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# IEQ-Compass – A Tool for Holistic Evaluation of Potential Indoor Environmental Quality in Schools

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## Abstract

The aim of this project is to develop a holistic evaluation tool of the indoor environmental quality of school buildings in Denmark. The purpose of the tool is to evaluate the IEQ potential to ensure comfort, health, well-being, and performance of the occupants in school buildings. The requirements for a good indoor environment in schools were investigated to create the framework of evaluation. The evaluation areas are within indoor air quality, thermal, visual, and acoustic indoor environment, as well the occupants' possibility to adjust the indoor environment. Based on the methodology from prior tool developed for evaluation of residential IEQ, parameters and criteria were developed within each IE parameter to fit the element that influence the IEQ of schools. The assessment methods of the IEQ potential in schools were developed from the literature review of the conditions to create a good IEQ in schools, industry calculation guidelines, building regulation, and standards. As a result of the project, the groundwork for fully developing a tool to label the IEQ of schools is performed and documented. Parameters and criteria are developed to assess the IEQ potential of schools, weighting among the parameters and criteria is introduced to fit the elements that influences the IEQ of schools. A new method to present the results is introduced to communicate the IEQ of the schools on room and building level for both users of the schools and professional consultants for design or renovation purposes of the school buildings.

# 1 Introduction

Humans spend on average 90 % of their time indoors, where 20 % of the awake time during the 10 school-mandatory years are spend in schools for Danish children [1]. The indoor environment is documented to have a great impact on the health, well-being, and performance of humans, and especially children are sensitive to the impact of the indoor environment [2]. Several studies of the indoor environment in Danish schools have proven that the indoor environment lack in many areas, where especially problems with the IAQ, over-temperatures, and noise are detected [1, 2, 3]. The benefits of improved indoor environment in Danish schools are analysed to have a positive effect on sick-leave and performance on both teachers and kids, as well as the learning of the kids. The socio-economic aspects of improving the indoor environment in schools is deemed beneficial; the costs of renovating the school buildings to improve the indoor environment is analysed to be smaller than the positive outcome of the improved health, well-being, performance, and learning of the children [4]. During the last decades, the attention of renovations has been the energy performance and - savings, with little to no attention to the indoor environment. To increase the attention of IEQ in schools a certification and labelling method of the IEQ should become available to the users, on the same level, or more communicated than the energy performance certificate labelling. Following several certification schemes of energy performance, sustainability, social sustainability, indoor environment, and economy aspects, no tool was found to evaluate and bring focus on all aspects of the indoor environment. Therefore, a tool with purpose to evaluate the IEQ potential of buildings on level with the energy performance certification were developed in the REBUS project [5]. Initially the tool was developed for residential buildings, more specifically apartments, but with the vision of expansion to more building types. The current study and development of IEQ-Compass has the purpose to holistically evaluate and communicate the indoor environmental quality to the users and owners of the school buildings in Denmark. The tool is intended to be used on a national level to spread awareness about the IEQ in Danish schools and inform the users, both parents, pupils, teachers, and owners of the schools about the IEQ at the school. To communicate the IEQ at the schools the tool is intended to be used both as a certification tool and help in decision making when renovating the school building stock in Denmark to include indoor environment in the renovation plans.

# 2 Methodology

The methodology addresses the approach applied developing the tool, section of content and weighting methods in the tool to achieve a holistic evaluation of the IEQ of school buildings.

## 2.1 Preliminary work and overall considerations

Assessment of indoor environmental quality is often done by surveys or measurements. Measurements reflect the IEQ during the time the measurements are performed, which is often during short period of time as it is costly and time consuming to perform measurements. Surveys rely on the observation of the IEQ of the occupants. Both methods are influenced by the behaviour of occupants or their perception of the IEQ and does therefore not show the potential of the IEQ in the building or room of evaluation. Especially in schools where there is a great change in occupants it is important to show the IEQ potential of the building design handling the load of a full class (e.g. sufficient air change rate) but independent of the occupants behaviour (e.g. how and when occupants open the windows).

The development of this tool aims to assess the building potential to provide a good IEQ through building design and implemented technical solutions. This does therefore not consider the behaviour of the occupants, which could have unintended effects on the IEQ.

