. By reorganising the room layout, the workstation scores remained the same, except for workstation 1, where the result got worse. This shows that with the suggested new layout, the STI performance of the workstations is similar. Relocating the workstations did not help to achieve a higher point for STI performance, but to increase the distance from the nearest disturbing workstation and create an acoustically uniform office.



26. Figure Points before Workstation layout change - Office room at Create - Focus on STI improvements



27. Figure Points after Workstation layout change - Office room at Create - Focus on STI improvements

21. Table

Office at Create after workstation layout change- Results of STI assessment and achieved points

Workstation	STI_P90	IEQ criteria score (STI_P90)
W1	0.8	1.6
W2	0.9	1.5
W3	0.9	1.5
W4	0.9	1.5
W5	0.9	1.5
W6	0.9	1.5
W7	0.9	1.5
W8	0.9	1.5
W9	0.9	1.5
W10	0.9	1.5
W11	0.9	1.5
W12	0.9	1.5
W13	0.9	1.5

3.4.5.1. *Effect on other parameters*

Operative temperatures.

The new layout, which introduces a more even spacing of the workstations, has little to none effect on the winter condition due to the already good previous results. However, it results in a slight improvement under summer conditions. By relocating some workstations further away from the windows, the new layout improves the conditions for the second row of workstations and reduces their exposure to direct solar radiation.

View out.

The change of workstations in terms of their layout in the room resulted in only a slight variation in the scores for the view. The reason for this is that the room and its construction and windows remained unchanged, and most of the factors affecting the results for individual workstations stayed the same. The results slightly differ only due to the reorganization of the layout, since the workstations were moved from grouped arrangements to even distribution within the room, leading to a slight change in their position toward windows.

4. Discussion

The results from the three case offices show that the proposed assessments were able to identify variations within the space. This is most evident on the view out parameter, which presents varying results across all three office rooms. The differences are mainly due to the distances from the windows and its geometry. For the operative temperatures, the results show only slight variations with winter conditions because of the lack of more diverse building performance of the case buildings when it comes to the construction. On the other hand, the summer condition highlights results with a bigger difference due to workstations that are directly lit by solar radiation. The speech transmission index showed variations only in the room where the workstation locations were not symmetrical or tightly fitted together. Those rooms in general performed badly due to the close proximity from one occupant to another.

The renovation of the external façade, where one of the windows was enlarged, improved the view out parameter for the workstations that were previously affected by the small size of the windows. The renovation also affected the operative temperatures as a larger glazing area introduced more direct solar radiation on the occupants close to the façade. The STI changed only slightly due to the change in the absorption area of the room.

The change of the layout, where more evenly spaced workstations were presented, aimed to improve the STI. The results show that even though the STI did not generally improve, it created a more uniform distribution of the results within the room. The view out and operative temperatures were affected by this change only slightly, also showing that this proposal did not have a big effect on the results.

The main reason why the condition did not improve was mostly due to the high number of workstations within the office; this could potentially be improved only by reducing the number of workstations. This process shows that even though the layout change implementation can change the experienced local IEQ conditions, it also points to the possibility that the occupants would benefit from a lower number of workstations.

The testing of the three case studies and two applied changes to the environment supported the aim of the methodology created for the workstation-specific evaluation tool, where the variations of IEQ between different locations within the space were proven. The applied changes to the room also affected the parameter that the proposal focused on, while affecting other parameters in a positive or negative way.

The results point to the possibility that the assessment tool, which is based on workstation-level evaluation, could improve the experienced IEQ of the occupants by only improving the layout. Adjusting the workstation placement is a low-cost and reversible improvement, making it helpful in case of limited budget or architectural constraints. It supports more sustainable and flexible office design that aims for higher productivity, which could enable better use of existing space.

The scope of this study was limited to three parameters' preparation and a limited amount of testing. Future work could expand this approach by including additional IEQ parameters and applying the method to a wider range of office types and layouts. Further testing would allow the methodology to be refined and validated across different buildings, supporting its potential as a tool for workstation-based IEQ assessment.

5. Conclusion

This study focused on the assessment of IEQ in open-plan office environments, with a focus on conditions experienced at individual workstations. Based on the literature review, a gap was identified as a lack of IEQ assessment schemes focusing on the evaluation of varying conditions within offices. To address this gap, a workstation-specific IEQ assessment methodology was developed, building on the principles of the IEQ compass for residential buildings.

The methodology presents the base for 16 different parameters relevant to occupants' well-being and productivity, addressing IEQ comforts. The resulting tables of parameters and criteria were designed to support workstation-level evaluation. Additionally, assessment suggestions were prepared for three parameters to support the application of the proposed methodology. This was tested on three open-plan office case studies with varying layouts, sizes, and construction conditions. The results showed that the proposed assessment is able to capture spatial variations that are not reflected on room-based evaluation methods. Additional renovation and layout change further showed how the tool can be used to identify critical areas and explore potential improvement strategies.

The limitations and strengths of the proposed methodology were highlighted. While the results confirm the relevance of the workstation-specific IEQ assessment, the study is limited to

selected parameters and a low amount of case studies. Despite this, the proposed framework provides a solid basis for future development.

6. Appendix

6.1.Literature review

		DGNB	Leed	Breeam	Well	LBC	TAIL	
Atmospheric comfort	Ventilation	Ventilation rates	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
		Ventilation filter	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
		Location of air intakes and exhaust	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
		construction pollution management	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
		Improve ventilation effectiveness-different solution	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
		ultraviolet treatment	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
		Increase outdoor air supply-different solutions	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
		ventilation monitoring-different solutions	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	operable windows - natural ventilation	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
	Local pollution	any internal pollution...	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Radon		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
	Pollutants	Particulate measure - different threshold for certification levels	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
		organic gases - different threshold for certification levels	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
		inorganic gases - different threshold for certification levels	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
		Pollution mapping	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
		pollution control	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Relative humidity		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
Natural ventilation - openings		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
Smoking	Outside of the building in given distance	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
Mold prevention		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	
Building envelope	infiltration	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	
Moisture		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
Thermal comfort	Operative temperatures	Summer/winter	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
	Draft	Summer/winter	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Relative humidity		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Radiant temperature	Asymmetric radiant temperature	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
		Radiant thermal comfort - radiant ceiling, walls, floors	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
		Floor temperature	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	User management	Temp. in summer/winter	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
		Infoscreens	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Cooling	Flow temperature	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	thermal zoning	occupancy per m2	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
	Personal heating options	heatable chairs, personal or shared blanket, etc.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Window placement	high opening for cold weather	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Shading, surroundings, wind		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Monitoring		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	
PMV/PPD		<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
Visual comfort	Artificial lighting	Control	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
		Flicker	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
		Illuminance/levels	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
		colour rendering	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
		Distribution	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Surface reflectance		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Daylight	Illuminance for relevant floor area	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
		Glazing area	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
		Provide enough daylight	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
		Daylight factor	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
	Sunlight	Shading	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
		Colour rendering	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
Glare		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
occupants lightning control		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
View out		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	
Biological lighting quality		<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
Acoustic comfort	Reverberation time	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
	Airborne sound insulation	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	
	Impact sound	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
	Noise from installations	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
	Noise from outdoors	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
Enhanced audio devices		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	

28. Figure Picture of the literature review of the already existing IEQ assessment tools

6.2. Selection of parameters

6.2.1. General procedure

The purpose of this section is to define the process of the selection of the main parameters used as a basis for evaluation of IEQ of office spaces. The goal is to focus on the factors that have the biggest impact on people's wellbeing and productivity, while keeping the method transparent and replicable for future use.

The selection process can be divided into three main steps: identification of relevant parameters and creation of a gross list, scoring to evaluate their performance, and formation of a final, reduced net list.

6.2.1.1. Creation of the initial list

The first step in the process was to identify which parameters are most relevant for the evaluation of IEQ in office buildings, with a focus on open-plan offices. Since there are many possible parameters that can effect the indoor environment, the selection was based on the findings from relevant regulations, guidelines, scientific publications and other IEQ assessment tools.

Parameters that were mentioned consistently across these sources and that has shown to have a documented impact on occupants' wellbeing or productivity, were included in the initial list. This approach ensured that the parameters selected represent the aspects of the indoor environment most significant to the office work.

To structure the approach, the parameters were divided into four main categories representing different aspects of indoor environment: thermal, atmospheric, visual and acoustic comfort.

After identifying the relevant parameters, each was described in more detail to clarify its role and importance in the IEQ evaluation. The summary table was created outlining:

- Description of the parameter
- Recommended values and possible requirements in Denmark
- Recommended values and possible requirements in EU
- Impact on humans
- Frequency, typical levels, temporal variation
- Measurability/documentation

- Other factors for the selection of net list

This step helped with consistency in understanding how each parameter contributes to the indoor environment and provide a clear basis for later comparison and scoring. It also helped to verify that all parameters could be practically assessed within the scope of our study.

6.2.1.2. *Scoring*

To prioritize the most relevant parameters for the final evaluation, each identified parameter was scored based on its impact on wellbeing and productivity. In this context, wellbeing was defined as combination of comfort and health, reflecting how the indoor environment influences occupants physical and mental state. Productivity was understood as the occupants ability to perform work tasks efficiently, stay focused and avoid performance loss caused by discomfort.

These two criteria were chosen because they reflect both human and economic aspects of the indoor environment. A workplace that supports employees wellbeing tends to reduce sick leaves, while higher productivity directly benefits companies through improved performance and final outcomes [14].

Each parameter was evaluated on 0-3 scale for both criteria. The scoring scale was intentionally kept small to avoid overcomplicating the assessment, as the evaluation was based on primarily on information from research publications and standards. Since it is difficult to precisely compare the importance of different parameters, a simple and transparent scoring system was considered the most reliable approach.

The scale was defined as:

- 0-No significant impact
- 1-Minor or indirect impact
- 2-Moderate impact with consistent evidence from literature or standards
- 3-Strong and well documented impact on wellbeing or productivity

This scoring process allowed us to systematically compare the parameters and identify those with the highest overall relevance for the final evaluation.

6.2.1.3. *Creation of net list*

After the scoring was completed, the parameters were reviewed based on their total and individual scores to determine which ones would be included in the final IEQ evaluation. Parameters that received score of 3 in either category were automatically included, as

this indicated its strong influence. In addition, the parameters with combined score of at least 3 across both categories were also included further.

Based on the final selection of the parameters, a set of summary tables was created to organize and present the results in a clear and systematic way. Each table was developed individually, primarily following the logic of where the influence on the indoor environment originates. This structure allowed the parameters to be grouped according their source. The resulting tables provide an overview of the most important IEQ parameters for office environments and form the basis for the proposed assessment tool.

6.2.2. Atmospheric comfort

6.2.2.1. Creation of the initial list

The atmospheric comfort parameters were selected based on the pollutants and air-quality factors most consistently identified across the key standards and literature relevant for office environments. These include DS/EN 16798 [22], WHO guidelines for indoor air quality [46] as well as scientific publications focusing on how specific pollutants influence health, perceived air quality and productivity. While comparing findings from these sources, several parameters repeatedly appeared as primary indicators of indoor air quality in the buildings.

- CO₂ concentration
- PM_{2.5}/PM₁₀
- Ultrafine particles (UFP)
- TVOC
- Formaldehyde
- SVOC
- O₃ (Ozone)
- NO₂/CO/SO₂
- Radon
- Relative humidity
- Moisture in materials/hidden mold
- Odor/perceived air freshness
- Microbial contamination (HVAC)

Because this assessment focused on open-plan offices, priority was given to parameters that reflect the conditions specific to these spaces: higher occupant density, reliance on mechanical ventilation and presence of office equipment. This means that in addition to

common atmospheric comfort indicators the list also includes parameters such as ultrafine particles from printers and new furniture, microbial contamination in ventilation systems, CO₂ and odour from occupants and their activities.

22. Table

Atmospheric comfort, creation of the initial list - CO₂ concentration

Parameter: CO ₂ concentration
Carbon dioxide is naturally occurring pollutant produced mainly by human respiration in indoor environments. It is not harmful at the concentrations typically found indoors, but serves as an important indicator of ventilation effectiveness and perceived air freshness. High levels indicate poor air exchange and are often associated with stuffy air, fatigue, reduced concentration [1].
Recommended values and possible requirements in Denmark: BR18-not exceed 1000ppm for classrooms, and BR18 and DS3033 reference DS/EN16798 (EU). [22,23,47]
Recommended values and possible requirements in EU: EN 16798 [22] categorize office rooms based on CO ₂ IEQ categories. Where the values are above outdoor concentration: I-550ppm, II-800ppm, III-1350ppm.
Impact on humans: High concentration are associated with perceived stuffiness, reduced cognitive performance, headaches and fatigue [1].
Frequency, typical levels, temporal variation: Typically in Denmark, 400-600ppm outdoors, 600-1200ppm indoors depending on occupancy and ventilation rate [22].
Measurability/documentation: Measured with CO ₂ sensors, continuous or spot readings.
Other relevant factors for the selection of net list: Strongly depends on occupancy density and air distribution, good indicator for IAQ control in open-plan offices.
Link to further info/projects:

23. Table

Atmospheric comfort, creation of the initial list - PM_{2.5}/PM₁₀

Parameter: PM _{2.5} /PM ₁₀
Fine particles originate from both outdoor sources (traffic, combustion, dust) and indoor sources such as printers, human movement, cleaning activities. In office environments, outdoor infiltration is typically the main contributor. Concentration depends strongly on outdoor air quality, filtration efficiency of ventilation system and cleaning practices [48]
Recommended values and possible requirements in Denmark: BR18-not mentioned directly, but mechanical ventilation must have filters.
Recommended values and possible requirements in EU: [49]-Defines outdoor air(ODA) and supply air(SUP) categories. Requires appropriate filter efficiency (ePM1, ePM2.5, ePM10) depending on outdoor air quality.
Impact on humans: Long term exposure can increase risk of respiratory and cardiovascular diseases, asthma and allergic reactions. Short term exposure can cause eye, throat irritation and sensation of stale air [1].
Frequency, typical levels, temporal variation: Indoor concentrations vary significantly over time. In well ventilated offices with effective filtration, PM _{2.5} levels are typically 5–20 µg/m ³ . Peak concentrations occur during strong outdoor pollution, cleaning, or printing activities [48].
Measurability/documentation: Measured using optical particle counters capable of differentiating size fractions.
Other relevant factors for the selection of net list: Efficient particle filtration in the AHU, maintaining clean supply ducts and regular replacement of filters are key measures for control [24]
Link to further info/projects:

24. Table

Atmospheric comfort, creation of the initial list - Ultrafine particles

Parameter: Ultrafine particles (UFP)
Ultrafine particles originate from both outdoor sources and indoor sources such as printers, copiers and other electronic office equipment. In office environments, outdoor infiltration is typically the main contributor. In mechanically ventilated offices the largest contribution often comes from infiltration or particle generated from office machinery [48].
Recommended values and possible requirements in Denmark: There are no limits for UFP in Danish or EU indoor air standards. The WHO (2021) and ISO 16000-34 recommends keeping concentration as low as achievable through source control and filtration.
Recommended values and possible requirements in EU:
Impact on humans: Because of their small size, UFP can be breathed in to the lungs, causing oxidative stress, inflammation and potential long term cardiovascular effects [50].
Frequency, typical levels, temporal variation: Indoor concentration depends strongly on occupancy and equipment use
Measurability/documentation: Measurements are more complex than for PM _{2.5} /PM ₁₀ and require specialized instruments.
Other relevant factors for the selection of net list: Regular maintenance and filter replacement in AHU. Locating emission sources in separate ventilated rooms [24].
Link to further info/projects:

25. Table

Atmospheric comfort, creation of the initial list - TVOC

Parameter: TVOC
Total volatile organic compounds represents the sum of all VOCs in indoor air. In offices, VOCs originate mainly from building materials, finishes, furniture, floor coverings, cleaning products and office equipment. VOCs are emitted continuously at different rates and can accumulate in badly ventilated spaces [48].

<p>Recommended values and possible requirements in Denmark:</p> <p>DS 3033 (Denmark) [47]: Class I<200 µg/m³, Class II<300 µg/m³, Class III<500 µg/m³.</p>
<p>Recommended values and possible requirements in EU:</p> <p>EU Ecolabel/M1 material classification: promotes lowemitting materials with ≤200 µg/m³ after 28 days.</p> <p>These correspond roughly to Category II air quality (EN 16798-1) in offices.</p>
<p>Impact on humans:</p> <p>Can cause odour, irritation of eyes and mucous membrane and headaches. Can cause reduced satisfaction and perceived air quality [1].</p>
<p>Frequency, typical levels, temporal variation:</p> <p>Concentration is typically highest in new or recently renovated offices and decreases over time.</p>
<p>Measurability/documentation:</p> <p>Measured according ISO 16000-6.</p>
<p>Other relevant factors for the selection of net list:</p> <p>Use low emission building products and furniture. Ensure sufficient ventilation during and after installation of new materials.</p> <p>Avoid storing cleaning products and solvents in occupied rooms.</p>
<p>Link to further info/projects:</p>

26. Table

Atmospheric comfort, creation of the initial list - Formaldehyde

<p>Parameter: Formaldehyde</p>
<p>Its colourless, reactive gas, that is commonly produced from composite wood products, furniture, paints and varnishes. Emission occurs for longer periods of time and decrease with the time and ventilation of the space [46].</p>
<p>Recommended values and possible requirements in Denmark:</p> <p>DS 3033 – low emission materials (E1 class) required by BR18</p>

<p>Recommended values and possible requirements in EU:</p> <p>EU Ecolabel/M1 material classification: promotes lowemitting materials with $\leq 50 \mu\text{g}/\text{m}^3$ after 28 days.</p>
<p>Impact on humans:</p> <p>Causes eye irritation, nose and throat irritation. Long exposure might lead to respiratory symptoms and asthma like reaction. The Agency of research on cancer classifies it as number one carcinogen. Short exposure mainly effects perceived air quality [1].</p>
<p>Frequency, typical levels, temporal variation:</p> <p>Typical values for furnished building are around $10\text{-}50 \mu\text{g}/\text{m}^3$. This value can significantly rise if the building is newly furnished but will go down over the time [46].</p>
<p>Measurability/documentation:</p> <p>Measured according ISO 16000</p>
<p>Other relevant factors for the selection of net list:</p> <p>Increased ventilation during and right after renovation or new furniture can help with the high values for first period. In general, high temperatures and RH supports emission [46].</p>
<p>Link to further info/projects:</p>

27. Table

Atmospheric comfort, creation of the initial list - SVOC

<p>Parameter: SVOC</p>
<p>In office environments, SVOC is mainly emitted from plastic flooring, electronic devices, insulation materials, or furniture coatings. They accumulate slowly and can persist over long periods of times because of their low volatility [46].</p>
<p>Recommended values and possible requirements in Denmark:</p> <p>It is recommended to minimize SVOC exposure by control of the source and in general low emission materials selection for the room.</p>
<p>Recommended values and possible requirements in EU:</p>

<p>Impact on humans:</p> <p>Their impact is mainly long-term as oppose to immediate irritation and disturbance for the occupants. It might cause skin and eye irritation or possibly to reproductive, and developmental effects [1].</p>
<p>Frequency, typical levels, temporal variation:</p> <p>In general, indoor air concentration is usually on low levels while the concentration of dust can be much higher. Since the emission is slow and continuous, higher rates are connected with new furnishing and renovations [46].</p>
<p>Measurability/documentation:</p> <p>Requires active air sampling on polyurethane foam or sorbent cartridges ISO16000 [51]</p>
<p>Other relevant factors for the selection of net list:</p> <p>Choose low emission furniture finishes, phthalate free flooring. Maintain regular cleaning to reduce dust and to avoid unnecessary fragrances while cleaning</p>
<p>Link to further info/projects:</p>

28. Table

Atmospheric comfort, creation of the initial list - Ozone

<p>Parameter: O₃ (Ozone)</p>
<p>Ozone is not produced indoor in larger amounts but mostly enters from outdoors, where its big component of outdoor smog. Indoors can be produced by electrical devices such as printers [46].</p>
<p>Recommended values and possible requirements in Denmark:</p> <p>Not specific requirements but DS 447 [24] recommends filter classes and source control</p>
<p>Recommended values and possible requirements in EU:</p>
<p>Impact on humans:</p> <p>Is strong irritant that can cause sore eyes, nose and throat. Can start coughing and chest tightness. Can also cause perceived air staleness [1].</p>

<p>Frequency, typical levels, temporal variation:</p> <p>Depends on ventilation rate, filter type in general, but is often mentioned as 10-40% of outdoor concentration [46].</p>
<p>Measurability/documentation:</p> <p>Requires active air sampling on polyurethane foam or sorbent cartridges ISO16000</p>
<p>Other relevant factors for the selection of net list:</p> <p>Limit using of UV based equipment in occupied spaces. Ensure right filters in ventilation system and their maintenance.</p>
<p>Link to further info/projects:</p>

29. Table

Atmospheric comfort, creation of the initial list - NO₂/CO/SO₂

<p>Parameter: NO₂ / CO / SO₂</p>
<p>Is produced by outdoor cars through their exhaust and gas combustion. Its part of industrial fuel combustion and might enter building in close proximity to traffic [46].</p>
<p>Recommended values and possible requirements in Denmark:</p> <p>DS447 [24] recommends that the air intakes for the ventilation systems are located far from the traffic sources and that the proper filters are used.</p>
<p>Recommended values and possible requirements in EU:</p>
<p>Impact on humans:</p> <p>Causes irritation of eyes, throat. Can cause asthma and different kinds of infections. Even at low concentrations these gasses can create low perceived air quality by occupants [1]</p>
<p>Frequency, typical levels, temporal variation:</p> <p>In general, they vary with different outdoor conditions, ventilations rates and the distance to the outdoor traffic.</p>
<p>Measurability/documentation:</p> <p>Measured by electromechanical sensors, or by portable indoor air quality monitors [46].</p>
<p>Other relevant factors for the selection of net list:</p> <p>Ensure that the ventilation intake isn't near any vehicles or traffic, maintain positive building pressure to prevent infiltration.</p>

Link to further info/projects:

30. Table

Atmospheric comfort, creation of the initial list - Radon

Parameter: Radon
Its radioactive gas formed in the ground. It travels through the foundation, and cracks of the buildings into the indoor environment. Its colourless, odourless [46].
Recommended values and possible requirements in Denmark: BR18- require that radon concentration indoors is limited and buildings are radon proofed. Should not exceed 100Bq/m ³
Recommended values and possible requirements in EU: Reference level should be smaller than 100Bq/m ³ and up to 300Bq/m ³ is accepted in existing buildings [46].
Impact on humans: Its carcinogen gas that can lead to cancer. It doesn't have immediate effect but overtime in can cause damage to the lungs [1].
Frequency, typical levels, temporal variation: The concentration varies with the location, in general the values are higher in winter since the ventilation is reduced.
Measurability/documentation: Measured by radon detector over period of 1-3 months to capture seasonal variations. Measurement should be done with accordance with DS3033 [47]
Other relevant factors for the selection of net list: The radon tight membrane should be used to seal the foundation in new constructions.
Link to further info/projects:

31. Table

Atmospheric comfort, creation of the initial list - Relative humidity

Parameter: Relative humidity
Reflects moisture balance of indoor air and has strong effect on some comforts like thermal and atmospheric. It also influences the material durability in the space [13].
Recommended values and possible requirements in Denmark: Recommended range is Class I = 35–50 %, Class II = 30–60 % [47].
Recommended values and possible requirements in EU: EN 16798 [22] recommends indoor RH between 30-60% for comfort category II. ASHRAE 55 [52] mentions comfort zone limits as 20-70%
Impact on humans: Low RH can cause skin dryness, eye irritation and static electricity leading to discomfort. High RH causes growth of mold and bacteria [46].
Frequency, typical levels, temporal variation: Normally is lower in winter scenarios in heated buildings and higher in summer conditions. Short term variations are usually caused by the occupancy.
Measurability/documentation: Measured using hydrometers or humidity sensors.
Other relevant factors for the selection of net list: Both temperature and RH should be monitored indoor to prevent material damage.
Link to further info/projects:

32. Table

Atmospheric comfort, creation of the initial list - Odor or perceived air freshness

Parameter: Odor or perceived air freshness
In office environments, uncomfortable odours come from materials, cleaning products, occupants or in general poor ventilation. It depends how its perceived by occupants when it comes to their sensitivity to odours [53].

Recommended values and possible requirements in Denmark: DS 3033 [47]Mentioned that the air should be free from unpleasant odours in class I and II
Recommended values and possible requirements in EU:
Impact on humans: Odour or in general unpleasant air is often first sign of insufficient ventilation. Even at low pollution levels odour can lead to reduced satisfaction with the air quality. This can also lead to headaches and irritation [53].
Frequency, typical levels, temporal variation: Varies through the day with the occupancy patterns, the activity like cleaning and ventilation rates
Measurability/documentation: Odour cannot be measured but can be evaluated by questionnaire for the occupants
Other relevant factors for the selection of net list: Maintain good ventilation rates, limit strong fragrances indoors like cleaning supplies, air sprays and ensure that the HVAC system is maintained from buildup in the ducts.
Link to further info/projects:

33. Table

Atmospheric comfort, creation of the initial list - Microbial contamination in HVAC

Parameter: Microbial contamination in HVAC
This refers to growth and accumulation of microorganisms like mold and fungi inside the ducts, filters and AHU. It develops when moisture and dust combine inside the system and this supports the microbial growth [54].
Recommended values and possible requirements in Denmark: DS447 [24] recommends regular inspections and cleaning intervals to prevent microbial growth

Recommended values and possible requirements in EU:
Impact on humans: Exposure can cause Sick Building syndrome complains such as fatigue and headaches [54].
Frequency, typical levels, temporal variation: The risk of microbial contamination rises when the filters and coils aren't regularly cleaned or when condensation drains are blocked. It tends to be higher in cooling season due to higher humidity [24]. DS447
Measurability/documentation:
Other relevant factors for the selection of net list: Ensure proper condensation drainage within the ventilation system. Replace filters according to manufacturers recommendations. Regular cleaning and maintenance is recommended [54].
Link to further info/projects:

6.2.2.2. Scoring

The final scoring of atmospheric comfort parameters follows the general method described previously. While many pollutants are well researched and have clear links to both wellbeing and productivity, others have more limited or indirect documentation. In several cases, studies focus primarily on health or perceived air quality without direct link to productivity. Because of this, some of the scores, especially for parameters with limited documentation, were based on reasoned assumptions supported by related findings in the literature.

34. Table

Atmospheric comfort criterion scoring

Parameter	Well-being	Productivity
CO ₂ concentration	2	3
PM _{2.5} /PM ₁₀	2	2
Ultrafine particles (UFP)	2	1
TVOC (Total volatile organic compounds)	2	2

Formaldehyde	2	1
SVOC (Semi-volatile organic compounds)	1	0
O ₃ (Ozone)	2	0
NO ₂ /CO/SO ₂	2	0
Radon	3	0
Relative humidity (RH)	2	1
Moisture in materials/Hidden mold	3	1
Odor/Perceived air freshness	3	2
Microbial contamination (HVAC systems)	3	1

6.2.2.3. *Creation of the net list*

The selected atmospheric comfort parameters were organized according to the origin of their influence: whether they come from the outdoor pollution, emission from the building and hygiene of the ventilation system, materials, office equipment or occupants related sources. Grouping the parameters in this way helps clarify the pathways through which pollutants enter or develop within the indoor environment and makes the structure easier to follow.

6.2.3. *Thermal comfort*

6.2.3.1. *Creation of the initial list*

As thermal comfort and room temperatures are among key factors that affect satisfaction with the indoor environment the most, the list primarily includes parameters related to temperature and factors that affect it. Different parameters showed the importance and effect on the occupants and were included in the list. The list was created based on the most frequently repeated components of thermal comfort that are relevant to office environments.

- Air temperature (overtemperatures)
- PMV/PPD
- Operative temperature
- Non-steady state thermal environments
- Mean air velocity
- Draught
- Surface temperatures (cold and warm floors)
- Radiant temperature asymmetry
- Vertical air temperature

35. Table

Thermal comfort, creation of the initial list - Air temperature (overtemperatures)

Parameter: Air temperature (overtemperatures)
Description/definition of the parameters, including source: One of the factors defining thermal comfort. It is a temperature that can be measured.
Recommended values and possible requirements in Denmark: “For buildings other than residential buildings, the developer determines the maximum number of hours per year of use during which a room temperature (the operative temperature) of 26 °C and 27 °C respectively may be exceeded. For many types of buildings with a use period similar to office buildings, an excess of no more than 100 hours above 26 °C and 25 hours above 27 °C will normally satisfy the provision.”[23] BR18
Recommended values and possible requirements in EU:
Impact on humans (sensory, symptoms, performance, illness, productivity): “Room temperature affects the performance. Rapid temperature swings have the same effects on office work as slightly raised room temperatures, while slow temperature swings just cause discomfort.” [16]
Frequency, typical levels, temporal variation:
Measurability/documentation (and any challenges related to this): Air temperature is measured with proper metes (thermometers).
Other relevant factors for the selection of the net list (e.g. good solution for reducing possible problems):
Link to further info/related projects etc.: Rehva 6 Guidebook

36. Table

Thermal comfort, creation of the initial list - PMV/PPD

Parameter: PMV/PPD
Description/definition of the parameters, including source: “The PMV index is defined in relation to the mean value of the thermal votes of a large group of people exposed to the same environment. But individual votes are scattered around this mean values and it is useful to be able to predict the number of people likely to feel uncomfortably warm or cool.” PPD describes predicted percentage dissatisfied. “It is an index that establishes a quantitative index related to the percentage of thermally dissatisfied people who feel too cool or too warm.” [13]
Recommended values and possible requirements in Denmark:
Recommended values and possible requirements in EU: “PMV is an index that predicts the mean value of the votes of a large group of persons on the seven-point thermal sensation scale, based on the heat balance of the human body.” [13]
Impact on humans (sensory, symptoms, performance, illness, productivity):
Frequency, typical levels, temporal variation:
Measurability/documentation (and any challenges related to this): PMV is calculated based on formula in DS/EN 7730, chapter 4.1. Can also be evaluated from a graph based on the air temperature, level of clothing and metabolic rate. PPD is dependent on PMV results, and can be read from the graph based on the PMV rate. DS/EN 7730, chapter 5 The relation between PMV and PPD is in DS/EN 7730, chapter 5, table 2. There is a computer program to calculate the PMV and PPD. The BASIC program calculates the PMV and PPD DS/EN 7730, Annex D. [13]
Other relevant factors for the selection of the net list (e.g. good solution for reducing possible problems):
Link to further info/related projects etc.:

Innova Thermal comfort

37. Table

Thermal comfort, creation of the initial list - Operative temperature

Parameter: Operative temperature
Description/definition of the parameters, including source: “The fictive uniform temperature of air and surrounding surfaces which will cause the same dry heat loss for a person as the actual temperatures of air and surrounding surfaces.” [21] “The uniform temperature of an enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual non-uniform environment.” [21]
Recommended values and possible requirements in Denmark:
Recommended values and possible requirements in EU:
Impact on humans (sensory, symptoms, performance, illness, productivity): “Room temperature affects the performance. Rapid temperature swings have the same effects on office work as slightly raised room temperatures, while slow temperature swings just cause discomfort.” [16]
Frequency, typical levels, temporal variation: Operative temperatures are specified for summer (cooling season) and winter (heating season), based on the types of building and space and based on indoor environmental category in DS/EN 7730, in A.4 design criteria for different types of space [13].
Measurability/documentation (and any challenges related to this): Operative temperature can be calculated using air temperature and mean radiant temperature.
Other relevant factors for the selection of the net list (e.g. good solution for reducing possible problems):
Link to further info/related projects etc.:

38. Table

Thermal comfort, creation of the initial list - Non-steady state thermal environments

Parameter: Non-steady state thermal environments
Description/definition of the parameters, including source: “Thermal environment is often in non-steady-state. Three types of non-steady-state conditions occur: temperature cycles, temperature drifts or ramps and transients.”
Recommended values and possible requirements in Denmark:
Recommended values and possible requirements in EU: Temperature cycles: “Temperature cycles can occur due to the control of the temperature in the space. If the peak-to-peak variation is less than 1 K, there will be no influence on the comfort and the recommendations for steady-state may be used.” DS/EN 7730 [13] Temperature drifts or ramps: “If the rate of temperature change for drifts or ramps is lower than 4 K/h, the methods for steady-state variation apply.” [13]
Impact on humans (sensory, symptoms, performance, illness, productivity): Higher peak variations in temperature cycles can decrease comfort of occupants. [13]
Frequency, typical levels, temporal variation:
Measurability/documentation (and any challenges related to this):
Other relevant factors for the selection of the net list (e.g. good solution for reducing possible problems):
Link to further info/related projects etc.:

39. Table

Thermal comfort, creation of the initial list - Mean air velocity

Parameter: Mean air velocity
Description/definition of the parameters, including source: Air velocity is the speed at which air moves from one place to another. In simple terms — it tells you how fast the air is flowing in a particular direction, such as from a fan, air conditioner, or vent.

Air velocity = the rate of air movement in a specific direction, measured in meters per second (m/s) [52]

Recommended values and possible requirements in Denmark:

For practical purposes, a mean air velocity of under 0.15 m/s and outside large fluctuations will normally be deemed to be satisfactory at air temperatures in excess of 21°C. In the event of temperatures in excess of 24°C, higher air velocities are acceptable. [55]

BR18:

in Denmark The Building Regulations prescribe a maximum air velocity of 0.15 m/s during the heating season. At higher air temperatures of 23-24°C, the risk of thermal discomfort is reduced, and higher air velocities can be accepted (up to 0.22 m/s) . The tensile model is included in ISO 7730 [13], as the Building Regulations refer to [23].

Recommended values and possible requirements in EU:

Impact on humans (sensory, symptoms, performance, illness, productivity):

Frequency, typical levels, temporal variation:

Measurability/documentation (and any challenges related to this):

Air velocity and turbulence intensity can be measured with a unidirectional thermal anemometer.

Air temperature is measured as stated above. Requirements for instruments in ISO 7726 [56].

For functional requirements and methods of specification, verification and monitoring of the thermal indoor climate, see DS 474, Code for indoor thermal climate [21].

Other relevant factors for the selection of the net list (e.g. good solution for reducing possible problems):

Protective measures.

Link to further info/related projects etc.:

40. Table

Thermal comfort, creation of the initial list - Draught

Parameter: Draught
<p>Description/definition of the parameters, including source:</p> <p>Draught is defined as undesirable local cooling of the body resulting from movement of air. The sensation of draught is associated with the air temperature, air velocity and turbulence intensity. Turbulence intensity is the relationship between standard deviation on air velocity and mean air velocity. [55]</p>
<p>Recommended values and possible requirements in Denmark:</p> <p>BR18 [23] :</p> <p>To limit draughts, the draught rate in the occupied zone in rooms with sedentary activity should not exceed 20%. Draught rate is defined as in DS/EN ISO 7730 [13] Ergonomics in the thermal environment - Analytical determination and interpretation of thermal comfort by calculating PMV and PPD indices and local thermal comfort criteria. The draught risk depends on the activity level, air temperature and air turbulence intensity. The occupied zone is the area in a room where people can be expected to stay for a longer period of time.</p> <p>With a draft rate of 20%, the following maximum mean air speeds are obtained in normal turbulence (Turbulence intensity of 40 percent): (table in BR18 ventilation guidance)</p> <p>DS/CEN/CR 1752 [57], Ventilation for buildings – Design criteria for the indoor environment (Danish Standards, 2001b) provides tools for creating an acceptable indoor climate for occupants of ventilated buildings. It specifies three different categories of anticipated quality of indoor climate which can be opted for when a room is to be ventilated. Category A meets an anticipated high level, category B an anticipated average level and category C an anticipated modest level.</p> <p>A draught rating (DR) can be expressed as a percentage of people who are likely to suffer discomfort caused by draughts. The diagrams in Figure 54 show the permitted mean air velocity for the three categories. The turbulence intensity can fluctuate between 30% and 60% in premises with mixer ventilation [55].</p>
Recommended values and possible requirements in EU:

Requirements in the EU Draught are assessed via the draft model, and for different quality categories, criteria have been set for the maximum acceptable proportion of dissatisfaction caused by the draft, e.g. 10%, 15% or 25%. For a given air temperature and turbulence intensity, the maximum acceptable air speed is determined.

Impact on humans (sensory, symptoms, performance, illness, productivity):

Thermal discomfort, uneven temperature precipitation, annoyance.

Muscle stiffness or tension, dry or irritated skin, lips and eyes, headache, runny nose

Frequency, typical levels, temporal variation:

Draughts are most frequent during the heating season.

Measurability/documentation (and any challenges related to this):

Draught rate is defined as in DS/EN ISO 7730 Ergonomics in the thermal environment - “Analytical determination and interpretation of thermal comfort by calculating PMV and PPD indices and local thermal comfort criteria“ [13].

DS/CEN/CR 1752, Ventilation for buildings – Design criteria for the indoor environment (Danish Standards, 2001b) provides tools for creating an acceptable indoor climate for occupants of ventilated buildings [57].

For functional requirements and methods of specification, verification and monitoring of the thermal indoor climate, see DS 474, Code for indoor thermal climate [21].

Other relevant factors for the selection of the net list (e.g. good solution for reducing possible problems):

Protective measures.

Link to further info/related projects etc.:

41. Table

Thermal comfort, creation of the initial list - Surface temperature (cold and warm floors)

Parameter: Surface temperatures (cold and warm floors)
Description/definition of the parameters, including source: Surface temperature refers to the temperature of a surface that people can touch or are exposed to, such as floors, walls, ceilings, windows, or furniture [13].
Recommended values and possible requirements in Denmark: DS/EN ISO 7730 [13] (Thermal environment — Analytical determination and interpretation of thermal comfort by PMV/PPD) The recommended values for PMV/PPD for different IEQ categories can be found in this standard
Recommended values and possible requirements in EU:
Impact on humans (sensory, symptoms, performance, illness, productivity):
Frequency, typical levels, temporal variation:
Measurability/documentation (and any challenges related to this): DS 474 – “Norm for specifikation af termisk indeklima” This Danish standard provides guidance on how to specify thermal indoor climate (including surface parameters) [21]. DS/EN ISO 7730 (Thermal environment — Analytical determination and interpretation of thermal comfort by PMV/PPD) [13] Although not a Danish-only standard, it is adopted in Denmark and referenced by BR18. It includes criteria for local thermal discomfort such as floor surface temperature difference and radiant asymmetry. DS 452 – “Termisk isolering af tekniske installationer” [58] While primarily about insulation of technical systems, it mentions surface temperatures (maximum surface temperature around 50 °C) in context of equipment/pipe insulation. Ergonomic / Working Environment – Arbejdstilsynet (Danish Working Environment Authority) guidance [59]

For office/workplace indoor climate: recommended typical temperatures (20-22 °C for sedentary work) and minimum around 18 °C. While not specifically about surface temperature, it is part of the comfort / environment context.

Bygningsreglementet BR18 (Denmark's Building Regulation) [23]

Under Chapter / Section on **Thermal indoor climate ('Termisk indeklima')**: It states that the thermal indoor climate is determined by *air temperature, surface temperatures* (i.e., temperatures of surrounding surfaces), *air velocity/turbulence*, and *humidity*.

Other relevant factors for the selection of the net list (e.g. good solution for reducing possible problems):

Link to further info/related projects etc.:

42. Table

Thermal comfort, creation of the initial list - Radiant temperature asymmetry

Parameter: Radiant temperature asymmetry
<p>Description/definition of the parameters, including source:</p> <p>Radiant temperature asymmetry means there is a difference in radiant heat coming from different directions around a person.</p> <p>In other words, one side of your body receives more radiant heat (or cold) than the other - making you feel uncomfortable [13].</p>
<p>Recommended values and possible requirements in Denmark:</p> <p>In Denmark, the Building Regulations do not directly specify radiation temperature asymmetry but refers to ISO 7730, which includes models for calculating the level of dissatisfaction caused by cold or warm ceilings and walls [13].</p>
<p>Recommended values and possible requirements in EU:</p> <p>requirements in the EU Same as in Denmark. Discomfort is assessed with the same models that take the direction of the radiation temperature asymmetry into account.</p>
<p>Impact on humans (sensory, symptoms, performance, illness, productivity):</p> <p>Thermal discomfort, Lower focus and productivity</p>

Frequency, typical levels, temporal variation:

Temperature asymmetry is rarely a problem in modern, well-insulated homes, where all surfaces maintain similar temperatures, closely matching the air temperature. Discomfort often arises when sitting near a window exposed to intense sunlight.

Measurability/documentation (and any challenges related to this):

Radiant temperature asymmetry can be determined either by using a radiometer for direct measurement or by indirect calculation. The indirect method involves analysing the room's geometry and determining the angular relationship from the point of interest, along with measuring the surface temperatures of areas that have uniform thermal conditions.

Other relevant factors for the selection of the net list (e.g. good solution for reducing possible problems):

DS/EN ISO 7730 (Thermal environment — Analytical determination and interpretation of thermal comfort by PMV/PPD) [13]

Although not a Danish-only standard, it is adopted in Denmark and referenced by BR18. It includes criteria for local thermal discomfort such as floor surface temperature difference and radiant asymmetry.