The following criteria were set for the development of the tool [5]:

- It must evaluate the building's potential to provide good IEQ, without being biased by occupant behaviour or taking it into consideration
- It must evaluate the occupants' possibilities to adjust and interact with the IEQ to adjust for preferences of the occupants.
- It must include the assessment of IAQ, thermal, visual, and acoustic IEQ in relation to comfort, health and well-being.
- It must be independent of physical measurements.
- It must be based on existing regulations and standards whenever possible.
- The assessment by the tool must be sufficiently detailed and at the same time easy and fast to use both regarding input data and output results.
- The tool must be applicable for existing buildings (to evaluate present status), renovation projects (to evaluate before and after renovation) and new buildings (to be used for design and benchmarking).

Furthermore, the project is developed to be used by consultants professionally trained within the built environment, hence the result of the tool can be used for decision making by the school, municipality, building companies. The objective of the tool is to be used as a label of the IEQ of the school building to be on par with the energy labelling certificate. Moreover, to inform of the IEQ at schools in Denmark and to be used as decision basis for renovations, improvements, etc. A hopeful desired side effect of the tool and grading the IEQ of schools is to enlighten about IEQ in schools among the users to affect a positive user behaviour on the IE.

## 2.2 Selection of Parameters, Criteria, and Weighting

The methodology of evaluating the IEQ were based on methods used in the prior tool developed for residential units. All four comforts parameters within indoor environment are included to have equal weighting in the total grade of the indoor environment, as well as the occupants' possibility to adjust the indoor environment. As for the prior tool developed other aspects of social sustainability is not included as the tool only focuses on the indoor environment, to develop a counterpart for the energy performance certification. This decision was taken to communicate the IEQ in similar manner, creating focus on the importance of the indoor environment as there is for the building energy consumption [5].

Development of the parameters included in the tool for schools were done in several steps, first a thorough assessment and discussion of all parameters in the tool for residential units were performed to preliminary figure out what parameters that could be applied in schools as well, which did not, and which that needed adjustment.

A literature research within the four comforts and occupants' possibility to adjust the indoor environment were performed. During the research on how each comfort influences the indoor environment, what parameters that are important for the IEQ in schools were studied, as well as the status and conditions at schools in Denmark. The work of revising, changing, implementing new and removing parameters then started based on the research of the IEQ in schools and the assessment of the prior tool parameters. It was discovered that problems with IAQ, noise levels, overtemperatures, and illuminance are present in Danish schools [1, 2, 3].

It was decided to keep the general evaluation of the IEQ; 4 parameters within each IE area, where one parameter within each IE area evaluated the occupants' possibility to adjust the indoor environment. It is furthermore decided to keep the fixated parameters and criteria weights in the tool to achieve a tool to work as benchmarking on a national level, with weighting of parameters and criteria to fit evaluation of IEQ in schools.

A new method of presenting the results were developed during working with the parameters, it was deemed necessary to develop a new method compared to the prior tool. In the prior tool for residential units, comparatively small areas are evaluated and one unit at a time, where for school buildings big areas and greater difference in usage is found, therefore a different method was developed. Generally, the evaluation of residential is performed pr. unit, whereas the same application would give a score for the entire school building area, even if there can be found different building characteristics, usage of room etc. Therefore, it was deemed necessary to evaluate pr. room level and grade differently.

# 3 Results

The evaluation of the 4 parameters for each indoor environmental comfort and their corresponding criteria are described in the following sections. Following is the method of presenting and communicating the results described.

## 3.1 Status of & Requirements for a Good IEQ in Danish Schools

The requirements for a good indoor environment in schools to ensure the comfort health, well-being, and performance of children have been analysed for the study within the 4 indoor environment comforts before the development of the *IEQ-Compass: Schools*. Within acoustic IE measures to keep a low noise level in the rooms of the school is desired. For atmospheric, it is desired to have a low pollution level in the room regardless of the high pollution loads. For the thermal IE, comfortable temperatures not too hot or cold temperatures with stricter demands than for adults should be implemented for children, nor draught is desired. Likewise, for the visual environment where good illumination levels are desired with a good distribution, not too high or low lighting levels. The elements associated, contributing, or preventing the problems with the indoor environment are thereby intended to assess in the IEQ-Compass for school buildings.