Link to further info/related projects etc.:

43. Table

Thermal comfort, creation of the initial list - Vertical air temperature

Parameter: Vertical air temperature

Description/definition of the parameters, including source:

Vertical air temperature refers to the difference in air temperature at different heights in a room — usually measured from head height to ankle or floor height.

Recommended values and possible requirements in Denmark:

According to ISO 7730 [13] and its Danish adoption DS/EN ISO 7730, the acceptable vertical air temperature differences are:

Seated occupants: Maximum 3°C vertical temperature difference between head (~1.1–1.2 m) and feet (~0.1 m)

Standing occupants: Maximum 4°C vertical temperature difference

These limits are designed to prevent discomfort caused by uneven heating or cooling in indoor spaces.

In BR18 there is not specific numerical limit values related to vertical air temperature

Recommended values and possible requirements in EU:

requirements in the EU Same as in Denmark. Discomfort is assessed with the same models that take the direction of the radiation temperature asymmetry into account.

Impact on humans (sensory, symptoms, performance, illness, productivity):

Thermal discomfort, Lower focus and productivity

Frequency, typical levels, temporal variation:

In practice, vertical differences typically range between 0.5–3 °C in well-designed HVAC systems.

Poorly designed systems (stratified heating or cooling) can produce 4–6 °C or more, leading to noticeable discomfort.

Dynamic changes occur as HVAC systems cycle, sunlight shifts, or occupants move.

Measurability/documentation (and any challenges related to this):

In Denmark, the primary standard for assessing thermal comfort, including vertical air temperature differences, is DS/EN ISO 7730:2025. This standard provides methods for evaluating the general thermal comfort of people in a space and their discomfort due to factors like vertical temperature gradients. It specifies measurement procedures and criteria for acceptable temperature differences between head and feet (typically $\leq 3^{\circ}\text{C}$ for seated occupants) [13].

Additionally, DS/EN ISO 7726 outlines the requirements for instruments used to measure physical quantities affecting thermal comfort, ensuring accurate and reliable data collection [56].

For compliance and documentation purposes, it's essential to:

- Measure vertical air temperature differences at specified heights (e.g., head and feet) using calibrated instruments.

<ul style="list-style-type: none"> • Document measurement locations and conditions under which measurements were taken. • Compare results against the criteria set forth in DS/EN ISO 7730 to assess compliance.
Other relevant factors for the selection of the net list (e.g. good solution for reducing possible problems):
Link to further info/related projects etc.:

6.2.3.2. Scoring

The final scoring of thermal comfort parameters follows the general method described previously. While many parameters are well researched and have clear links to both wellbeing and productivity, others have more limited or indirect documentation. In several cases, studies focus primarily on health without direct link to productivity. Because of this, some of the scores, especially for parameters with limited documentation, were based on reasoned assumptions supported by related findings in the literature.

44. Table

Thermal comfort criterion scoring

Parameter	Well-being	Productivity
Air temperature	3	3
Operative temperature	3	3
PMV/PPD	3	3
Non steady state environment	1	1
Mean air velocity	2	2
Draught	2	3
Surface temperatures	3	2
Radiant temperature asymmetry	2	2
Vertical air temperatures	2	1

6.2.3.3. The selected list of parameters

The list of selected parameters initially included the highest performing parameters : Air temperature, operative temperatures, PMV/PPD, draught, surface temperatures and radiant temperature asymmetry. These parameters were then organised into the final table where the evaluation method for each of them was taken into consideration. This led to tightening of the

final table where the local discomfort is assessed in form of operative temperatures, surface temperatures and draught, while the air temperatures are looked as more global room concept where the hourly calculation is introduced according to BR18 [23].

The PMV/PPD was excluded from the final assessment as this method is highly dependant on the simulations as the actual room relative humidity and air velocity play important role.

The table is organised based on summer and winter condition, mainly due to variation of the thermal comfort with the outdoor conditions. This led to more polished and organised structure of the table.

6.2.4. *Visual comfort*

6.2.4.1. *Creation of the initial list*

The list of specific parameters concerning visual comfort in office spaces was build up from different sources, standards and different evaluation tools based on the importance of their role in the office environment. Different repeating parameters which showed their importance were mainly regarding daylight and electric light in the room, and various aspects of windows, solar shading and view out.

- View
- Sunlight
- Glare protection
- Daylight
- Colour rendering (probably delete)
- Reflectance of surfaces
- Electric lighting
- Colour rendering
- Glare protection
- Flickering
- Solar shading

45. Table

Visual comfort, creation of the initial list - View

Parameter: View
Description/definition of the parameter, including source: View is a visual contact with the surroundings that is usually through windows of a building, providing information about the surrounding landscape/city scape, possibility to experience weather changes and to follow the time over the day.

There must a quality view provided in office spaces to provide comfort to occupants. View of the surroundings must be maintained for a satisfactory part of the period of use [60].

Recommended values and possible requirements in Denmark:

“Workspace, living room, Classrooms and living spaces, etc. must be equipped with windows that are positioned so that people in the rooms can look out onto the surroundings. Interiors and sun protection must be designed and constructed to ensure that a view of the surroundings can be maintained for a satisfactory part of the period of use.” [23] BR18 § 378

Recommended values and possible requirements in EU:

The view is evaluated based on different requirements. The standards describe distances of the view outside (min. 6 m), the layers visible are evaluated (a layer of sky, landscape, ground) (mini.: landscape layer). The size of the daylight opening is an important factor considering all the openings and size of the utilized area. Horizontal sight angle from the occupants' position (min.: 14 degrees) and it describes that the window should have a glazing material that provides clear view and is naturally coloured [25].

Impact on humans (sensory, symptoms, performance, illness, productivity):

The information that people are getting through the view can relieve the fatigue associated with long periods of being indoors. “It offered the refreshment and relaxation afforded by a change of scene and focus“ [61].

Frequency, typical levels, temporal variation:

Mentioned in DS/EN 17037 and in section above

Measurability/documentation (and any challenges related to this):

With simple evaluation like distances or visible layers.

Other relevant factors for the selection of the net list (e.g. good solution for reducing possible problems):

Link to further info/related projects etc.:

46. Table

Visual comfort, creation of the initial list - Sunlight

Parameter: Sunlight
Description/definition of the parameter, including source: Important criterion of interior space that contributes to well-being of people in the room. Minimum exposure should be provided in certain rooms to support people's well-being. It is important in hospitals, playrooms and some spaces in dwellings, however it is welcomed in most of the buildings and spaces in EU [25].
Recommended values and possible requirements in Denmark:
Recommended values and possible requirements in EU: Exposure to sunlight is evaluated through daylight hours, calculating minimum number of hours during the day in which the space receives direct sunlight. This evaluation with given values is mostly used for dwellings (min. 1,5 h) [25].
Impact on humans (sensory, symptoms, performance, illness, productivity): Sunlight can contribute to occupants' well-being. It enhances overall brightness of the interior. However, the dissatisfaction can be caused by a permanent exclusion of sunlight as much as from its excess [62].
Frequency, typical levels, temporal variation:
Measurability/documentation (and any challenges related to this): The assessment of hours of sunlight – sunlight exposure in a space for a selected day [25] .
Other relevant factors for the selection of the net list (e.g. good solution for reducing possible problems):
Link to further info/related projects etc.:

47. Table

Visual comfort, creation of the initial list - Glare protection

Parameter: Glare protection
Description/definition of the parameter, including source: Glare is a negative sensation caused by sunlight. It happens when bright areas have higher illuminance than the luminance to which the eyes are adapted to. It causes discomfort in visual performance and visibility. Also direct sunlight can cause a risk of glare [63].
Recommended values and possible requirements in Denmark:
Recommended values and possible requirements in EU: Glare is evaluated by Daylight Glare Probability (DGP). This assesses a protection from glare in rooms with activities like reading, writing or using display devices, where the occupants are not able to choose different position. It should need go over the threshold of more than a fraction of usage time $DGP_e < 5\%$ of 0,45 [25].
Impact on humans (sensory, symptoms, performance, illness, productivity): Glare causes discomfort or loss in visual performance or visibility. It will also cause annoyance of the occupants [63].
Frequency, typical levels, temporal variation: Based on DGP it can be categorized if the glare is an issue. Different ranges of DGP specify in glare is perceived/not-perceived, disturbing or intolerable [25].
Measurability/documentation (and any challenges related to this): It can be calculated based on a formula from DS/EN 17037 [25]. It includes the luminance distribution within the field of view and the size, intensity and location of the glare source in regard to the line of sight.
Other relevant factors for the selection of the net list (e.g. good solution for reducing possible problems):
Link to further info/related projects etc.:

48. Table

Visual comfort, creation of the initial list - Daylight

Parameter: Daylight
Description/definition of the parameter, including source: Daylight can contribute to the lighting needs of any type of building. It is provided by sufficient openings throughout the year. Usually described by daylight factor, which is given illuminance on a plane received directly or indirectly from the sky [63].
Recommended values and possible requirements in Denmark: “Workrooms, living rooms in institutions, classrooms, dining rooms, hereinafter referred to as workrooms, etc., as well as living rooms and kitchens must have such an influx of daylight that the rooms are sufficiently illuminated.” BR18 § 379 10 % rule Illuminance from daylight should be 300 lux or more for at least half of the relevant floor area for at least half of the daylight hours [23].
Recommended values and possible requirements in EU: “A space is considered to provide adequate daylight if a target illuminance level is achieved across a fraction of the reference plane within a space for at least half of the daylight hours.” It should be minimum 300 lux as a target illuminance for 50 % of space, and minimum 100 lux across 95 % of space [25].
Impact on humans (sensory, symptoms, performance, illness, productivity):
Frequency, typical levels, temporal variation: the recommended levels can be found in DS/EN17037 [25])
Measurability/documentation (and any challenges related to this): Can be documented by 10 % rule. The glass area should correspond to at least 10 percent of the relevant floor area.

The daylight provision in the space should be measured on the reference plane 0,85 m above the floor, considering illuminance in the room on the grid and illuminance outside during overcast sky [23].

Other relevant factors for the selection of the net list (e.g. good solution for reducing possible problems):

Link to further info/related projects etc.:

49. Table

Visual comfort, creation of the initial list - Reflectance of surfaces

Parameter: Reflectance of surfaces
Description/definition of the parameter, including source:
Recommended values and possible requirements in Denmark:
Recommended values and possible requirements in EU: “To create a well-balanced luminance distribution the luminaries of all surfaces shall be taken into consideration. They are determined by the reflectance of and the illuminance on the surfaces.” [26]
Impact on humans (sensory, symptoms, performance, illness, productivity): Proper reflectance of the surfaces provides room brightness. Higher surface reflectance can lead to better visual comfort [26].
Frequency, typical levels, temporal variation: Following ranges for main elements are recommended: Ceiling 0,7-0,9, walls 0,5-0,8, floor 0,2-0,6. But specific values for specific rooms are in DS/EN 12464 Clause 7 [26].
Measurability/documentation:

Other relevant factors for the selection of the net list (e.g. good solution for reducing possible problems):

Link to further info/related projects etc.:

50. Table

Visual comfort, creation of the initial list - Electric lighting

Parameter: Electric lighting
Description/definition of the parameter, including source: Electric lighting is specified by illuminance from lighting fixtures in the space. It includes illuminance in the space (which is measured on the grid), illuminance on the task area, illuminance on the surrounding area, and illuminance of the background [26].
Recommended values and possible requirements in Denmark: “Acceptable lighting conditions must be ensured through electrical lighting. The lighting must be established so that it corresponds to the use of the individual rooms in the building.” BR18 § 382, 383 “Workspaces must be equipped with energy-efficiency lighting.” “Workspaces must be equipped with automatic daylight control if there is sufficient daylight.” “Workspaces must be implemented with lighting systems divided into zones with the possibility of use according to daylight conditions and activities. In smaller work spaces, e.g. single-person offices, the requirements can be waived. BR18 § 382 “In workplaces, the building regulations require that DS/EN 12464-1 be followed.” [23]
Recommended values and possible requirements in EU: Illuminance should be considered on tasks and activity areas, the immediate surrounding area and background areas.

Illuminance on the task or activity area: should be considered on the reference surface and its level should be maintained as required for different rooms with different activities.

Illuminance of the close surrounding area should be close to the illuminance of the certain task or activity area. The band around task area should be at least 0,5 m. The required illuminance levels are specified in DS/EN 12 464 [26].

Impact on humans (sensory, symptoms, performance, illness, productivity):

Good lighting conditions provide satisfactory visual comfort, where the workers have a feeling of well-being, and in a direct way it also contributes to a higher productivity level and a higher quality of work. It also provides safety and visual performance, where the workers are able to perform their visual tasks, even under difficult circumstances [26].

Frequency, typical levels, temporal variation:

Values for illuminance on the task area, immediate area, and background area are specified for different rooms with different tasks DS/EN 12 464, Clause 7 [26].

Measurability/documentation (and any challenges related to this):

The illuminance should be measured on the grid. The points in the grid are created for specifying the illumination values and verifying for the task and activity area, immediate area, and background area. The grid cells approximating to a square are preferred, the ratio of length to width of a grid cell shall be kept between 0,5 and 2. And the maximum grid size is calculated based on the formula in DS/EN 12464, chapter 5.4 [26].

Other relevant factors for the selection of the net list (e.g. good solution for reducing possible problems):

Link to further info/related projects etc.:

51. Table

Visual comfort, creation of the initial list - Colour rendering

Parameter: Colour rendering
Description/definition of the parameter, including source: Colour rendering specifies the ability of the light source of reproduce the colours [26]
Recommended values and possible requirements in Denmark:
Recommended values and possible requirements in EU: “Colours in the environment, of objects and of human skin shall be rendered with sufficient accuracy according to the task.” DS/EN 12464 [26] “To provide an objective indication of the colour rendering properties of a light source, the general colour rendering index Ra is used. The maximum Ra is 100.” [26]
Impact on humans (sensory, symptoms, performance, illness, productivity): Colour in the environment have affect on visual performance, the feeling of comfort and well-being [26].
Frequency, typical levels, temporal variation:
Measurability/documentation (and any challenges related to this): There are different values specified for different types of rooms with different tasks. DS/EN 12 464 Clause 7 [26]
Other relevant factors for the selection of the net list (e.g. good solution for reducing possible problems):
Link to further info/related projects etc.:

52. Table

Visual comfort, creation of the initial list - Glare protection

Parameter: Glare protection
Description/definition of the parameter, including source: Glare is an unpleasant factor caused by bright areas. It can be caused by lit surfaces, windows or roof lights. The two options are discomfort or disability glare. [63].
Recommended values and possible requirements in Denmark: The values for glare are specified in DS/EN 12 464 [26].
Recommended values and possible requirements in EU: Glare shall be avoided by shielding the light source or by limiting the luminance of the luminous surfaces, and by limiting the discomfort glare. The UGR method should be applied. For the limiting luminaire luminance minimum shielding angles for specified light source luminance should be applied. The choice of lighting installation should be done with suitable luminaire of a given space. The rating of the discomfort glare shall be determined using the CIE Unified Glare Rating (UGR) tabular method. The UGR values should not exceed the UGR limit values for given spaces (DS/EN 12464, Clause 7, Table 34), and it is calculated based on a formula (DS/EN 12464, 5.5.3.2)[26].
Impact on humans (sensory, symptoms, performance, illness, productivity): Glare can cause errors, fatigue and accidents.
Frequency, typical levels, temporal variation:
Measurability/documentation (and any challenges related to this):
Other relevant factors for the selection of the net list (e.g. good solution for reducing possible problems):

Link to further info/related projects etc.

53. Table

Visual comfort, creation of the initial list - Flickering

Parameter: Flickering
Description/definition of the parameter, including source Flicker is “the perception of visual unsteadiness induced by a light stimulus, the luminance or spectral distribution of which fluctuates with time, for a static observer in a static environment” [64].
Recommended values and possible requirements in Denmark
Recommended values and possible requirements in EU Flicker is specified by using the IEC short-term flicker indicator and test method [64]
Impact on humans (sensory, symptoms, performance, illness, productivity) Flickering can reduce visual comfort and task performance and can lead to physiological effects such as fatigue or headaches [64].
Frequency, typical levels, temporal variation
Measurability/documentation (and any challenges related to this)
Other relevant factors for the selection of the net list (e.g. good solution for reducing possible problems)
Link to further info/related projects etc.

6.2.4.2. Scoring

Also visual comfort parameters were scored based on their influence of the visual conditions on well-being and productivity of the occupants in the offices. Productivity was often described differently for various visual tasks in office environments; however, for the purpose of rating of the given parameters, these tasks were merged and evaluated as an impact for the given parameter.

54. Table

Visual comfort criterion scoring

Parameter	Well-being	Productivity
View	3	2
Sunlight	3	2
Glare	1	2
Daylight	2	2
Colour rendering	1	1
Reflectance of surfaces	1	1
Electric lighting	2	3
Colour rendering (colour temperature)	3	2
Glare	2	2
Flickering	2	3

6.2.4.3. Creation of the net list

The final list of parameters and different criteria within was specified based on the rating and grouped based on the topics. The main topics were split into view, daylight, and electric lighting. All the other aspects belong under one of each parameter. Final list was created as seen below with the addition of user ability to adjust the visual conditions in the room.

6.2.5. Acoustic comfort

- Airborne- acoustic insulation level - noise from other indoor rooms
- Impact sound from building elements
- Reverberation time in the stairwell
- Reverberation time in the office
- Traffic noise/façade insulation

- Technical installation
- Noise from people/activities – workstation noise level
- Speech transmission index/Speech intelligibility and sound transmission attenuation

55. Table

Acoustic comfort, creation of the initial list - Airborne- acoustic insulation level - noise from other indoor rooms

Parameter: Airborne- acoustic insulation level - noise from other indoor rooms
<p>Description/definition of the parameter, including source, where it makes sense:</p> <p>Airborne sound insulation is an expression of the extent to which airborne sound - for example, conversation or music from loudspeakers - is transmitted from one room to another. Airborne sound is transmitted in the following ways:</p> <ul style="list-style-type: none"> – Directly through partition walls or suspended floors – Through flanking structures – Through any sound-leaking apertures. [55]
<p>Recommended values and possible requirements in Denmark:</p> <p>Airborne sound insulation R'w</p> <ul style="list-style-type: none"> – Between offices ≥ 40 dB – Between meeting rooms and other rooms ≥ 48 dB <p>Sound insulation requirements must be higher between confidential rooms and others. Additionally, specific requirements should be established for rooms with connecting doors.[55].</p> <p>Table 5.1 contains proposed design values for airborne sound insulation and impact sound level in office buildings corresponding to compliance with BR18's general provision in Section 368, subsection 1, stating that "<i>Buildings must have sound conditions that are satisfactory in terms of health and comfort in relation to the use</i>" [23]</p>
<p>Recommended values and possible requirements in the EU:</p> <p>EU No EU requirements. All sound requirements are national.</p>
<p>Impact on humans (sensory, symptoms, performance, illness/death):</p> <p>Sensory: Constant background noise, overheard speech, loss of privacy</p> <p>Performance: Lower focus, more mistakes, poorer communication</p>

Frequency, typical levels, temporal variation:

Measurability/documentation (and any challenges related to this):

Airborne sound insulation can be documented with measurements carried out in accordance with DS/EN ISO 16283-1:2014 – S3[30], Acoustics - Field measurement of sound insulation in buildings and of building elements - Part 1: Airborne sound insulation (Danish Standard, 2018), with weighting according to DS/EN ISO 717-1-S4 [29](Danish Standard, 2020), Acoustics - Rating of sound insulation in buildings and of building elements - Part 1: Airborne sound insulation.

Field measurements are carried out in accordance with Rasmussen, Hoffmeyer & Olesen (2017), Carrying out building acoustic measurements (SBI instruction 217 – S5, 2nd ed.)[65]. Any calculations can be carried out according to DS/EN ISO 12354-1:2017-S6 Building acoustics [66].

Other relevant factors for the selection of the net list (e.g. good solutions for reducing possible problems):

Construction solutions for new construction can be found in Rasmussen, Petersen & Hoffmeyer (2011), Sound insulation between buildings – new construction [67].

Link to further info/related projects etc.

Manufacture website

56. Table

Acoustic comfort, creation of the initial list - Impact sound from building elements

Parameter: Impact sound from building elements

Description/definition of the parameter, including source, where it makes sense

The impact sound level indicates the sound which is generated in a room when a standardised tapping machine hammers on the floor in another room.

Impact sound is often transmitted both directly through a suspended floor and through flanking structures [55].

Recommended values and possible requirements in Denmark

Impact sound level, $L'_{n,w}$

- In offices and meeting rooms from floors in corridors ≤ 58 dB
- In offices and meeting rooms from floors in other rooms ≤ 63 dB

Noise in offices from building services, $L_{Aeq,30s} \leq 35$ dB

Noise in offices from traffic, $L_{den} \leq 38$ dB (SBI230)[55]

(BR18 guidance) [23]

Recommended values and possible requirements in the EU

EU No EU requirements. All sound requirements are national.