The indoor environment of Danish schools has been measured and analysed in several ways during the last decade, where some of the most extensive analyses included measurements for more than 200 Danish schools [2, 1]. From measurements of the indoor environment in schools, problems within all parameters are detected; pollution loads above 1000 ppm half of the time, and the BR18 limit of 1000 ppm were exceeded for more than 20 minutes at least once in 91 % of the classrooms [1]. The analysis of thermal comfort is analysed to be within the comfort levels of adults, however as children are more sensitive to warm temperatures these temperatures are too high during the heating season [1, 2, 6]. Similar are results for acoustic measurements, which comply with the regulations most of the time, however the sound level is measured above 65 dB 63 % of the time. For the visual comfort the lux level is measured to be between 300 and 2000 lux 49 % during the occupation time during the heating season, where it was measured to be below requirements of 300 lux 49 % of the occupation time. Most of the Danish school buildings are old buildings, where only ~ 10 % of the built area is built after 1995, where the mechanical ventilation demand where included in the building regulation. With the old building stock built after old regulations means the buildings will in many cases not comply with recent requirements for ventilation, daylight, sound insulation and thermal properties. This could be a source of the bad IEQ in Danish schools.

## 3.2 Parameters and Criteria in the Tool

This section presents evaluation methods of the IEQ potential in IEQ-Compass: Schools within each IE comfort the parameters and their corresponding criteria are presented. The criteria within the parameters are developed with the same scoring methodology of a top score of 10 and lowest score of 0, as in the prior tool IEQ-Compass: Residential.

### 3.2.1 Acoustic Comfort (ACOU)

The acoustic comfort evaluates the building potential to provide good acoustic environment. Acoustic discomfort predominantly can be caused by noise, both from outside and within the building. The noise can have negative effect on human's comfort, well-being, health and performance outcomes [7]. Acoustic environment can be also influenced by acoustic properties of a room. Therefore, the main parameters influencing acoustic comfort are Noise from surrounding, Noise propagation between the rooms, Acoustic comfort withing the room and Occupants' possibility to adjust the acoustic IEQ, see Table 1.

*Table 1 – Parameters, criteria, and their weights for the acoustic IEQ (ACOU).*

| Parameter | | Parameter weights | Criteria | | Criterion weights |
|---|---|---|---|---|---|
| ACOU1 | Noise from surroundings | 35 % | 1.1 | Low impact of external noise | 80 % |
| | | | 1.2 | Windows opening possibilities towards the silent side | 20 % |
| ACOU2 | Noise propagation between rooms | 35 % | 2.1 | Air sound insulation | 50 % |
| | | | 2.2 | Impact sound level | 50 % |
| ACOU3 | Acoustic comfort within the room | 25 % | 3.1 | Technical installations | 60 % |
| | | | 3.2 | Reverberation time | 40 % |
| ACOU4 | Occupants' possibility to adjust the acoustic IE | 5 % | 4.1 | Possibility to open windows in multiple directions | 100 % |

First parameter ACOU1 is assessing how the noise from outside the building is influencing acoustic comfort within the room. Therefore, it was necessary to specify what is noise level outside the building and external wall acoustic insulation property. The day-evening-night outside noise level $\mathrm{L_{den}}$ can be specified in 3 ways. Firstly, it can be taken from environmental noise map published by Miljøstyrelsen, if the school is located in the investigated map areas [8], see Figure 1. Otherwise, the outside noise level can be taken from interpolation of example results from Nord2000 software [9]. Those example results were developed for various road types with different speed limitations and distance to the road. Regarding wall acoustic properties in the IEQ-Compass there is a list of typical danish constructions with assigned sound insulation value [10]. With does two parameters a day-evening-night inside noise level inside, $\mathrm{L_{den(indoor)}}$ can be calculated. The score for ACOU1.1 criterion is calculated based on $\mathrm{L_{den(indoor)}}$ value and scoring range is from $\mathrm{L_{den(indoor)}}$ ≤ 23 dB to ≤ 38 dB, with linear scoring distribution respectively from 10 to 0 points. Moreover, 20 % of weight for ACOU1 parameter is evaluated by window opening possibilities towards the silent side. This parameter is scored based on the $\mathrm{L_{den}}$ which should be assigned to each openable window. The grading scale is a linear function for marginal values, between 10 points for $\mathrm{L_{den}}$ ≤ 33 dB and 0 points for $\mathrm{L_{den}}$ ≤ 55 dB.