Impact on humans (sensory, symptoms, performance, illness/death)

Sensory: Audible thuds, vibrations, lack of quiet

Performance: Lower focus, communication issues, productivity loss

Frequency, typical levels, temporal variation

Measurability/documentation (and any challenges related to this)

Impact sound insulation between rooms can be documented with measurements. Measurements are carried out according to DS/EN ISO 16283-2:2018 – S10 [68] Building acoustics - Calculation of acoustic properties of buildings from the properties of building elements - Part 2: Impact sound insulation between rooms (Danish Standard, 2018a) with weighting according to DS/EN ISO 717-2 – S11 [29](Danish Standard, 2020), Acoustics - Rating of sound insulation in buildings and of building elements - Part 2: Impact sound level.

Other relevant factors for the selection of the net list (e.g. good solutions for reducing possible problems)

Link to further info/related projects etc.

57. Table

Acoustic comfort, creation of the initial list - Reverberation time in the stairwell

Parameter: Reverberation time in the stairwell – (requirements for housing and schools defined)
<p>Description/definition of the parameter, including source, where it makes sense</p> <p>Reverberation time is an expression of the speed at which the sound in a room attenuates. Reverberation time varies according to the size of a room and the sound-absorbing properties of its surfaces [55].</p> <p>The reverberation time indicates the time in seconds it takes for the sound pressure level to drop 60 dB (after the sound source has stopped).</p>
<p>Recommended values and possible requirements in Denmark</p> <p>Room acoustic for stairwell:</p> <p>$T \leq 1.3$ s (500-2000 Hz), which applies to new construction and renovation situations. T20 according to ISO 3382-2 . Max. in each 1/1 octave band</p> <p>Room acoustic for corridors:</p> <p>$T \leq 1.3$ s (500-2000 Hz), which applies to new construction and renovation. T20 according to ISO 3382-2. Max. in each 1/1 octave band. – HOUSING</p> <p>$T \leq 0.9$ s (500-2000 Hz), which applies to new construction and renovation.. T20 according to ISO 3382-2. Max. in each 1/1 octave band. -SCHOOLS</p> <p>[69]</p> <p>BR18- S2 - The building regulations' guidance on sound conditions 1.4 Control of sound conditions by measurements or calculations:</p> <p>Room acoustic for staircase:</p> <p>$T \leq 1.3$ s (500-2000 Hz), which applies to new construction and renovation situations.</p> <p>The maximum value for the reverberation time applies to each 1/1-octave band in the frequency range. At 125 Hz, however, 20% can be added to the specified maximum value [23].</p>

Recommended values and possible requirements in the EU EU No EU requirements. All sound requirements are national.
Impact on humans (sensory, symptoms, performance, illness/death)
Frequency, typical levels, temporal variation
Measurability/documentation (and any challenges related to this) Measurement is carried out according to DS/EN ISO 3382-1- S13 [28], Acoustics - Measurement of room acoustic parameters - Part 1: Performance spaces. (Danish Standard, 2009) Field measurements are carried out in accordance with Rasmussen, Hoffmeyer & Olesen (2017), Carrying out building acoustic measurements [65]. Calculations can be carried out according to DS/EN 12354-6:2004 [70], Building acoustics - Calculation of acoustic properties of buildings from the properties of building elements - Part 6: Sound absorption in enclosed spaces, (Danish Standard, 2004).
Other relevant factors for the selection of the net list (e.g. good solutions for reducing possible problems) Manufacture website
Link to further info/related projects etc.

58. Table

Acoustic comfort, creation of the initial list - Reverberation time in the office

Parameter: Reverberation time in the office
Description/definition of the parameter, including source, where it makes sense Reverberation time is an expression of the speed at which the sound in a room attenuates. Reverberation time varies according to the size of a room and the sound-absorbing properties of its surfaces [55].

Reverberation time refers to the duration, measured in seconds, that it takes for the sound pressure level in a space to decrease by 60 decibels once the sound source stops. This time is influenced by factors such as the room's size, shape, and design, as well as the quantity, type, and placement of sound-absorbing materials.

Recommended values and possible requirements in Denmark

Proposals for design values for office buildings:

- Single-person offices and meeting rooms should have a reverberation time of no more than 0.6 s
- In offices for several people, the absorption area A should be greater than $1.1 \times$ the floor area [55].

BR18-Sound conditions (§ 368 - § 376) guidance for office construction in Chapter 5.4 includes the following absorption area ranges for large offices.

Recommended values and possible requirements in the EU

Impact on humans (sensory, symptoms, performance, illness/death)

Frequency, typical levels, temporal variation

- 1) The maximum value for the reverberation time applies to each 1/1-octave band in the frequency range. At 125 Hz, however, 20% can be added to the specified maximum value.
- 2) The minimum value for the absorption area applies to each 1/1-octave band in the frequency range. At 125 Hz, however, 20% can be deducted from the stated minimum value.
- 3) The design values apply in furnished rooms. For large offices, there will be a distribution of the sound absorption between the building and the interior. For the building, an absorption area $\geq 1.0 \times$ floor area is suggested.
- 6) Only hallways without living and working areas. Where the areas are used to some extent for living or working areas, $T \leq 0.6$ s is used.

Measurability/documentation (and any challenges related to this)

Measurement is carried out according to DS/EN ISO 3382-1 -S13 [28], Acoustics - Measurement of room acoustic parameters - Part 1: Performance spaces. (Danish Standard, 2009)

Field measurements are carried out in accordance with Rasmussen, Hoffmeyer & Olesen (2017), Carrying out building acoustic measurements [65].

Calculations can be carried out according to DS/EN 12354-6:2004 – S14 [70], Building acoustics - Calculation of acoustic properties of buildings from the properties of building elements - Part 6: Sound absorption in enclosed spaces, (Danish Standard, 2004).

DS/EN ISO 14257 – S17 [71], Acoustics – Measurement and parametric description of spatial sound distribution curves in workrooms for evaluation of their acoustical performance (Danish Standards, 2002a).

Other relevant factors for the selection of the net list (e.g. good solutions for reducing possible problems)

Other advanced reverberation time calculations: Eyring's (Norris–Eyring) Equation, Millington–Sette Equation, Fitzroy Equation (Directional Absorption Correction), Arau–Puchades Equation, Kuttruff Equation (Energy Decay Correction), Lam's or Neuman–Klar Equations (Modern Corrections)

Manufacture websites

Link to further info/related projects etc.

59. Table

Acoustic comfort, creation of the initial list - Traffic noise/façade insulation

Parameter: Traffic noise/façade insulation
Description/definition of the parameter, including source, where it makes sense The limit value applies to traffic noise from roads and railways and is expressed by Lden indoors. The limit value applies to roads and railways separately, cf. <i>the Building Regulations' guidance on noise conditions</i> (Trafik-Bygge- og Boligstyrelsen, 2020 – S18) [72]
Recommended values and possible requirements in Denmark Denmark Sound class C: Lden: 33 dB (indoors) applicable to new construction and renovation situations as described before.

Sound class D: Lden: 38 dB

The limit values apply to each traffic noise source separately.

The functional requirement for domestic buildings is deemed to be met if they are built as class in DS 490 – S19 [73], Sound Classification of Dwellings. According to the standard for indoor traffic noise, certain limit values apply to ensure compliance with functional requirements. Specifically, these limit values concern buildings located near roads and railways. If traffic intensity causes noise levels to exceed 58 dB for roads or 64 dB for railways at any individual building, these limits are relevant. The limit value is expressed as the Lden value. The limit value applies separately to roads and railways [55].

Recommended values and possible requirements in the EU:

All sound requirements are national

Impact on humans (sensory, symptoms, performance, illness/death)

Annoyance, distraction, impaired speech perception, headache, fatigue, stress, irritability,
Reduced concentration, increased errors, lower productivity

Frequency, typical levels, temporal variation

Measurability/documentation (and any challenges related to this)

Limit values for four key sound conditions in domestic buildings are specified in DS 490 - S19 [73], Sound classification of dwellings (Danish Standards, 2007d)

The equivalent traffic noise level at the façade is calculated using the Nord2000 calculation model. Alternatively, the traffic noise level can be read from a noise map, if one has been created.

The sound insulation of the external wall can be documented by calculation and/or by measurements. Measurements are carried out according to DS/EN ISO 16283-3:2016 – S20 [74], Acoustics - Field measurement of sound insulation in buildings and of building elements - Part 3: Sound insulation of façades (Danish Standard, 2016) with weighting according to DS/EN ISO 717-1 (2013) – S4 [29], Acoustics - Assessment of sound insulation in buildings and of building elements - Part 1: Airborne sound insulation.

Calculation of the traffic noise level indoors is carried out according to the principles according to Rasmussen, Hoffmeyer & Olesen (2017), *Carrying out building acoustic measurements*. Calculations can be carried out according to DS/EN ISO 12354-3:2017 – S21[75], Building acoustics. Calculation of acoustic properties of buildings based on the properties of building elements. Part 3: Airborne sound insulation against external noise (Danish Standard, 2017c).

Other relevant factors for the selection of the net list (e.g. good solutions for reducing possible problems)

SBi Guidelines 237, Lydisolering mellem boliger - nybyggeri [Sound insulation between dwellings - new buildings] (Rasmussen, Petersen & Hoffmeyer, 2011) [67].

Various publications from the Danish Road Directorate and the Danish Environmental Protection Agency.

Link to further info/related projects etc.

60. Table

Acoustic comfort, creation of the initial list - Technical installation

Parameter: Technical installation
Description/definition of the parameter, including source, where it makes sense Relates to noise from the building's technical installations, for example ventilation systems, water and drainage installations, elevators, etc.
Recommended values and possible requirements in Denmark According to Bygningsreglementet BR18 (via its “Vejledning til kontorbyggeri – Støj fra tekniske installationer”), Table 5.3 gives project-design values for noise from technical installations in office buildings [23]: For offices: $L_{A,eq} \leq 35$ dB(A). For meeting rooms / videoconference / auditoria: ≤ 30 dB(A). If there is low-frequency noise, additional guidance: $L_{pA, LF} \leq 30$ dB (10-160 Hz) and G-weighted infrasonic level $L_{pG} \leq 85$ dB.

Under the earlier Bygningsreglementet BR10/guidance: For offices ("kontorer"), for noise from technical installations: $L_{Aeq,30s} \leq 35$ dB.

The Arbejdstilsynet guidance on "Akustik i arbejdsrum" refers to these building-regulation values for offices and suggests adherence.

Recommended values and possible requirements in the EU

All sound requirements are national

Impact on humans (sensory, symptoms, performance, illness/death)

Main impacts: annoyance, distraction, fatigue, stress.

Performance decreases: concentration, accuracy, and productivity.

Health effects: rarely severe in offices, but chronic stress-related and cardiovascular impacts are possible with long-term exposure.

Frequency, typical levels, temporal variation

Measurability/documentation (and any challenges related to this)

Measurements should be made during operation as specified in DS/EN ISO 10052-S24 [76], Acoustics - Measurement of airborne and impact sound insulation and noise from technical installations in buildings - Estimation method (Danish Standard, 2005) and measurement guidelines in Rasmussen, Hoffmeyer & Olesen (2017), *Carrying out building acoustic measurements* (SBI instruction 217, 2nd ed.) [65].

Other relevant factors for the selection of the net list (e.g. good solutions for reducing possible problems)

Rasmussen, Petersen & Hoffmeyer (2011). *Sound insulation between dwellings – new construction* [67].

Link to further info/related projects etc.

61. Table

Acoustic comfort, creation of the initial list - Noise from people/activities - workstation noise level

Parameter: Noise from people/activities – workstation noise level
Description/definition of the parameter, including source, where it makes sense noise generated by people’s physical actions and interactions that people undertake in the workspace environment
Recommended values and possible requirements in Denmark Depends on internal office agreements, as well as the office-required activities.
Recommended values and possible requirements in the EU
Impact on humans (sensory, symptoms, performance, illness/death) Less focus and concentration if the environment is noisy and loud.
Frequency, typical levels, temporal variation
Measurability/documentation (and any challenges related to this) DS/ISO 22955:2021 [77] – Acoustics - Acoustic quality of open-plan offices
Other relevant factors for the selection of the net list (e.g. good solutions for reducing possible problems) SBI-anvisning 258 [78]
Link to further info/related projects etc.

62. Table

Acoustic comfort, creation of the initial list - Speech transmission index/ Speech intelligibility

Parameter: Speech transmission index/ Speech intelligibility and sound transmission attenuation
Description/definition of the parameter, including source, where it makes sense The Speech Transmission Index (STI) is a quantitative measure of how clearly speech can be understood in a given acoustic environment.

<p>Recommended values and possible requirements in Denmark</p> <p>Within a teaching group, an STI in excess of 0.6 between teacher and pupil and from pupil to pupil should enable clear communication. In open teaching areas and open-plan offices, it is difficult to achieve sufficient elimination of disturbance (a sufficient degree of privacy) between groups or individuals. The STI is also used to characterise the degree of privacy or acoustic seclusion between a source sound and a workstation. The target is less than 0.2 for the STI between teaching groups and less than 0.3 between workstations in office areas [55].</p>
<p>Recommended values and possible requirements in the EU</p>
<p>Impact on humans (sensory, symptoms, performance, illness/death)</p>
<p>Frequency, typical levels, temporal variation</p>
<p>Measurability/documentation (and any challenges related to this)</p> <p>DS/EN 60268-16 [43], Sound system equipment - Part 16: Objective rating of speech intelligibility by speech transmission index (Danish Standards, 2003c)</p> <p>DS/EN ISO 14257, Acoustics – Measurement and parametric description of spatial sound distribution curves in workrooms for evaluation of their acoustical performance (Danish Standards, 2002a).</p> <p>DS/EN ISO 14257 (Danish Standards, 2002a), and calculations made using an appropriate computer model for acoustics for rooms [71].</p>
<p>Other relevant factors for the selection of the net list (e.g. good solutions for reducing possible problems)</p> <p>Manufacture design values</p>
<p>Link to further info/related projects etc.</p> <p>A scientific paper from a Baltic Nordic Acoustics meeting [79]</p>

6.2.5.1. Scoring

Acoustic parameters were evaluated according to their relevance for occupant well-being and work-related performance in office environments. Sound conditions influence comfort,

concentration, and communication, particularly through noise levels, speech audibility, and reverberation characteristics. Although individuals may vary in their sensitivity to acoustic conditions depending on the specific work task, this assessment examines typical office activities as a whole. Each parameter was therefore assessed based on its general effect on well-being and productivity rather than task-specific requirements.

63. Table

Acoustic comfort criterion scoring

Parameters	Well-being	Productivity
Airborne- acoustic insulation level - noise from other indoor rooms	1	2
Impact sound from building elements	1	2
Reverberation time in the stairwell	1	1
Reverberation time in the office	3	3
Traffic noise/façade insulation	3	2
Technical installation	2	2
Noise from people/activities – workstation noise level	3	3
Speech transmission index/Speech intelligibility and sound transmission attenuation	2	3

6.2.5.2. Creation of the net list

Based on initial evaluations and research, a final set of acoustic parameters and related criteria was established and organised according to their role in shaping the acoustic environment, focusing on offices. The parameters cover transmission of sound between spaces, internal and external noise sources, room acoustic behaviour, and speech-related effects. All identified acoustic aspect criteria were assigned to one of the parameters.

6.3. Tool outline

6.3.1. Design – tool structure

The tool includes two sections to facilitate the evaluation process. One section includes information about the building, and the other is the evaluation section with all comforts and parameters. It is built up that inserting information in the tool helps the process and makes the

evaluation simple. The information from the building information section can be used in the evaluation process of the separate parameters and helps to make the evaluation simple and more time-efficient.

The first part building information section, includes important information and values that will be useful in the evaluation process of different parameters. This section is divided into multiple parts. It begins with general information about the building, its location, and areas. Next, the information is collected on a building level, which collects information about the environment surrounding the building, building elements and their parameters, and technical installations. All other sections are focused on the room level, and they are separated by different comfort aspects.

The second, main part focuses on the evaluation of various aspects of indoor environmental comfort, including its parameters and criteria. This section specifies the evaluation process and the data that needs to be collected to complete the evaluation successfully. It may use the information obtained from the building information section.

6.3.2. Labelling system example

Example through an acoustic comfort table how to calculate the final point for acoustic comfort:

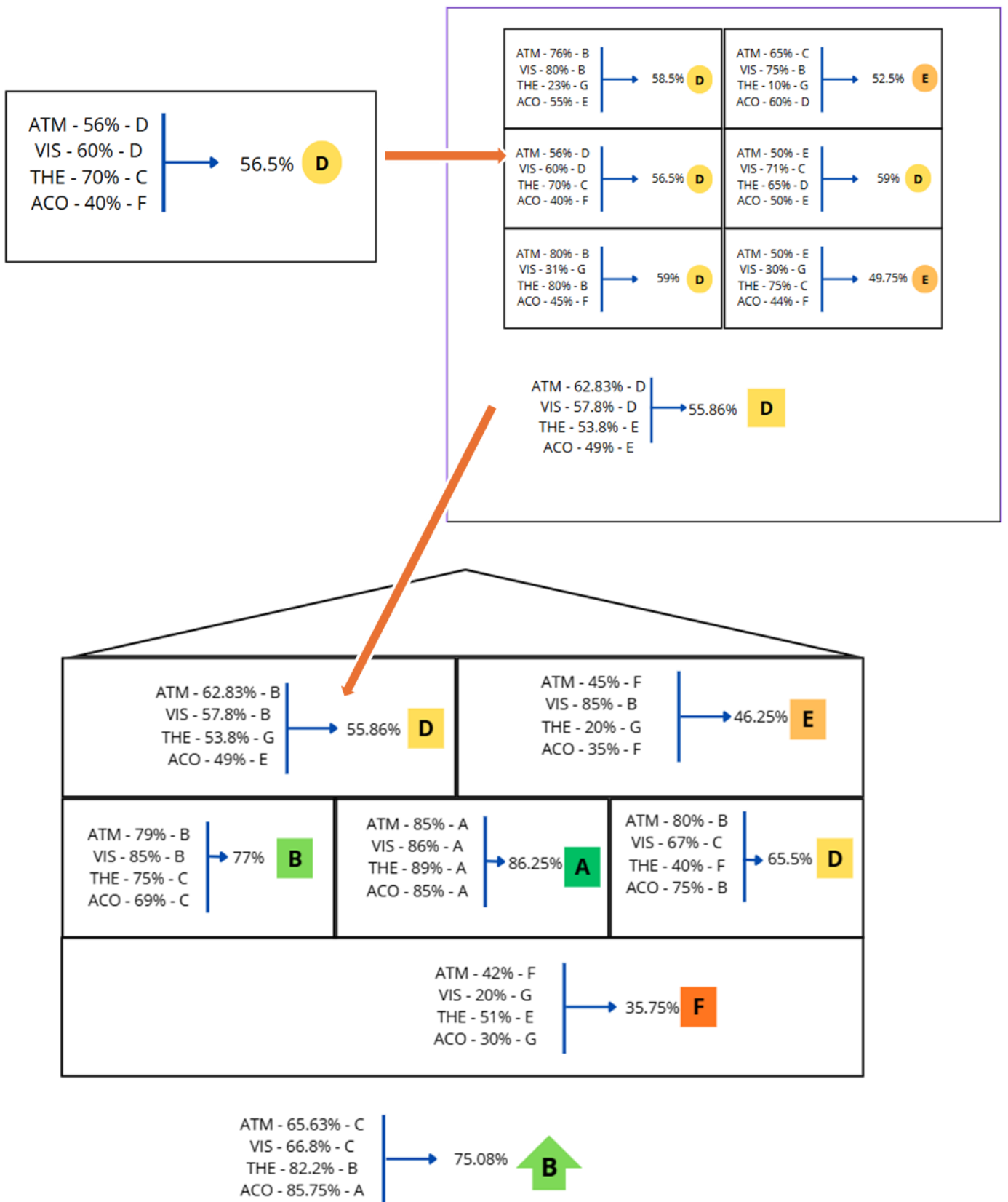
64. Table

Labelling system - example for criteria scoring (acoustic comfort criteria table)

	Parameters	Criteria	Point range
ACO1	Noise from outdoors and façade acoustic insulation	Traffic noise	0-10
		Façade acoustic insulation level - Airborne	0-10
ACO2	Partitions	Airborne- acoustic insulation level - noise from other indoor rooms	0-10
		Impact sound from building elements	0-10
ACO3	Sound in the office room	Reverberation time in the office	0-10
		Technical installation	0-10
		Speech transmission index	0-10
		Internal rules for sound/noise control	0-10
ACO4	User control	Are there different rooms dedicated to different activities	0-10

Each criterion receives 0-10 points. And each of the four comfort domains contributed equally to the combined IEQ score, with each one accounting for 25% of the overall label. The maximum points that can be reached for acoustic comfort are 90 points. If the evaluated workstation, room only reaches, for example, 70 points. Then the reached score would be converted to a percentage of its maximum. In this case, $70/90$ is 0.778. This multiplied by the 25% (since each IEQ comfort contributes equally) would give the weight contribution of the whole, so 25×0.778 would give 19.45%.

The following figure shows, through an example, how the labelling process works in a case building:



29. Figure Example how the labelling system works at a case building

At the workstation level, each workstation is assessed for the four IEQ comfort domains separately. In the illustrated example, one workstation achieves 56% for ATM (class D), 60% for VIS (class D), 70% for THE (class C), and 40% for ACO (class F). The average of these four domain percentages is 56.5% which is labelled with D. The final result IEQ label for the workstation fulfils the rule that the final label may not exceed the lowest-performing domain (F) by more than two classes.

At the room level, the open-plan office consists of multiple workstations, each with its own domain-specific percentages and overall label. For each IEQ domain, the room-level score is calculated as an average of the corresponding workstation percentages. Based on the example above, the average of the six workstation atmospheric percentages is 62.83%, which would result in a D label for the average atmospheric comfort in the room. After calculating the percentage for all four IEQ comfort levels of the room, the averages of these percentages will result in the overall label for the room. For the represented example, that would be 55.86%, so the score represents label D. Label D is a good representation of the room, since the overall label may not exceed the lowest of the four individual classes by more than two levels.

At the building level, several rooms with different IEQ performances are added together. Each room contributes to the building-level calculation proportionally to its floor area, ensuring that larger rooms have a greater influence on the final result. For each IEQ domain, an area-weighted average is calculated across all rooms. As the example represents the overall score of the building would be 75.05% which would be labelled B.

6.3.2.1. Discussion for the most accurate decision-making process for labelling

To determine the most accurate final label for each level (workstation, room, and building), we considered three possible options: the lowest label from the four IEQ comfort labels, the average of the labels, or the average, but restricted to a maximum of two levels above the lowest of the four area labels. A table was created to facilitate this decision-making process, ensuring the resultant label is as accurate as possible. The three methods for determining the overall IEQ class differ in how they balance good and bad performance across the four IEQ comfort areas. The first option, “The lowest label of the four IEQ comfort labels”, strongly highlights poor performance, ensuring that a single weak comfort category is clearly visible. However, it may underestimate overall performance when other comfort parameters perform well. The second option, to use the average of the four IEQ comfort parameters, provides a more balanced view by reflecting both strong and weak results, but it may fail to show whether one IEQ comfort

performs seriously poorly if the others score very well. The last option, to use the average of the four IEQ comfort scores for labelling, but the final label can only be up to two levels above the lowest, offers a compromise. It considers the overall performance while preventing very good scores from fully compensating for a poor-performing comfort domain. This preserves visibility of weaker areas while still representing the full range of IEQ comfort performance. Overall, each method offers a different balance between highlighting weaknesses and reflecting overall performance quality.

6.4. Evaluation of parameters

6.4.1. Operative temperatures

Operative temperature is used in thermal assessment of the IEQ as one of the main indicators for evaluating how occupants perceive thermal comfort as it combines the effect of air temperature and mean radiant temperature. While room average or difference between two locations is commonly applied in standards, it doesn't necessarily represent the local conditions inside the space.

In office environments, the thermal conditions might fluctuate significantly caused by big size of many open-plan offices. And since the occupants are expected to perform sedentary activity and one selected locations, they might be more sensitive to these fluctuations.

For these reasons, the assessment for operative temperature related to the location in the room for summer and winter conditions were prepared.

6.4.1.1. THER1 Summer comfort-Operative temperatures

In summer conditions, local variations inside the office are often significantly influenced by solar radiation. Solar exposure can lead to higher surface temperature of the windows and external elements, which increases the mean radiant temperature in general. This happens especially close to the windows even when the air temperature remains relatively stable. To capture this effect, the solar radiation is directly included in the prepared assessment that is described further.

In here, both short wave and long wave are considered, where short wave reaching occupants may cause direct local discomfort on the sun exposed workstations. Long wave radiations is included as radiation from solar heated surfaces as windows and other external elements.

The *surface temperature* is calculated through the u-values of the selected element. Where the determination of the boundary conditions is selected based on SBI 202 [36] and the table of these conditions can be seen further.

To include the solar radiation on the surfaces and more accurately determine outside boundary conditions, the method of Sol-air temperature calculation is used. This method is described in ASHRAE Handbook of fundamentals [35], where for vertical surfaces this formula can be used.

$$t_{sol-air} = t_{a,out} + \frac{\alpha \cdot I_{sol}}{h_{out}}$$

Where: $t_{a,out}$ – is outdoor temperature

α – solar absorbance of the surface

I_{sol} - is the incident solar radiation on façade

h_{out} -is external heat transfer coefficient

The result of the Sol-air temperature calculation is used as outdoor air temperature for calculation of the surface temperatures.

Sun lit workstations.

To determine the potential of local discomfort caused by solar radiation directly on the occupants, the method of using the calculation of mean radiant temperature which is adjusted with direct solar radiation, was selected. This method is described in ASHRAE Standard 55 [52] and is represented as an additional contribution to the mean radiant temperature rather than direct increase of the air temperature. The formula for calculation of the addition to the mean radiant temperature is:

$$\Delta MRT = \frac{\alpha_p \cdot E_{sol} \cdot f_p}{h_r}$$

Where: α_p - solar absorbance of clothing of occupants

E_{sol} -solar radiance reaching the occupants

f_p -the projected area factor

h_r -radiant heat transfer coefficient

The solar absorbance of clothing and radiant transfer coefficient are taken as standard values from the ASHRAE Standard 55 [52]. The projected area factor is also described in the same standard, where the amount of the direct solar radiance is selected based on each workstation. The solar radiance reaching the occupants is calculated through the actual solar radiance of the window and takes into consideration the g-value and the shading factor. The shading factor is used from SBI 202 [36].

This method is used only on the workstations that are directly lit by the solar radiation. The distance, where the sun penetrates into the building is calculated from fenestration in ASHRAE Fundamentals [35], where the formula is:

$$d = \frac{h}{\tan(\gamma)}$$

Where: h -vertical distance between the top of the window and the bottom

γ -solar altitude angle for selected time

The workstations located within this penetration distance and without external obstructions are classified as directly sit by the sun.

In this case, the external solar shading is taken into consideration with the shading factor only in case that the building has integrated automatic external solar shading that is there to limit solar gains. It is assumed that it would be activated during critical conditions. Not including the solar shading in this case would contradict the designated operation of the building. For manually operated solar shading, it is assumed not to be included in the critical summer assessment. This assumption reflects findings that the occupants usually prioritize view out and daylight and tend to activate the shading only after the discomfort already occurred.

Mean radiant temperature.

The mean radiant temperature is calculated from the view factor from the selected location in the room and the internal surface temperatures. The view factor is determined from the Guidebook Varme or klimateknik Ventilationsteknik [37]. The formula for calculating MRT from the view factor and the surface temperature is:

$$t_{mrt} = \sum_i F_{p,i} \cdot t_{s,i}$$

Where: $F_{p,i}$ - the view factor between the occupant and surface i

$F_{p,i}$ - the surface temperature of the surface

This method is described more in detail in ASHRAE fundamentals [35] and the Guidebook Varme og klimateknik Ventilationsteknik [37].

For workstations exposed to the direct solar radiation, the MRT is adjusted by adding the solar increase, while the shaded workstations are based solely on the surface temperatures.

Operative temperatures.

In our case, the aim is to get the operative temperature for the assessment. Based on EN 16798 [22] and Guidebook Varme og klimateknik Ventilationsteknik [37], the operative temperature can be approximated by formula:

$$t_o = \frac{t_a + t_{mrt}}{2}$$

Where: t_a - indoor air temperature

t_{mrt} -mean radiant temperature

With underlying condition that maximum air velocity in the room is 0,2m/s. In the office environment the assumption is made that the maximum air velocity isn't reached as its consistent thinking with the design limits of category III in set standard for sedentary work.

Outlining conditions.

The indoor/outdoor temperature.

In the summer condition, the indoor temperature for the calculation is used 24,5°C as its stated in DS 474 [21] as optimal summer indoor temperature.

The outdoor temperature for summer condition is used as 26°C. This value taken from DS 469 [80] as a typical design day for cooling and overheating assessment in Denmark.

Solar radiation values.

The values are taken from Sbi 202 [36], which shows the values of global solar radiation during every month in Denmark. The values used are the maximum hourly values for August. This table shows the orientation and the vertical or horizontal results.

The evaluation of the results.

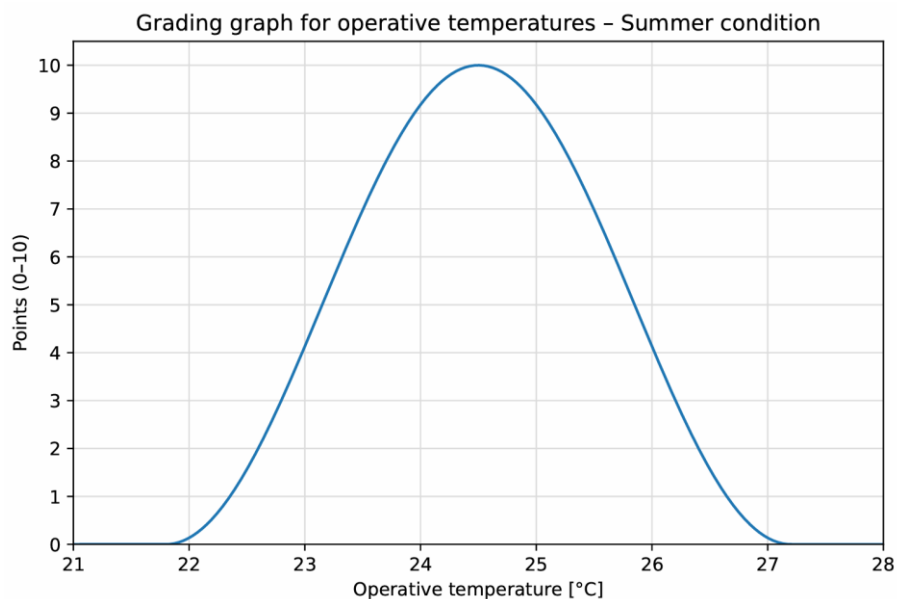
The results for each workstation are assessed on the 0-10 point scale. The points are distributed based on the IEQ categories for operative temperatures from ISO 7730 [13], where for summer in office rooms:

65. Table

IEQ categories for operative temperature – summer condition

Category	Operative temperature
I	24.5±1.0
II	24.5±1.5
III	24.5±2.5

Based on this table the grading graph was created, which is to be use for the conversion of the resulting operative temperatures into points.



30. Figure Grading graph for operative temperature - Summer condition

6.4.1.2. THER1 Winter comfort -Operative temperatures

Since the summer and winter conditions aim to assess the critical conditions, the winter evaluation doesn't include the solar radiation into the calculation process. This calculation represents cold winter condition with overcast sky which is typical for the Denmark.

Overall method follows the guide from the summer condition with excluding the Sol-air temperature calculation for determination of surface temperatures. Also since the assumption is overcast sky, the direct solar radiation isn't evaluated in this case either.

The operative temperatures are calculated from the MRT and the mean air temperature. The MRT is determined the same way as summer condition with guidance of the ASHRAE fundamentals [35] and the Guidebook Varme og klimateknik Ventilationsteknik [37], through the view factor and the surface temperatures.

The outlining conditions.

The indoor/outdoor temperature.

In the winter condition, the indoor temperature for the calculation is used 22°C as its stated in DS 474 [21] as optimal winter indoor temperature.

The outdoor temperature for winter condition is used as -5°C. This value taken from DS 447 [24] as a typical value used for calculation with outdoor temperature for ventilation design and supported by DRY weather file as a value realistic for Denmark conditions that is very rarely exceeded. The -12 °C which is used for calculation of u-values as described in DS418 [81] and also used for design of the heating system was considered. Since this condition is very extreme and would in general worsen the results of the assessment based on not realistic conditions, the results would always reflect indoor thermal conditions that aren't representative of the actual IEQ in the room.

Evaluation of the results.

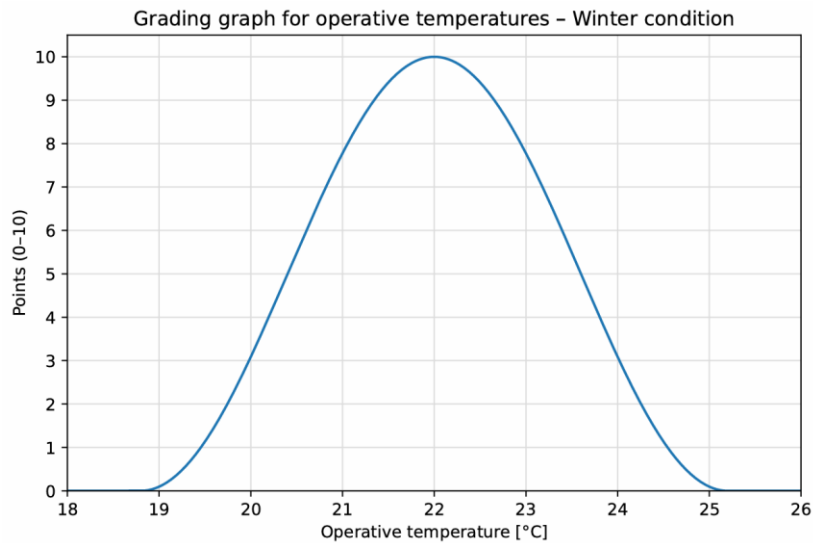
The results for each workstation are assessed on the 0-10 point scale. The points are distributed based on the IEQ categories for operative temperatures from ISO 7730 [13], where for summer in office rooms:

66. Table

IEQ categories for operative temperature - winter condition

Category	Operative temperature
I	22±1.0
II	22±2.0
III	22±3.0

Based on this table the grading graph was created, which is to be use for the conversion of the resulting operative temperatures into points.



31. Figure Grading graph for operative temperature - winter condition

6.4.2. View out

For the evaluation of the view, different approaches were often considered to select the most suitable one for an open-plan office environment. Multiple studies, standards, and evaluation tools were incorporated in the consideration for the final evaluation.

6.4.2.1. VIS 1.1 Quality of the view

Evaluation of the quality of the view includes assessing the different layers visible within the view. Research shows that views including nature benefit occupants' health and mental state more than urban views. People tend to have more positive reactions to views including nature, so it is recommended to have a landscape layer that features natural scenery rather than urban [38].

Two options were considered for the scoring of this evaluation. First option follows the standard DS/EN 17037 [25] and presents only four grading categories (Table 67). The second option separates the landscape layer by awarding more points when it includes nature compared to urban views. This approach better supports and prioritizes options for occupants (Table 68).

67. Table

View out – Scoring table for visible layer in the view including the separation in scoring for nature and urban landscape

Visible layers	0	1	2	3	5
Number of layers	0	1 (needs to be landscape - urban)	1 (needs to be landscape - nature)	2 (landscape + one)	all

68. Table

View out – Scoring table for visible layers in the view based on original categories in DS/EN 17037

Visible layers	0	1	3	5
Number of layers	0	1 (needs to be landscape)	2 (landscape + one)	all

However, as visible from a few cases (Excel file-View out evaluation), the views from the windows typically showcase a landscape layer with a mixture of urban and natural. As a result, the landscape layer has not been divided, as it would not be straightforward to determine which option is more suitable.

The second part of the Quality of the view is the outside distance of the view. This considers the nearest obstruction visible in the view from the window. As research from Kent M. and Schiavon S. indicates, people usually prefer distant objects in their view, as it offers a more comfortable viewing experience [40].

A linear graph was created for this evaluation, corresponding outside distance and points that can be awarded. The graph follows the ranges from DS/EN 17037 [25], considering the minimum and maximum distance as a base. 6 m representing the minimum, and 50 representing the maximum awarded points, leaves all the distances in between to linear representation. 6 m were considered as a minimum since from few cases it shows it is still small but acceptable distance. Keeping 50 m as the maximum awarding distance comes from an evaluation that 50 m already offers enough comfortable view.

6.4.2.2. *VIS 1.2 Windows and obstructions*

Obstructions in office spaces can appear in different forms, both inside and outside. Considering only fixed obstructions, the specification can differ in office spaces. Generally, in

a standard office, furniture is the primary fixed obstruction, as it is not moved frequently. The layout of the office is typically organized around workstations.

The rating system for obstructions, including solar shading, is inspired by the rating system for obstruction in the IEQ Compass [8]. This system can be similar to one for residential buildings, only what is considered an obstruction is adjusted specifically to offices.

According to the standards DS/EN 17037 [25], windows should be clear, without patterns, and neutrally coloured to provide a comfortable view. However, the standard does not specify the acceptable light transmittance of the glazing. LEED v.4.1 [10] uses the same rules in its evaluation, including light transmittance of the glazing with a minimum value of 40 %.

Most office buildings typically have windows that meet the transmission level, so this evaluation part mainly serves to award extra points for exceptional transmittance to provide an exceptional view. Higher transmittance allows more daylight into the room, offering more visual clarity and a better view [38]. One research suggests that a light transmittance of 80 % is an ideal value for a clear view, however, this value usually applies to single-glazed windows [82]. And in modern offices, double-glazed windows have become a standard [83].

For that reason, suggestion from research [84] shows that 70 % of transmittance offers good lighting conditions in the room, also during autumn and winter, so it support good view through the window. This is the chosen value for rewarding one extra point in this part of the evaluation.

6.4.2.3. VIS 1.3 Position of the workstation

The specific position of different workstations towards the windows should be evaluated, as different positions might offer different views. Two key factors specifying this were considered here: the distance of the workstation from the glazing and the horizontal sight angle.

Various studies and tools examine the distance in the room from the glazing. Specifications from LEED v.4.1, Living Building Challenge, and standards were evaluated in the Table below to consider the most fitting approach for this evaluation.

69. Table

View out - Different studies summary of the Position of the workstation

Distance of the Workstation from the window	Source	Pros	Cons
Within 9 m	LBC		<ul style="list-style-type: none"> • Too specific for different types of rooms • For smaller rooms it would cover the whole depth of the room, so any position would be within the limits
Within 3 times of the head of the window	LEED	<ul style="list-style-type: none"> • Can fit any room • Also partly evaluates a size of the window (with horizontal sight angle) 	
No distance considered, size of the windows for the room	DS/EN 17037 and other tools	Provides enough window area for the room	It is not workstation-specific

After careful consideration of how to set the maximum distance for the workstation, it is clear that this part of the assessment could be excluded. This is because the distance primarily serves to assess the portion of the window/view height that occupants can see, which also influences the layers in the view experienced from a certain workstation. Since these layers are crucial for enhancing quality of view, it was decided to focus only on those in the assessment (layers are specified in criterion VIS 1.1)

The horizontal sight angle is normally evaluated for the room, where the most representative position with regard to the occupied area and façade is chosen. From this point, the horizontal sight angle is evaluated towards the glazing area [25].

For the workstation-specific evaluation, each workstation is evaluated separately based on the graph. The graph is based on maximum and minimum values for the horizontal sight angle set in standard, and the values in between are evaluated linearly. The minimum set for 14 degrees was due to the consideration that anything offering smaller degrees does not provide a comfortable view (Appendix Excel View). And a maximum of 54 degrees was also taken from standards, considered as a wide comfortable view without the need for a bigger angle.

Evaluation position.

The position of each workstation usually varies based on the layout of the room, which means that workstations are often oriented differently and may face different façades. In an office setting, the standard working position is seated, which is also the position used for evaluation (1,2 m from the ground). Standing position is considered an exception, but the tool only accounts with standard conditions [25].

Due to the layout and different rotations of workstation, not all the windows are considered for evaluation for each workstation. The evaluation focuses on providing a comfortable view for the occupants. So the ideal conditions for the occupants' comfort were outlined based on the research.

The workstation should generally support neutral posture, as it is recommended that occupants limit unnecessary head rotation [85]. In the seated position, facing forward without any rotation is considered comfortable. However, there are situations where the workstations may not face a window, requiring some rotation to gain a view.

Research indicates that people can nasally (straight through the nose) see up to around 70 degrees. The possible rotation of the head for most people is up to 60 degrees. Combining this, without body rotation, people can see up to 95 degrees on each side [86]. All of this is specified for a healthy individual.

Research indicates that people can nasally (straight through the nose) see up to around 70 degrees. The possible rotation of the head for most people is up to 60 degrees. Combining this without body rotation, people can see up to 95 degrees on each side. All of this is specified for a healthy individual [86].