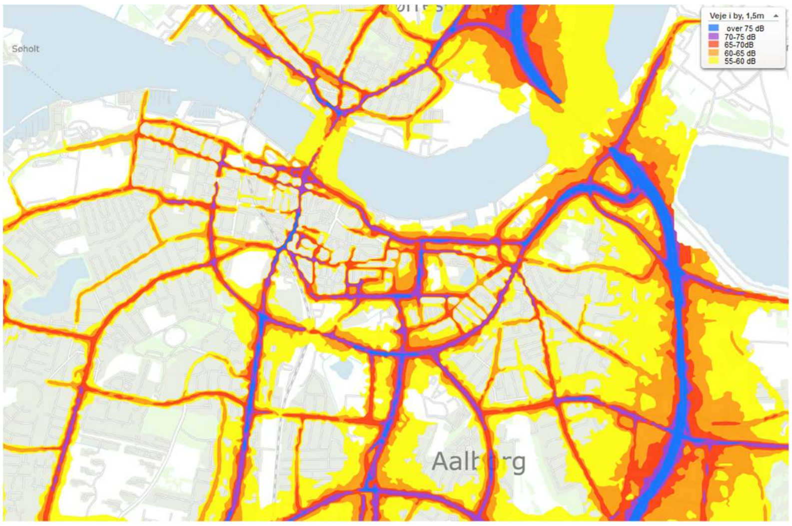


*Figure 1 – The average traffic noise level in the Aalborg city map in dB [8].*

ACOU2 is the parameter representing potential of noise propagation between rooms. Score for this parameter is equally divided between ACOU2.1 and ACOU2.2 criteria. The first criterion evaluates airborne sound insulation of internal walls in the room. Therefore, in the IEQ-Compass: Schools there is list of sample internal walls with assigned weighted apparent sound reduction index $R'_w$ [11]. Very similar solution was also applied for Impact sound level criterion where list of sample flooring with assigned weighted impact sound pressure level $L'_w$ values were also used [11]. With specific values for those factors, for both criteria scoring can be already calculated. For different room types in the school, various grading scales were developed. However, for the classroom gradings were set in a range $R'_w$ ≥ 59 and 49 for airborne sound insulation and $L'_w$ ≤ 48 dB and 63 for impact sound level, for respectively maximal (10) and minimal (0) scoring.

ACOU3 is scored based on technical installations (ACOU3.1) and reverberation time (ACOU3.2) criteria. The maximal scoring (10 points) for technical installations is divided between different types of installations. A sound insulation of the ventilation system gets maximally 6 points score, a room adjacent to an elevator possibility 3 points score, while visible drainage pipes can score up to 1 point. Meanwhile, for reverberation time there is long sample list of different finishing materials with corresponding absorption coefficients. With this factor and Sabine's formula application, reverberation time can be easily calculated [12]. The grading scale for this criterion variates between the room types but the same linear function method was preserved. For classrooms scoring range is between T ≤ 0,4 s and ≤ 0,8 sec with respective scoring 10 and 0 points.

ACOU4 is representing occupants' possibility to adjust acoustic comfort. Only 5 percent score weight was given to this parameter, as occupants does not have significant impact on acoustic comfort. The points for this are given for possibility to open window in one or multiple facades, respectively getting 7,5 and 10 points.

### 3.2.2 Atmospheric Comfort (ATM)

The atmospheric comfort evaluates the potential of the building to provide a good indoor air quality. The main factors that influence the indoor air quality is categorised into Ambient Air Quality, Building & Ventilation Method, Activities, and lastly the Occupants' possibility to Adjust the Indoor Environment. The parameters and criteria of the atmospheric IE is presented in Table 2

*Table 2 – Parameters, criteria, and their weights for the assessment of Atmospheric Indoor Environment*

| | Parameter | Parameter weights | | Criteria | Criterion weights |
|---|---|---|---|---|---|
| ATM1 | Ambient Air Quality | 15 % | 1.1 | Outdoor air quality and filtration | 100 % |
| ATM2 | Ventilation Method | 40 % | 2.1 | Ventilation method & Commissioning | 70 % |
| | | | 2.2 | Air flow | 20 % |
| | | | 2.3 | Emissions from materials | 10 % |
| ATM3 | Activities | 25 % | 3.1 | Activity and ventilation | 100 % |
| ATM4 | Occupants' possibility to adjust the atmospheric IE | 20 % | 4.1 | Ventilation boost, natural ventilation | 30 % |
| | | | 4.2 | Ventilation boost, mechanical ventilation | 40 % |
| | | | 4.3 | Automatic control of ventilation rate | 30 % |

ATM1 is the parameter that evaluates the ambient air quality. The air supply of the building has a great impact on the indoor air quality and is therefore based on the ambient pollution level and if there is filter present in the ventilation method, as a filter can improve the air quality of the supplied air into the building. The ambient air quality is evaluated based on the annual average concentration of $PM_{2,5}$ at the given location of the school building obtained from the Danish national pollution map [13]. A score of the pollution level is given based on the maximum permissible value is 15 µg/m³ recommended by Well air quality standards, the recommended limit by the World Health Organisation is 10 µg/m³ and the minimum concentration level obtainable in the map of 5 µg/m³ [14, 15]. Bonus points are given if there is filtering of the supply air present to improve the air quality of the supplied air. The bonus point is given based on filter type, ventilation method, and if there is a service contract of changing the filter.

ATM2 is the evaluation of how the building and ventilation method influences the indoor air quality. The criteria of this parameter are included to evaluate how the building design and – technologies contribute to the indoor air quality. The first criterion of ATM2 evaluates the pollution from materials and furnishing in the building; introducing new materials into the building can release pollutants and it is therefore desired to build, renovate, and furnish with low polluting materials [16]. The second criterion of evaluation within ATM2 is the ventilation method and how it performs in the room. The scoring of ventilation method is based on the general performance based on driving forces of the ventilation method, as well as tests performed in classrooms evaluating how well different ventilation methods perform [1, 2, 17]. Within the evaluation of ventilation method, there can be obtained bonus points based on service and commissioning of the ventilation system. A service contract and commissioning of the ventilation system and its components will ensure that the ventilation system is performing as intended. Unlike Swedish regulation, Denmark does not have demands for commissioning during the lifetime of ventilation systems, which could explain the better IAQ in Swedish schools, also when only comparing schools with mechanical ventilation [2, 18]. As a third criterion within ATM2 evaluation of air flow is included. This criterion is strongly related to the ventilation method and is included as part of the evaluation to ensure if an air flow great enough is present to ensure a good IAQ in the room. As there in school buildings usually are found high occupancy load, likewise will the pollution load be. Therefore, to ensure a good IAQ the rooms must be ventilated with an air flow great enough to remove the pollutants. This criterion can therefore evaluate if there is the air flow needed, which the evaluation of ventilation method and performance of the ventilation method does not evaluate; a perfectly working ventilation system can be sized too small to ensure a good IAQ. The scoring of air flow is based on standards and building regulations of several countries and calculated for each room based on the occupants and room area [19, 20, 21]. A room for occupation, like a classroom or laboratory, will get top score if the air flow corresponds to 7 l/s pr. occupant and 0,7 l/s pr. m² and worst score if the air flow corresponds to 7 l/s pr. occupant and 0,7 l/s pr. m². The air flow of the room is intended to get from either building design documentation, calculation of natural ventilation potential, or from documentation of performance tests of the ventilation system. The additional measures of evaluation in ATM2, commissioning and air flow, are included to ensure the performance of the ventilation, as it was discovered during the literature review that there are many cases of insufficient ventilation in Danish schools, also when mechanical ventilation were present [2].

ATM3 is the parameter that evaluates the activities carried out in the school building and how it influences the IAQ. As many different activities are carried out in a school building, the evaluation of the activities is simplified to how the activities pollute, and the ventilation method needed to ventilate for pollution created by the activities. Activities from no additional pollution than evaluated in ATM2, to dangerous pollutions in laboratories are evaluated and corresponding ventilation method from no additional ventilation to process ventilation. The evaluation of this parameter is intended to be scored hence the criteria complement each other; a score of 10 is given if no extra polluting activities happen, however highly polluting activities can only get a score of 10 if complementary ventilation is present, thereby laboratories for physics and chemistry can only gain a score by having process ventilation, as required by the Danish Working Environment Authority [22].

Lastly, ATM4, the occupants' possibility to adjust the atmospheric indoor environment. The main influence the occupants have on the atmospheric indoor environment is to adjust the ventilation. To accommodate different ventilation methods, boosting of both natural and mechanical ventilation is present in the scoring, as well as automatic control of mechanical ventilation.

### 3.2.3 Thermal Comfort (THER)

The thermal comfort evaluates the potential of the building to provide a good thermal indoor environment. The main factors that influence the thermal indoor environment is categorised into Temperatures during summer, Temperatures during winter, Draught, and lastly the Occupants' possibility to Adjust the Indoor Environment. The thermal IE parameters and criteria is presented in Table 3.