6.4.3. *Speech transmission index*

6.4.3.1. *Different STI estimation methods*

Estimation method for the Speech Transmission Index (STI), differing in complexity and applicability. A widely used simplified approach originates from Bradley (1986) [87]. His research shows that speech intelligibility in rooms is primarily governed by the speech-to-noise ratio (SNR) at the listener position. Within $-15 \text{ dB} \leq \text{SNR} \leq +15 \text{ dB}$, STI increases approximately linearly with SNR, as also demonstrated by Houtgast and Steeneken [88].

Early STI-related evaluations were therefore based on SNR. It assumes that intelligibility increases monotonically with increasing SNR. The following equation presents the method:

$$\text{STI} \approx a \cdot \log_{10} (1 + 10^{\text{SNR}/10}).$$

This formulation represents a highly simplified interpretation of the modulation transfer. Later, the method was formalised by Houtgast and Steeneken [89] and codified in IEC 60268-16 [43]. While useful for very early screening, the omission of reverberation and spatial effects makes this method non-compliant with modern Danish office-acoustic practice

To improve realism, Bradley (1986) [87] later extended the SNR-based model by introducing reverberation time (RT_{60}) as an additional parameter to account for temporal smearing of speech caused by reflections. This combined approach is equationally expressed below:

$$\text{STI} \approx f(\text{SNR}) - k \cdot \text{RT}_{60}.$$

This method provides improved predictions in acoustically simple and enclosed rooms. However, it assumes a uniform reverberation field and does not account for spatial variations in speech level. Because of that, the applicability to open-plan offices and workstation-based STI evaluation is limited.

An alternative historical approach is the Peutz method, based on the percentage articulation loss of consonants ($\%AL_{\text{cons}}$). Developed by Peutz (1971) [90], it relates intelligibility loss to reverberation time, room volume, distance, and source directivity, typically. The equation representing the method is:

$$\%AL_{\text{cons}} \propto \frac{\text{RT}_{60} \cdot D^2}{V \cdot Q}.$$

Although this is a historically important method, the method was primarily validated for classrooms and auditoriums; it is not suitable for modern office environment evaluation.

Modern STI evaluation for offices is based on spatial decay ratio-distance models, formalised in ISO 3382-3 focuses on the talker-listener relation. The speech level at distance r is given by

$$L_{p,S}(r) = L_{p,S}(1 \text{ m}) - D_{2,S} \log_2(r),$$

and the resulting SNR is converted to STI using procedures defined in IEC 60268-16 [43]. This approach is fully aligned with DS/ISO 3382-3 and current workstation-based acoustic design practice, supported by Nordic research as well, notably Hongisto (2005) [91].

6.4.3.2. *Conceptual framework:*

Speech privacy at a workstation is defined as the degree to which speech from surrounding workstations is unintelligible at the listener position. This is a listener-centric problem, as speech exposure varies significantly depending on the relative position and orientation of talkers. Rather than evaluating average room conditions, the proposed method evaluates speech transmission from every potential talker to every listener, enabling identification of worst-case scenarios.

For a set of N workstations, a full talker–listener matrix is constructed: $STI_{j \rightarrow i}$ where j represent the talker workstation and i represent the listener workstation. Each matrix element represents the predicted speech intelligibility of the talker j at listener i .

6.4.3.3. *Inputs:*

Each workstation i is assigned a fixed reference position defined by Cartesian coordinates (x_i, y_i) , representing the nominal acoustic source and receiver location at seated head height. These coordinates are assumed to be constant and form the geometric basis of the entire calculation.

For every possible talker–listener pair (i, j) , the centre-to-centre distance is calculated using the Euclidean distance formula:

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

This distance represents the direct propagation path for speech and is used to calculate sound level decay with distance.

6.4.3.4. *Speech Level at the Receiver*

The speech level at the receiver describes the sound pressure level of a speaker's voice at a neighbouring workstation before any influence from background noise, screens, orientation, or visual shielding is considered. A reference speech level at 1 m from the talker is used to represent typical conversational speech, in line with common modelling practice for open-plan offices and the intent of ISO 3382-3 [42]. As sound travels through the space, its level reduces due to geometric spreading, with sound pressure decreasing in proportion to distance. This can be expressed by using a $20 \cdot \log_{10}(d)$ relationship, reflecting the physical nature of sound pressure propagation. As a result, the speech level drops by roughly 6 dB each time the distance between the talker and the listener doubles. This calculated level defines the upper bound of speech audibility at the receiver and provides the starting point for subsequent signal-to-noise and STI evaluations in accordance with ISO 60268-16 [43].

Speech is modelled as a point source with an A-weighted sound pressure level at 1 m, denoted $L_{p,1m}$. Assuming spherical spreading in an open-plan environment, the speech level at the receiver position is calculated as:

$$L_{S,ij} = L_{p,1m} - 20 \log_{10}(d_{ij})$$

This formulation accounts only for geometric attenuation and excludes room absorption effects, as STI in open-plan offices is dominated by distance and masking rather than reverberation [42,91].

6.4.3.5. *Background Noise Level, L_n [dB(A)]*

At the acoustic comfort criteria, there is a separate parameter that focuses on the background noise level, where the workstation-specific values can be used here. However, this paper did not include the method for background noise level evaluation; therefore, the background noise values were used from standards and did not differ by workstation.

The Danish Building Regulations (BR18) do not prescribe fixed background noise levels for offices, but require that acoustic conditions are appropriate for the intended use [23]. In the standard DS/EN ISO 11690-1 Table 2 [92], the maximum recommended background noise levels are given for different kinds of rooms, including office rooms. According to ISO 3382-3 Annex C [42], a manufacturer-independent standard, where effective masking is achieved at between 40–45 dB(A) indicates good acoustic room condition.

Values used based on the standards:

- Quiet office / quiet zones: 30–40 dB(A)
- Typical open-plan office with HVAC: 35–45 dB(A)

A uniform A-weighted background noise level $L_{n,i}$ is assumed for all receiver positions. This noise level represents the operational condition and includes HVAC noise and steady-state ambient contributions.

The baseline signal-to-noise ratio without any screening, orientation, or visual obstruction effects is calculated as:

$$SNR_{0,ij} = L_{S,ij} - L_N$$

This value represents the maximum potential intelligibility between workstations.

Speech Level at 1 m, $L_{p,1m}$ [dB(A)]

Speech Level at 1 m, $L_{p,1m}$ [dB(A)] is the A-weighted sound pressure level of a talker measured at a distance of 1 meter directly in front of the talker, in a free field. In ISO 9921:2003 Annex A (Table A.1) [44] vocal effort of a male speaker and related A-weighted speech level are given, which was also implemented in the Excel tool. In addition in ISO 3382-3 [42] describes a further assumption of a representative speech level of approximately 65 dB(A) for the evaluation of speech propagation in open-plan offices

Values used for Speech Level at 1 m:

- Relaxed speech: approximately 54–59 dB(A)
- Normal speech: approximately 60–65 dB(A)
- Raised voice: approximately 66–78 dB(A)

6.4.3.6. Spatial Decay Rate of Speech, $D_{2,s}$ [dB per distance doubling]

The spatial decay rate $D_{2,s}$ describes the decrease in A-weighted speech sound pressure level per doubling of distance in an open-plan office. In the standard ISO 3382-3:2022 [42] Acoustics – Measurement of room acoustic parameters – Part 3: Open-plan offices, the spatial decay rate of speech, $D_{2,ss}$, as a key descriptor of acoustic quality in open-plan offices.

Measured values reported in ISO 3382-3 are shown (values used in the tool as well):

- Poor acoustic conditions: approximately 3–4 dB

- Typical open-plan offices: approximately 5–7 dB
- Highly absorptive offices: ≥ 7 dB

In Danish practice, $D_{2,s}$ values are commonly associated with ceiling absorption class, floor coverings, and room furnishing density.

6.4.3.7. *Insertion Loss of Desk Screens and Partitions, IL [dB]*

Insertion loss (IL) is the reduction in sound level caused by inserting an obstacle or element, such as a desk screen or partition, into the sound path between a source and a receiver. ISO 3382-3 explicitly notes that desk screens provide limited attenuation of speech and that their effect should not be overestimated. There is no single Danish or international standard prescribing insertion loss values for desk screens. Instead, Danish acoustic consultants rely on field measurements in open-plan offices, laboratory tests or conservative planning assumptions.

Insertion loss values for desk screens and partitions used in this study are based on typical planning-level attenuation [42]; Nordic Acoustic Meeting proceedings), where low screens (≤ 100 cm) provide negligible to modest reduction (~ 0 –3 dB), medium screens (~ 120 –140 cm) yield moderate reduction (~ 4 –6 dB), and high or floor-to-ceiling partitions can provide larger attenuation (~ 6 –10 dB) when direct line-of-sight is effectively blocked. Manufacturer laboratory data inform upper bounds but are adjusted conservatively for real office conditions.

6.4.3.8. *Line-of-Sight (LOS) Classification*

ISO 3382-3 [42] distinguishes between direct sound and diffuse sound components in open-plan offices. The LOS classification is a planning abstraction used to determine whether direct sound transmission is present between the talker and the listener. For each workstation pair, a line-of-sight condition is defined using a binary parameter:

$$LOS_{ij} = \begin{cases} 1, & \text{direct visual line-of-sight present} \\ 0, & \text{line-of-sight blocked} \end{cases}$$

Values used:

- Same desk cluster, no screen: LOS = 1
- High desk screen between desks: LOS = 0
- Low desk screen: LOS = 1
- Separate room/wall/corner: LOS = 0

6.4.3.9. Orientation (Directivity) Correction

Speech radiation is not omnidirectional. The relative orientation of the talker and listener is therefore accounted for using an orientation-dependent correction $IL_{\text{orient},ij}$. This correction reflects reduced speech radiation when the talker is facing away. STI has been calculated according to DS/EN IEC 60268-16 [43], assuming a talker facing the listener position (0°). Orientation categories (e.g. face-to-face, side-on, back-to-back) are assigned discrete attenuation values consistent with simplified STI modelling approaches described in [4]ISO 60268-16.

6.4.3.10. Calculations

For each talker- listener pair the SNR values were calculated based on the following equation:

$$SNR_{ij}^{\text{base}} = L_{S\ ij} - D_{2,S} \log_2 \left(\frac{r_{ij}}{r_0} \right) - L_N$$

where $L_{S\ ij}$ is the reference speech level at a receiver position, r_{ij} is the distance between the talker and listener, r_0 is a reference distance, and L_N is the background noise level. This formulation reflects the spatial decay behaviour described in ISO 3382-3 [42].

After that, the effective insertion loss is subtracted from the baseline SNR to obtain the full combined signal-to-noise ratio:

$$SNR_{\text{FC},ij} = SNR_{0,ij} - IL_{\text{eff},ij}$$

This value is the governing acoustic quantity from which speech intelligibility is derived.

At the effective insertion loss calculation, all speech intelligibility affecting factors are combined linearly to produce a single effective insertion loss:

$$IL_{\text{eff},ij} = IL_{\text{part},ij} + (1 - LOS_{ij}) \cdot IL_{\text{LOS}} + IL_{\text{orient},ij}$$

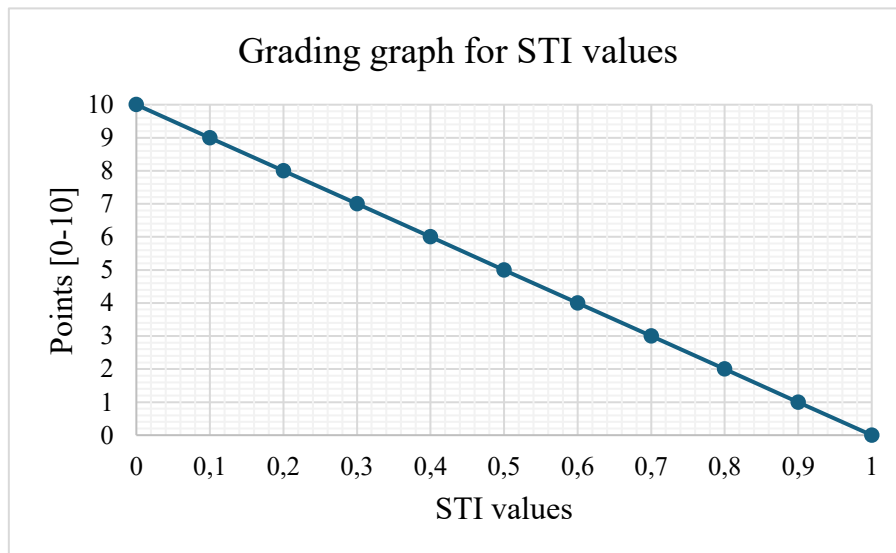
- $IL_{\text{part},ij}$ – Partition Insertion Loss
- LOS_{ij} – Line-of-sight indicator
- $(1-LOS_{ij})$ - Additional attenuation due to LOS blocking
- IL_{LOS} - LOS-related attenuation constant
- $IL_{\text{orient},ij}$ – Orientation correction

This formulation ensures that partition attenuation, line-of-sight blocking, and speech directivity act simultaneously, representing a realistic operational condition rather than an isolated best-case scenario. In the introduced Excel tool, the effective insertion loss due to partitions and line-of-sight blocking is applied as a propagation loss, while talker orientation is treated separately as a source directivity correction. Although these contributions may be conceptually grouped, they are applied in separate calculation stages to avoid double-counting. Finally, the fully combined SNR values are converted to STI, using the equation above:

$$STI_{ij} = \frac{SNR_{FC,ij} + 15}{30} \text{ for } -15 \leq SNR_{FC,ij} \leq +15 \text{ dB}$$

The resulting STI values are constrained to the interval $0 \leq STI \leq 1$. This linear approximation is consistent with the mid-range STI–SNR relationship defined in ISO 60268-16 [43] and is widely used for comparative design evaluation where modulation transfer functions are not explicitly modelled.

The evaluated value for each workstation, based on the calculation, is STI_P90. STI_P90 represents a conservative but realistic descriptor of speech intelligibility, indicating that 90%



32. Figure Acoustic comfort - Grading graph for STI values

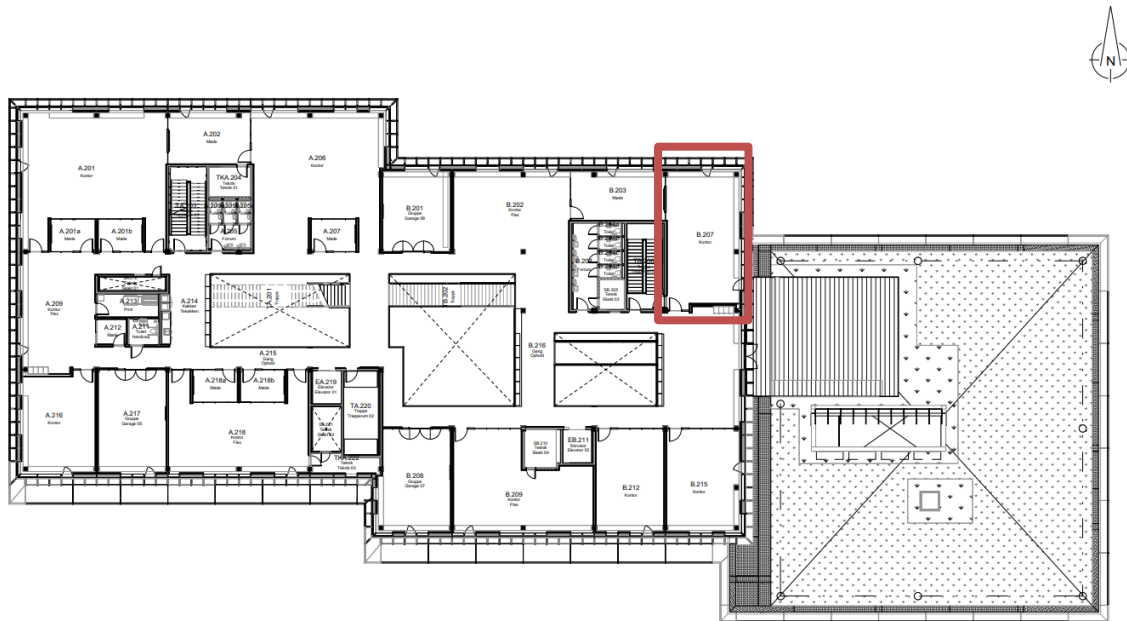
of potential speech events at a workstation do not exceed this intelligibility level. This percentile-based approach aligns with the planning intent of ISO 3382-3 [42]. The STI_P90 for each workstation is converted to points, based on the above inserted graph. The points can be used later in the IEQ Compass.

6.5. Application of the tool

6.5.1. Case buildings

6.5.1.1. Floor plans

Innovate:



33. Figure Case building floor plan and location of the evaluated office – Innovate (Source:Bygningstegn timer)

6.5.1.2. *U-values*

Innovate:

70. Table

U-value calculation of an outer wall for the building Innovate

Existing external wall			
Material	Thickness	λ	R
Units	[m]	[W/mK]	[m ² °C/W]
Internal Surface Resistance			0.13
Glass covering	0.09	1	0.09
Air gap	0.03	0.18	0.17
Wooden battens	0.06	0.12	0.50
Insulation	0.2	0.04	5.00
Wooden battens	0.06	0.12	0.50
Wooden battens/insulation	0.03	0.04	0.75
External Surface Resistance	-	-	0.04
Total			7.18
U-value			0.14

FBV1:

71. Table

U-value calculation of an outer wall for the building Frederik Bajers Vej

Existing external wall			
Material	Thickness	λ	R
Units	[m]	[W/mK]	[m ² °C/W]
Internal Surface Resistance			0.13
Concrete element	0.15	0.8	0.19
Insulation	0.15	0.036	4.17
brick	0.108	0.7	0.15
External Surface Resistance	-	-	0.04
Total			4.68
U-value			0.21

Create:

72. Table

U-value calculation of an outer wall for the building Create

Existing external wall			
Material	Thickness	λ	R
Units	[m]	[W/mK]	[m ² °C/W]
Internal Surface Resistance			0.13
15 mm plaster	0.015	0.9	0.02
200 concrete	0.2	0.7	0.29
Insulation	0.25	0.04	6.25
108 mm brick	0.035	0.7	0.05
External Surface Resistance	-	-	0.04
Total			6.77
U-value			0.15

6.5.2. Innovate results

6.5.2.1. Operative temperatures

The winter condition performs well across all workstations. This is due to low u-values of the external wall and the glazed areas. Another reason is that most of the workstations are far from the curtain walls.

73. Table

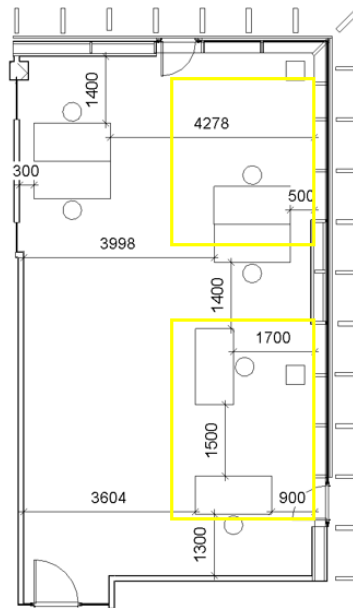
Office at Create - Results and achieved scores for Operative temperature (winter condition at the left and summer condition on the right)

Winter		
Workstation	Operative temperature	Points
W1	21.6	9.7
W2	21.4	9.3
W3	21.4	9.3
W4	21.3	9
W5	21.7	9.8
W6	21.6	9.7

Summer		
Workstation	Operative temperature	Points
W1	25.2	8.5
W2	25.4	6.2
W3	24.8	9.5
W4	25.5	6
W5	24.5	9.9
W6	24.5	9.9

The summer condition highlights the Workstation 4 and 2 as slightly uncomfortable due to its direct solar radiation. Because of the shading factor of the solar radiation assessment on the occupants, which in this case is high due to the shading beams on the external side of the façade, the workstations that are hit by the small amount of the sun are still relatively comfortable. The

figure below shows the areas that are lit by the direct solar radiation. The workstation 1 is only partly exposed to the sun, which is visible on the final result.



36. Figure Office at Create - areas that are lit by the direct solar radiation

6.5.2.2. *View out*

The office in Innovate, with 6 different workstations, was evaluated for the view through the glazing. It includes glazing on two façades, specifically curtain walls. For this evaluation, it is separated into three glazing zones, since they are separated by walls.

Generally, the office provides views through two different façades, through wide horizontal sight angles thanks to the curtain wall, allowing most positions to see all visible layers. However, there are many obstructions negatively affecting the views both inside and outside. Inside, it is mostly two columns and furniture, while outside, solar shading made of wooden planks partly blocks the curtain wall.

Workstation 2 is the only exception. It is positioned backwards to one of the curtain walls, providing a view through only one façade. It is also the worst performing workstation, since that curtain wall only offers a view through a narrow horizontal sight angle and many obstructions. On the other hand, the best performing workstation is workstation 4, which received a score of 23.1 points, offering a great view due to its location in the room.

The general evaluation for the whole room awards 20 points, considering all separate curtain wall sections separately and choosing the best performing one. The reference point for this assessment was placed in the occupied zone, as since the room has workstations located

differently, mostly along the walls, the view from the reference point does not significantly differ from the results from the workstations.

6.5.2.3. *Speech transmission index*

In the chosen office in a building Innovate all the workstations were tested for (STI) performance. The assessment was integrated with workstation geometry, talker–listener distances derived from fixed workstation positions, relative orientation between workstations, line-of-sight conditions, and the acoustic attenuation provided by screens and furniture. A representative background noise level was applied uniformly to all receiver positions. For the evaluation, the previously described calculations were used in the Excel files for STI evaluation.

The average speech level at 1m and the background noise value were used from the Danish standards, and these two values will not differ in the case of building applications. Spatial decay of speech per distance doubling set up to 8 [dB/doubling], which is assumed to be a highly absorptive class of the room with normal furnishing. Based on the pictures (Measurement plan), it is visible that the walls are covered with acoustic absorption panels. There are no sound absorption panels between workstations. The line of sight between the workstations is direct without any obstacles. At the Innovate office building, the room geometry and the workstation positions and numbers, in this case 6, are different from the other tested office rooms.

The talker-listener matrix presented below shows the heatmap for the STI results for each talker-listener combination. It shows that the closest neighbour for a listener is the most disturbing.

Talker / Listener	WS1	WS2	WS3	WS4	WS5	WS6
WS1	0	0,654697	0,554687	0,437651	0,358436	0,292319
WS2	0,554697	0	0,704387	0,516688	0,34404	0,274483
WS3	0,354687	0,604387	0	0,802514	0,452107	0,529432
WS4	0,437651	0,466688	0,802514	0	0,541939	0,452107
WS5	0,358436	0,44404	0,552107	0,591939	0	0,802514
WS6	0,2	0,2	0,429432	0,452107	0,802514	0

37. Figure Office at Create - heatmap for talker-listener STI matrix

6.5.3. *FBV results*

6.5.3.1. *Operative temperatures*

The winter condition shows more noticeable variations in the workstation. Its visible that the workstations closest to the windows perform slightly worse than the ones place next to them. The 7,8 points represent IEQ category II, which overall is good result for the room. The slightly

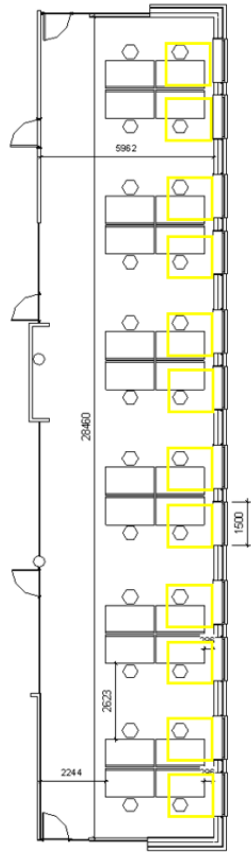
lower values compared to other two case buildings is due to higher u-values for external walls and windows.

74. Table

Office at Frederik Bajers Vej - Results and achieved scores for Operative temperature (winter and summer conditions)

Winter			Summer		
Workstation	Operative temperature	Points	Workstation	Operative temperature	Points
W1	21.1	8.3	W1	25.8	4.8
W2	21.4	9.1	W2	25.1	8.5
W3	21.1	8.2	W3	25.9	4.3
W4	21.4	9	W4	25.3	7.9
W5	21	7.8	W5	26	4.1
W6	21.3	8.9	W6	25.3	7.8
W7	21	7.8	W7	26	4.1
W8	21.3	8.9	W8	25.3	7.8
W9	21	7.8	W9	26	4.1
W10	21.3	8.9	W10	25.3	7.8
W11	21	7.8	W11	26	4.1
W12	21.3	8.9	W12	25.3	7.8
W13	21	7.8	W13	26	4.1
W14	21.3	8.9	W14	25.3	7.8
W15	21	7.8	W15	26	4.1
W16	21.3	8.9	W16	25.3	7.8
W17	21	7.8	W17	26	4.1
W18	21,3	8.9	W18	25.3	7.8
W19	21	7.8	W19	26	4.1
W20	21.3	8.9	W20	25.3	7.8
W21	21	7.8	W21	26	4.1
W22	21.3	8.9	W22	25.3	7.8
W23	21	7.8	W23	26	4.1
W24	21.3	8.9	W24	25.3	7.8

The summer condition presented in the table highlights the workstation in close proximity to the windows as more uncomfortable in summer conditions due its risk of direct solar radiation on the occupants.



38. Figure Highlight of the office room places where there is a risk of direct solar radiation on the occupants – FBV1

6.5.3.2. *View out*

The situation in this office was slightly different due to the office layout. Each group of four workstations is separated by acoustic panels, which completely block the view to other windows. In this case, each group of four workstations considers only the two closest windows in the façade. As a result, each workstation evaluates two windows; the relation to each window is evaluated separately. The better-performing window for each workstation is chosen.

Since the layout of the room and windows is regular and follows a pattern, all the workstations score quite similarly. This consistency is due not only to the room's layout but also to the identical windows and the same high outside distance of the first obstruction in the view. The row of workstations closest to the windows scores higher because these positions have visibility of all three layers in the view. In contrast, the row further away only has access to the landscape and sky.

This demonstrates that a regular layout and geometry of the room contribute to uniform access and quality of the view.

Additionally, the room as a whole was evaluated. The reference point is placed representatively in the occupied zone, and the middle of the glazing area evaluates all the windows in the room. However, even the best performing window does not reach the score of individual workstations with 15.6 points.

6.5.3.3. *Speech transmission index*

The most workstations included an open-plan office with 24 workstations were chosen to test in the building Frederiks Bajers Vej 1. The input data, the calculation matrix, and the different acoustic results can be seen in the Excel files for STI As mentioned before, the average speech level at 1m and the background noise value were used from the Danish standard. The Spatial decay of speech per distance doubling at this office was set to 9 [dB/doubling], which represents a high absorption class with dense furnishing. It is visible in the pictures shown in the Measurement plan, that this office has an absorbent ceiling, acoustic panels on the walls and between workstations, and the floor cover is carpet. The workstation placement is structured and symmetric in the office, and all workstations are separated with acoustic panels. Between every four workstations (grouped), there is a big acoustic panel to increase acoustic comfort throughout the whole room. So between workstations 1,2,3, and 4, the insertion loss is set to 6 dB, and set the same at workstations 5,6,7 and 8; 9,10,11 and 12; 13,14,15 and 16; 17,18,19 and 20; 21,22,23 and 24. Between the grouped workstations, the partition insertion loss is set to 10 dB because of the high absorption panel, what is fully blocks the workstations groups acoustically from each other. The line of sight is set to the value 0 at the LOS matrix, since the sound panels between the desk block the sight.

The result for STI_P90 for each workstation is the same, since the acoustic conditions do not differ.

The following talker-listener matrix shows the heatmap of STI results for each talker-listener combination. It is visible that the grouped workstations have the biggest impact acoustically on each other, and the other grouped workstations do not because of the high, fully blocking acoustic panels.

Talker / Listener	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9	WS10	WS11	WS12	WS13	WS14	WS15	WS16	WS17	WS18	WS19	WS20	WS21	WS22	WS23	WS24
WS1	0	0,617	0,717	0,567	0,325	0,302	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
WS2	0,617	0	0,567	0,717	0,302	0,325	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
WS3	0,717	0,567	0	0,617	0,3	0,252	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
WS4	0,567	0,717	0,617	0	0,252	0,3	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
WS5	0,2	0,2	0,3	0,252	0	0,617	0,717	0,567	0,325	0,302	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
WS6	0,2	0,2	0,252	0,3	0,617	0	0,567	0,717	0,302	0,325	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
WS7	0,2	0,2	0,325	0,302	0,717	0,567	0	0,617	0,3	0,252	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
WS8	0,2	0,2	0,302	0,325	0,567	0,717	0,617	0	0,252	0,3	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
WS9	0,2	0,2	0,2	0,2	0,2	0,2	0,3	0,252	0	0,617	0,717	0,567	0,325	0,302	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
WS10	0,2	0,2	0,2	0,2	0,2	0,2	0,252	0,3	0,617	0	0,567	0,717	0,302	0,325	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
WS11	0,2	0,2	0,2	0,2	0,2	0,2	0,325	0,302	0,717	0,567	0	0,617	0,3	0,252	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
WS12	0,2	0,2	0,2	0,2	0,2	0,2	0,302	0,325	0,567	0,717	0,617	0	0,252	0,3	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
WS13	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,3	0,252	0	0,617	0,717	0,567	0,325	0,302	0,2	0,2	0,2	0,2	0,2	0,2	0,2
WS14	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,252	0,3	0,617	0	0,567	0,717	0,302	0,325	0,2	0,2	0,2	0,2	0,2	0,2
WS15	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,325	0,302	0,717	0,567	0	0,617	0,3	0,252	0,2	0,2	0,2	0,2	0,2	0,2
WS16	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,302	0,325	0,567	0,717	0,617	0	0,252	0,3	0,2	0,2	0,2	0,2	0,2	0,2
WS17	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,3	0,252	0	0,617	0,717	0,567	0,325	0,302	0,2	0,2
WS18	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,252	0,3	0,617	0	0,567	0,717	0,302	0,325	0,2
WS19	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,325	0,302	0,717	0,567	0	0,617	0,3	0,252	0,2
WS20	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,302	0,325	0,567	0,717	0,617	0	0,252	0,3	0,2
WS21	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,3	0,252	0	0,617	0,717	0,567	0,2
WS22	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,252	0,3	0,617	0	0,567	0,717
WS23	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,325	0,302	0,717	0,567	0	0,617
WS24	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,302	0,325	0,567	0,717	0,617	0

39. Figure Office at Frederik Bajers Vej - heatmap for talker-listener STI matrix

6.5.4. Create results

6.5.4.1. Operative temperatures

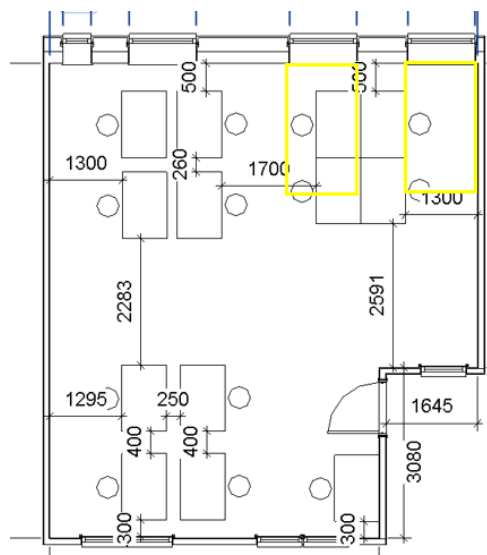
The winter condition showed minimal variations with points throughout the space. The main reasoning was the very low u values of the external walls, triple glazed energy windows and access to the external wall only on one side of the room. The glazed area in general didn't affect the operative temperatures significantly. The workstations placed in the deeper part of the room are not affected by the external wall at all due to the distance from it, which makes the view factor very small.

75. Table

Office at Create - Results and achieved scores for Operative temperature (winter and summer conditions)

Winter			Summer		
Workstation	Operative temperature	Points	Workstation	Operative temperature	Points
W1	22	10	W1	24.5	10
W2	22	10	W2	24.5	10
W3	22	10	W3	24.5	10
W4	22	10	W4	24.5	10
W5	22	10	W5	24.5	10
W6	21.8	9.8	W6	24.5	10
W7	21.8	9.8	W7	24.5	10
W8	21.6	9.7	W8	24.6	9.9
W9	21.4	9.3	W9	24.6	9.9
W10	21.6	9.7	W10	25.8	5.2
W11	21.8	9.8	W11	25.8	5.2
W12	21.4	9.2	W12	26.6	1.2
W13	21.6	9.7	W13	26.6	1.2

On the other hand, the summer condition show critical values at workstation 12 and 13 where they are expected to be directly lit by direct solar radiation. As can be seen on the drawing which highlight the area that is evaluated as affected by direct solar radiation. The workstation only partly touched by the direct sunlight are still showing lower results compared to the rest of the room.



40. Figure Highlight of the office room places where there is a risk of direct solar radiation on the occupants – Create

6.5.4.2. *View out*

In the Create office, all 16 workstations were evaluated towards every window in the room, but only some were considered based on evaluation requirements for the positions. Due to the layout of the workstations and differences in window sizes and location, the results in the rooms differ across the room.

The workstations with the lowest score are mostly located in the back of the room, scoring from 11.9 to a maximum of 15 points. These workstations are situated quite far from the façade, and it offers view at very narrow horizontal sight angles. From that distance, mostly only two layers of the view are visible. In contrast, workstations in the area closer to the windows generally received higher score due to their locations, which provide better visibility of more layers and broader viewing angles.

Workstation 12 and 13, positioned right next to the window, achieve high scores of 22.4 and 22.5 points. These workstations benefit from the best views in the room, providing visibility of all layers under larger horizontal sight angles, while facing minimal obstructions.

There was a significant difference in the score in the evaluation of the whole room. The reference point, situated in the occupied zone a little further behind the first area of workstations, facing the window façade, is located directly towards the wall. This position has windows at very narrow angles, providing a less favourable view.

6.5.4.3. *Speech transmission index*

At the open-plan office room in Create, 13 workstations were tested to evaluate their STI acoustic performance. The input data, the calculations matrix, and the different acoustic results can be seen in the Excel files for STI. The average speech level at 1m and the background noise value were used from the Danish standards, and these values remained consistent across all office cases. The Spatial decay of speech per distance doubling at this office was set to 5 [dB/doubling], which represents a moderate absorption class with slightly dense furnishing. As shown in the Measurement plan, there are no acoustic panels on the walls, although the office contains a significant amount of furniture. Only one workstation has an acoustic panel, and the other workstation is blocked with a movable writing board. The arrangement of the workstations is unstructured, and the room has an L-shaped geometry. While the room's geometry is not directly considered in the analysis tool, it is factored into the Insertion Loss

calculations. The values for each workstation for the line of sight are 1, which represents that there are low screens between workstations.

The following talker-listener matrix displays the heatmap of STI results for each talker-listener combination. It is visible that there is a fairly high STI result in the matrix, represented also with red-toned cells.

Talker / Listener	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9	WS10	WS11	WS12	WS13
WS1	0	0,779375	0,595945	0,590708	0,771517	0,469092	0,617608	0,599534	0,595645	0,753861	0,753839	0,725032	0,725015
WS2	0,779375	0	0,85	0,85	0,85	0,551623	0,553873	0,523268	0,525042	0,618665	0,615827	0,596524	0,59416
WS3	0,795945	0,85	0	0,85	0,85	0,753873	0,85	0,725042	0,823268	0,603574	0,600498	0,583843	0,581228
WS4	0,790708	0,85	0,85	0	0,85	0,794143	0,85	0,760409	0,85	0,828512	0,824738	0,807836	0,80465
WS5	0,771517	0,85	0,85	0,85	0	0,85	0,794143	0,724701	0,760409	0,647366	0,643775	0,623508	0,620555
WS6	0,802425	0,551623	0,753873	0,794143	0,85	0	0,85	0,85	0,85	0,732611	0,723826	0,795579	0,787051
WS7	0,617608	0,553873	0,85	0,85	0,794143	0,85	0	0,85	0,85	0,783485	0,772677	0,777884	0,767547
WS8	0,782867	0,523268	0,725042	0,760409	0,85	0,85	0,85	0	0,85	0,85	0,85	0,85	0,85
WS9	0,595645	0,525042	0,823268	0,85	0,760409	0,85	0,85	0,85	0	0,777884	0,767547	0,783485	0,772677
WS10	0,753861	0,618665	0,470241	0,628512	0,647366	0,732611	0,783485	0,728912	0,777884	0	0,85	0,85	0,85
WS11	0,753839	0,815827	0,667165	0,824738	0,843775	0,790493	0,85	0,787051	0,834214	0,85	0	0,85	0,85
WS12	0,725032	0,596524	0,583843	0,607836	0,623508	0,595579	0,777884	0,599277	0,783485	0,85	0,85	0	0,85
WS13	0,725015	0,79416	0,647895	0,80465	0,820555	0,787051	0,85	0,790493	0,85	0,85	0,85	0,85	0

41. Figure Office at Create - heatmap for talker-listener STI matrix

6.5.5. Room-based assessment results

6.5.5.1. Operative temperatures

The representative condition in the room in all of the offices were taken as point in the middle of the occupied zone. For the critical condition, in all the rooms the location was placed close to the glazing area and along external wall. This location is expected to be the most critical due to the proximity to cold surfaces, which increases the view factor of the window.

76. Table

Operative temperature - comparison of result for room-based assessment

	Critical condition (Top)	Representative condition (Top)
Innovate	21.3	21.6
FBV	21	21.3
Create	21.4	21.6

Even though the results are able to catch two different variations, these can in general be two very different results. The location specific assessment is able to highlight all the range in between.

6.5.5.2. View out

The evaluation for the room as a whole was conducted in every case office. All the criteria are evaluated from one reference point in the room, which should be representative for the

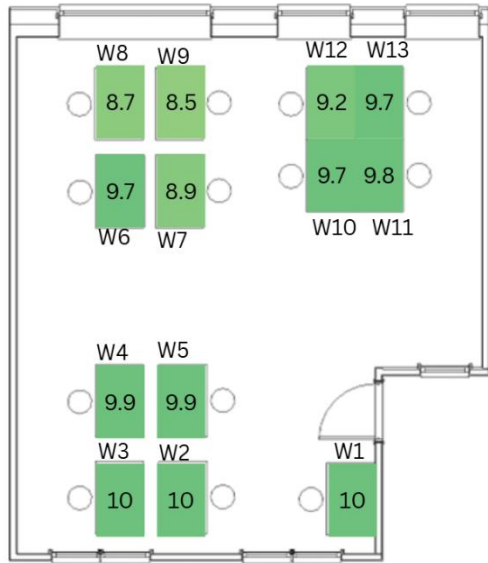
occupation of the room, so it is placed in the middle of the occupied zone, related to the glazing area. The results vary from the workstations, since the important factor here is the reference point. The results show that only one reference point is not representative for all the positions in the room.

Workstation	Criteria			Score
	VIS 1.1	VIS 1.2	VIS 1.3	
Innovate	10	6	4	20
Whole room	8	7	1,6	16.6
Create	10	7	0	17

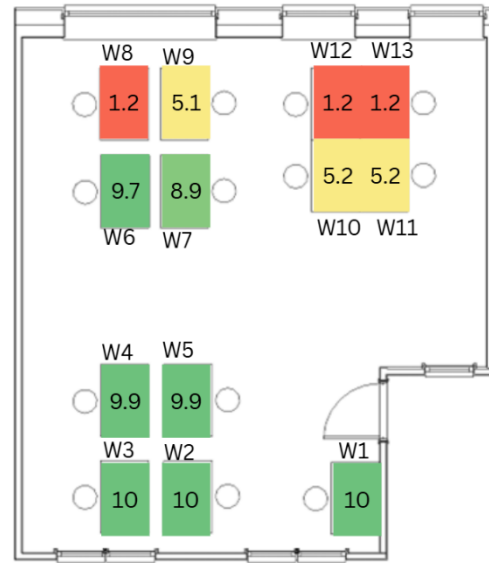
6.5.6. Renovation (view out improvements)-results

6.5.6.1. Operative temperatures

The renovation proposal didn't slightly changed the operative temperature results for winter condition. Some of the workstations 8 and 9 showed lower results due to enlargement of the glazing area, making the view factor of the window bigger. Since the glazed area is the coldest surface in the surroundings, it effected the results.

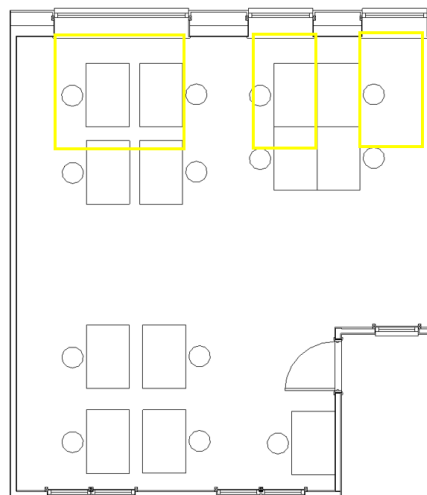


41. Figure Operative temperature scores after renovation - Office room at Create – Winter condition



42. Figure Operative temperature scores after renovation - Office room at Create – Summer condition

The summer condition in this scenario worsened workstations 8 and 9 due to higher potential risk of discomfort caused by direct solar radiation. The two workstations are now in the area highlighted as illuminated by the direct sunlight.

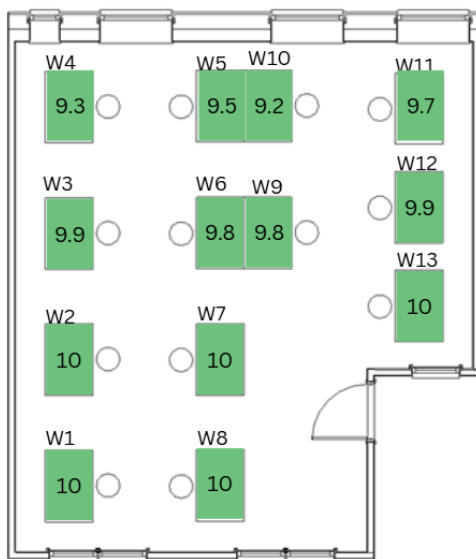


43. Figure Highlight of the office room places where there is a risk of direct solar radiation on the occupants – office at Create after renovation

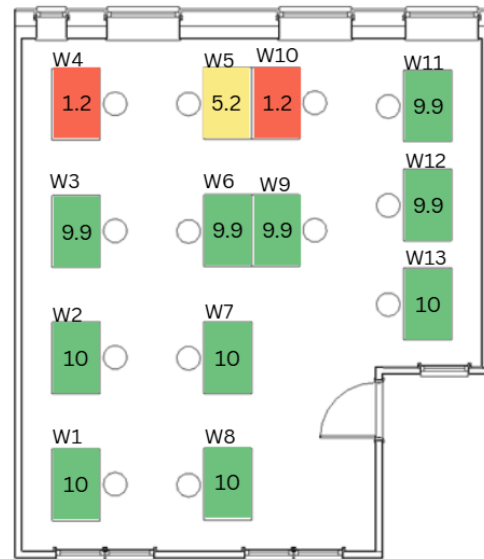
6.5.7. Change of layout (STI improvement)-results

6.5.7.1. Operative temperatures

The change of the layout of the workstations effected the winter conditions minimally, since the placement stil covered the whole office but in this case is spaced more evenly. The summer condition also chnaged only slightly. The workstation 4 become positioned in direct solar radiation due to its position. On the other hand, the workstation 11 improved since the slight location change moved the workstation from the direct sunlight.



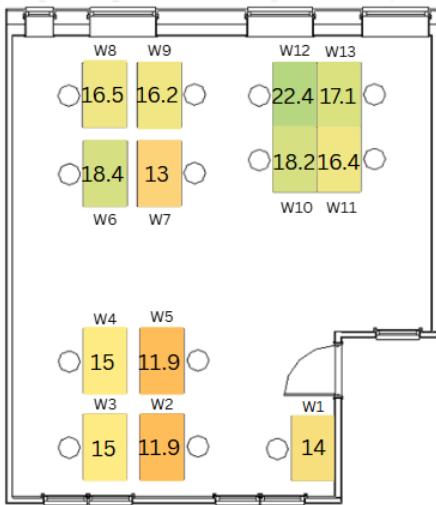
44. Figure Operative temperature scores after change of office layout - Office room at Create – Winter condition



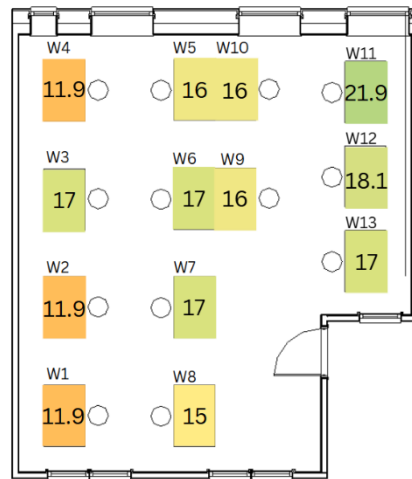
45. Figure Operative temperature scores after change of office layout - Office room at Create – Winter condition

6.5.7.2. View out

The change of workstation layout in the office in Create change the score on each workstation slightly. The score is represented visually, showing the original scenario (Figure 46) and the situation after reorganization (Figure 47). The table present score for each criterion for the updated layout. The change in score is mainly affected by the criteria, which depend on the relation of the workstation to the façade.



46. Figure View out scores before change of office layout - Office room at Create



47. Figure View out scores after change of office layout - Office room at Create

77. Table

Results of the view out assessment for each criterion and achieved points for view out after the layout change of the office - Create

Workstation	Criteria			Score
	VIS 1.1	VIS 1.2	VIS 1.3	
W1	4.9	7	0	11.9
W2	4.9	7	0	11.9
W3	10	7	0	17
W4	4.9	7	0	11.9
W5	10	6	0	16
W6	10	7	0	17
W7	10	7	0	17
W8	8	6	0	15
W9	10	6	0	16
W10	10	6	1	17
W11	10	7	4.9	21.9
W12	10	7	1.1	18.1
W13	10	7	0	17

7. List of references

- [1] Felgueiras F, Mourão Z, Moreira A, Gabriel MF. Indoor environmental quality in offices and risk of health and productivity complaints at work: A literature review. *Journal of Hazardous Materials Advances* 2023;10.
- [2] Fissore VI, Fasano S, Puglisi GE, Shtrepi L, Astolfi A. Indoor Environmental Quality and Comfort in Offices: A Review. *Buildings* 2023; DOI: 10.3390/buildings13102490.
- [3] Kwon M, Remøy H, Van Den Bogaard M. Influential design factors on occupant satisfaction with indoor environment in workplaces. *Building and Environment* 2019:356; DOI: 10.1016/j.buildenv.2019.05.002.
- [4] Al Horr Y, Arif M, Katafygiotou M, Mazroei A, Kaushik A, Elsarrag E. Impact of indoor environmental quality on occupant well-being and comfort: A review of the literature. *International Journal of Sustainable Built Environment* 2016:1; DOI: 10.1016/j.ijbsbe.2016.03.006.
- [5] Al Horr Y, Arif M, Kaushik A, Mazroei A, Katafygiotou M, Elsarrag E. Occupant productivity and office indoor environment quality: A review of the literature. *Building and Environment* 2016:369; DOI: 10.1016/j.buildenv.2016.06.001.
- [6] Kang S, Ou D, Mak CM. The impact of indoor environmental quality on work productivity in university open-plan research offices. *Building and Environment* 2017:78; DOI: 10.1016/j.buildenv.2017.07.003.
- [7] Sarbu I, Sebarchievici C. Aspects of indoor environmental quality assessment in buildings. *Energy and Buildings* 2013:410; DOI: 10.1016/j.enbuild.2013.02.005.
- [8] Larsen TS, Rohde L, Jønsson KT, Rasmussen B, Jensen RL, Knudsen HN et al. IEQ-Compass – A tool for holistic evaluation of potential indoor environmental quality. *Building and Environment* 2020; DOI: 10.1016/j.buildenv.2020.106707.
- [9] DGNB Renovering og nybyggeri. 2025.
- [10] LEED v4.1 BD C Guide. 2025.
- [11] BREEAM Standards. <https://breeam.com/standards>.
- [12] Wargocki P, Wei W, Bendžalová J, Espigares-Correa C, Gerard C, Greslou O et al. TAIL, a new scheme for rating indoor environmental quality in offices and hotels undergoing deep energy renovation (EU ALDREN project). *Energy and Buildings* 2021;244.
- [13] Standard Dansk. DS/EN ISO 7730:2025 Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. 2025.

- [14] Shetaw M, Gyoh L, Gerges M, Dimka N. A Bibliometric Review of Indoor Environment Quality Research and Its Effects on Occupant Productivity (2011–2023). *Sustainability* 2024; DOI: 10.3390/su16229618.
- [15] Dębska L, Krawczyk N, Kapjor A. Analysis of Thermal and Humidity Sensations in Educational Buildings in Eastern European Climate Conditions. *J sustain dev energy water environ syst* 2023;1; DOI: 10.13044/j.sdewes.d11.0461.
- [16] Andersson Johnny, Wargocki Pawel, Hanssen Sten Olaf, Seppänen Olli, Boerstra Atze, Clements-Croome Derek et al. REHVA Guidebook No. 6 - Indoor Climate and Productivity in Offices - How to Integrate Productivity in Life-Cycle Cost Analysis of Building Services. : REHVA, the Federation of European Heating, Ventilation and Air Conditioning Associations, 2006.
- [17] Zahariev RI. THE IMPACT OF INTERIOR LIGHTING ON HEALTH AND VISUAL COMFORT. *RS Global - World Science* 2025; DOI: 10.31435/ws.2(88).2025.3415.
- [18] Banbury SP, Berry DC. Office noise and employee concentration: Identifying causes of disruption and potential improvements. *Ergonomics* 2005;48:25–37.
- [19] Singh A, Syal M, Grady SC, Korkmaz S. Effects of Green Buildings on Employee Health and Productivity. 2010; DOI: 10.2105/AJPH.2009.180687).
- [20] Fisk WJ, Black D, Brunner G. Benefits and costs of improved IEQ in U.S. offices. *Indoor Air* 2011;21:357–67.
- [21] Standard Dansk. DS 474 Code for Thermal Indoor Climate. 2019.
- [22] Standard Dansk. DS/EN 16798-1:2019 Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lightning and acoustics - Module M1-6. 2019.
- [23] Bygningsreglementet. <https://www.bygningsreglementet.dk/>.
- [24] Standard Dansk. DS 447:2021 Ventilation for buildings -Mechanical, natural and hybrid ventilation systems. 2021.
- [25] Standard Dansk. DS/EN 17037:2018+A1:2021 Daylight in buildings. 2022.
- [26] Standard Dansk. DS/EN 12464-1:2021 Lighting of work places -Part 1: Indoor work places. 2021.
- [27] Stadar Dansk. DS/EN 14501:2021+A1:2025 Blinds and shutters - Thermal and visual comfort - Performance characteristic classification. 2025.
- [28] Standard Dansk. DS/EN ISO 3382-1 Measurement of room acoustic parameters -Part 1: Performance spaces. 2009.

- [29] Standard Dansk. DS/EN ISO 717-1:2020 Acoustics -Rating of sound insulation in buildings and of building elements -Part 1: Airborne sound insulation. 2020.
- [30] Standard Dansk. DS/EN ISO 16283-1 Field measurement of sound insulation in buildings and of building elements -Part 1: Airborne sound insulation. 2014.
- [31] International WELL Building Institute. WELL V2 Standard. 2025.
- [32] Living Building Challenge. <https://living-future.org/lbc/>.
- [33] ASHRAE Standard 62.1 - Ventilation and Acceptable Indoor Air Quality. 2025.
- [34] Clements N, Zhang R, Jamrozik A, Campanella C, Bauer B. The Spatial and Temporal Variability of the Indoor Environmental Quality during Three Simulated Office Studies at a Living Lab. Buildings 2019; DOI: 10.3390/buildings9030062.
- [35] ASHRAE Handbook - Fundamentals. , 2021.
- [36] Statens Byggeforskningsinstitut. Naturlig ventilation i erhvsbygninger. 2002 <https://edu.anvisninger.dk/anvisninger/p-anv202-naturlig-ventilation-i-erhvervsbygninger>.
- [37] B.Stampe, Ole. Varme- og klimateknik, ventilationsteknik. , 2000.
- [38] Fošner A, Zbašnik-Senegačnik M, Kristl Ž. Window View Preferences in Various Environmental and Activity Contexts. Sustainability 2023; DOI: 10.3390/su152316215.
- [39] Ko WH, Schiavon S, Zhang H, Graham LT, Brager G, Mauss I et al. The impact of a view from a window on thermal comfort, emotion, and cognitive performance. Building and Environment 2020; DOI: 10.1016/j.buildenv.2020.106779.
- [40] Kent M, Schiavon S. Evaluation of the effect of landscape distance seen in window views on visual satisfaction. Building and Environment 2020; DOI: 10.1016/j.buildenv.2020.107160.
- [41] World Health Organization. Environmental Noise Guidelines for the European Region. 2018.
- [42] Standard Dansk. DS/EN ISO 3382-3:2022 Acoustics -Measurement of room acoustic parameters -Part 3: Open plan offices. 2022.
- [43] Standard Dansk. DS/EN IEC 60268-16:2020 Objective rating of speech intelligibility by speech transmission index. 2020.
- [44] Standard Dansk. DS/EN ISO 9921 Ergonomics - Assessment of speech communication. 2003.
- [45] European Commission, Energy. https://energy.ec.europa.eu/index_en.
- [46] World Health Organization. WHO Guidelines for Indoor Air Quality - Selected pollutants. : World Health Organization, 2010.

- [47] Standard Dansk. DS 3033:2011 Voluntary classification of the quality of the indoor climate in residential houses, schools, childrens' day-care centres and offices. 2011.
- [48] Standard Dansk. DS/ISO 16000-6:2021 Indoor air -Part 6: Determination of organic compounds (VVOC, VOC, SVOC) in indoor and test chamber air by active sampling on sorbent tubes, thermal desorption and gas chromatography using MS or MS FID. 2021.
- [49] Standard Dansk. DS/EN 16798-3:2025 Energy performance of buildings - Ventilation for buildings - Part 3: For non-residential buildings - Performance requirements for ventilation and room-conditioning systems (Modules M5-1, M5-4). 2025.
- [50] Marval J, Tronville P. Ultrafine particles: A review about their health effects, presence, generation, and measurement in indoor environments. *Building and Environment* 2022; DOI: 10.1016/j.buildenv.2022.108992.
- [51] Standard Dansk. DS/ISO 16000-3:2022 Indoor air - Part 3: Determination of formaldehyde and other carbonyl compounds in indoor and test chamber air - Active sampling method. 2022.
- [52] ASHRAE Standard 55 - Thermal Environmental Conditions for Human Occupancy. 2023 <https://www.ashrae.org/technical-resources/bookstore/standard-55-thermal-environmental-conditions-for-human-occupancy>.
- [53] Torriani G, Torresin S, Lara-Ibeas I, Albatici R, Babich F. Perceived air quality (PAQ) assessment methods in office buildings: A systematic review towards an indoor smellscape approach. *Building and Environment* 2024; DOI: 10.1016/j.buildenv.2024.111645.
- [54] Gorlach J, Gazda D, Trusz A, Walaszczyk J, Szczęśniak S, Piekarska K. Ventilation and air conditioning systems are a source of antibiotic-resistant bacteria - A review. *Building and Environment* 2025; DOI: 10.1016/j.buildenv.2025.112583.
- [55] Aalborg Universitet K, ø, benhavn. Anvisning om Bygningsreglement 2010. 2014 <https://edu.anvisninger.dk/anvisninger/anv230-anvisning-om-bygningsreglement-2010>.
- [56] Standard Dansk. DS/EN ISO 7726:2025 Ergonomics of the thermal environment - Instruments for measuring and monitoring physical quantities. 2025.
- [57] Standard Dansk. DS/CEN/CR 1752 Ventilation for buildings - Design criteria for the indoor environment. 2001.
- [58] Standard Dansk. DS 452:2013+Ret.1+Till.1:2020 Thermal insulation of technical service and supply systems. 2020.
- [59] Arbejdstilsynet. <https://at.dk/>.
- [60] He S, Zhang W, Guan Y. The Impact of Building Windows on Occupant Well-Being: A Review Integrating Visual and Non-Visual Pathways with Multi-Objective Optimization. *Buildings* 2025; DOI: 10.3390/buildings15142577.

- [61] Kaplan R. The role of nature in the context of the workplace. 1993
[https://doi.org/10.1016/0169-2046\(93\)90016-7](https://doi.org/10.1016/0169-2046(93)90016-7).
- [62] Jamrozik A, Clements N, Hasan SS, Zhao J, Zhang R, Campanella C et al. Access to daylight and view in an office improves cognitive performance and satisfaction and reduces eyestrain: A controlled crossover study. Building and Environment 2019; DOI: 10.1016/j.buildenv.2019.106379.
- [63] Standard Dansk. DS/EN 12665:2024 Light and lighting-Basic terms and criteria for specifying lighting requirements. 2024.
- [64] Standard Dansk. DS/IEC TR 61547-1:2020 Equipment for general lighting purposes - EMC immunity requirements -Part 1: Objective light flickermeter and voltage fluctuation immunity test method. 2020.
- [65] Udførelse af bygningsakustiske målinger. 2014 <https://edu.anvisninger.dk/anvisninger/p-anv217-udforelse-af-bygningsakustiske-malinger>.
- [66] Standard Dansk. DS/EN ISO 12354-1:2017 Building acoustics -Estimation of acoustic performance of buildings from the performance of elements -Part 1: Airborne sound insulation between rooms. 2017.
- [67] Lydisolering mellem boliger - nybyggeri. 2011
<https://edu.anvisninger.dk/anvisninger/anv237-lydisolering-mellem-boliger-nybyggeri>.
- [68] Standard Dansk. DS/EN ISO 16283-2:2018 Acoustics -Field measurement of sound insulation in buildings and of building elements -Part 2: Impact sound insulation. 2018.
- [69] Standard Dansk. DS/EN ISO 3382-2 Acoustics -Measurement of room acoustic parameters -Part 2: Reverberation time in ordinary rooms. 2008.
- [70] Standard Dansk. DS/EN 12354-6 Building acoustics -Estimation of acoustic performance of buildings from the performance of elements -Part 6: Sound absorption in enclosed spaces. 2004.
- [71] Standard Dansk. DS/EN ISO 14257 Acoustics -Measurement and parametric description of spatial sound distribution curves in workrooms for evaluation of their acoustical performance. 2002.
- [72] Trafikstyrelsen. <https://www.trafikstyrelsen.dk/>.
- [73] Standard Dansk. DS 490:2018 Sound classification of dwellings. 2018.
- [74] Standard Dansk. DS/EN ISO 16283-3:2016 Facaders lydisolation Acoustics -Field measurement of sound insulation in buildings and of building elements -Part 3: Façade sound insulation. 2016.
- [75] Standard Dansk. DS/EN ISO 12354-3:2017 Building acoustics -Estimation of acoustic performance of buildings from the performance of elements -Part 3: Airborne sound insulation against outdoor sound. 2017.

- [76] Standard Dansk. DS/EN ISO 10052:2021 Acoustics - Field measurements of airborne and impact sound insulation and of service equipment sound - Survey method. 2021.
- [77] Standard Dansk. DS/ISO 22955:2021 Acoustics -Acoustic quality of open office spaces. 2021.
- [78] Anvisning om bygningreglement 2015. 2017
<https://edu.anvisninger.dk/anvisninger/anv258-anvisning-om-bygningsreglement-2015-br15>.
- [79] Petersen CM, Rasmussen B. Acoustic design of open-plan offices and comparison of requirements in the Nordic countries. 2018.
- [80] Standard Dansk. DS 469:2013 Heating and cooling systems in buildings. 2013.
- [81] Standard Dansk. DS 418:2011 + Till.1:2020 Calculation of heat loss from buildings. 2020.
- [82] BS 8206 Lightning for Building - Code of practice for daylighting. 2008.
- [83] Akram MW, Hasannuzaman M, Cuce E, Cuce PM. Global technological advancement and challenges of glazed window, facade system and vertical greenery-based energy savings in buildings: A comprehensive review. Energy and Built Environment 2021:206; DOI: 10.1016/j.enbenv.2021.11.003.
- [84] Aarts, M.P.J., Chraibi, Sanae, Aries, M.B.C. et al. Light transmittance range of glass for visual comfort in an office environment. 2011 <https://research.tue.nl/en/publications/light-transmittance-range-of-glass-for-visual-comfort-in-an-office/>.
- [85] Standard Dansk. DS/EN ISO 9241-1 Ergonomic requirements for office work with visual display terminals (VDTs) - Part 1: General introduction. 1997.
- [86] Torrejon A, Callaghan V, Hani H. Panoramic Audio and Video: towards an Immersive Learning experience. 2013
https://www.researchgate.net/publication/257809591_Panoramic_Audio_and_Video_towards_an_Immersive_Learning_experience.
- [87] Bradley JS. Speech intelligibility studies in classrooms. The Journal of the Acoustical Society of America 1986;80:846–54.
- [88] HOUTGAST T. The modulation transfer function in room acoustics as a predictor of speech intelligibility. Acustica 1973;28:66–73.
- [89] Steeneken HJM, Houtgast T. A physical method for measuring speech-transmission quality. The Journal of the Acoustical Society of America 1980;67:318–26.
- [90] PUETZ UM. Articulation loss of consonants as a criterion for speech transmission in a room. J Audio Eng Soc 1971;19:915–9.
- [91] Mølhav L, Kjærgaard SK, Sigsgaard T, Lebowitz M. Interaction between ozone and airborne particulate matter in office air. Indoor air 2005;15:383–92.

[92] Standard Dansk. DS/EN ISO 11690-1:2020 Acoustics -Recommended practice for the design of low-noise workplaces containing machinery -Part 1: Noise control strategies. 2020.