*Table 3 – Parameters, criteria, and their weights for the assessment of Thermal Indoor Environment.*

| Parameter | | Parameter weights | Criteria | | Criterion weights |
|---|---|---|---|---|---|
| THER1 | Temperatures, Summer | 30 % | 1.1 | Overtemperatures | 90 % |
| | | | 1.2 | Cold surfaces | 10 % |
| THER2 | Temperatures, Winter | 30 % | 2.1 | Comfort temperature | 50 % |
| | | | 2.2 | Surface temperatures | 50 % |
| THER3 | Draught | 20 % | 3.1 | Leakages | 30 % |
| | | | 3.2 | Downdraught | 20 % |
| | | | 3.3 | Draught from ventilation | 50 % |
| THER4 | Occupants' possibility to adjust the thermal IE | 20 % | 4.1 | Ventilation boost, natural ventilation | 25 % |
| | | | 4.2 | Ventilation boost, mechanical ventilation | 10 % |
| | | | 4.3 | Automatic control of mechanical ventilation | 15 % |
| | | | 4.4 | Solar shading | 20 % |
| | | | 4.5 | Cooling | 5 % |
| | | | 4.6 | Temperature regulation | 25 % |

THER1 is the parameter that evaluates the indoor environment during summer, this is assessed by evaluating the critical conditions there could be present; the overtemperatures and the risk of discomfort if cooling is present. The first criteria of is evaluation of the presence of overtemperatures during the occupied hours. The temperatures during the hours of the year are calculated based on thermal gains and losses, including factors as the outdoor air temperature, internal loads, solar gains, and losses through the façade and ventilation. As occupants produce heat it has been decided to include the loads based on the number of occupants in the room. The operation hours are set to be within all periods of the year, 5 days a week during the hours from 8 to 16, as this is the normal opening hours of schools and the intended usage of the school building. The scoring of overheating hours – and temperature limits is based on the building regulation, children's adaptive comfort model, temperature limits for working conditions, and guidance for indoor environment simulations [23, 19, 6, 24, 25]. During the literature review it was discovered that children has a lower comfort temperature than adults and the limit values to reach top score is therefore based on this, and the normal methodology of giving a good score of ~ C, for applying with the building regulation were shifted to complying with the advised limit temperature from the Danish Working Environment Authority of 25°C and the standards DS/EN 7730 and 15251 [25, 20]. Secondly the criteria evaluating discomfort due to cold surfaces due to are assessed. This criterion is included to be simple and assess if there is a risk of discomfort due to cooling systems there may be present, this is however not normally installed in Danish schools. The evaluation of the risk of discomfort due to radiant asymmetry is based on the temperature differences limits in DS/EN 7730 for cold walls, ceilings, and floors [25].

THER2 parameter evaluates the thermal indoor environment during the heating season. The thermal environment during the cold season depends on heating sources and the building envelope. This parameter is therefore divided into two criteria evaluating the general possibilities to provide a satisfactory thermal indoor environment during the heating season and the second criteria if there is risk of discomfort due to cold surfaces in the building envelope. The thermal comfort during the heating season is depended on the heating sources, which in many can be assumed to can provide a minimum temperature of 20°C as heating systems are sized based on critical conditions occurring rarely and during small timeframes in Denmark, therefore the control possibilities, placement of heating sources, and adaptability of the system ass well the thermal insulation of the building envelope is assessed. Control possibilities of the heating system is weighted to have greatest influence. Secondly the criterion of discomfort due to cold surfaces is evaluated. The assessment of cold temperatures is calculated as hourly values, taking the thermal properties of the window and external wall, outdoor temperatures, and assumption of constant 20°C of indoor air into account. The temperature difference is evaluated from hours where a risk of discomfort based on DS/EN 7730 values for cold walls [25].

THER3 parameter evaluates the risk of discomfort due to draught during all seasons. Draught is unwanted cooling of the body due to air movements and the risk of draught should therefore be evaluated, likewise the critical thermal conditions during summer and winter. For the evaluation of draught three criteria is included for evaluation, where the first evaluates the conditions of windows, second evaluates risk of downdraught due to cold surfaces during heating season, and third evaluates the risk of discomfort due to ventilation method. The first criterion assesses the conditions of the window as the closing mechanism, the rubber strips and joint between window and construction. The second criterion calculates the risk of downdraught created from cold windows during the winter. The potential velocity creased due to the temperature difference between the room and window surface temperature is calculated and velocities greater than 0,18 m/s is evaluated. The last criterion evaluates the risk of draught due to ventilation method. Several parameters are evaluated, including if there is heating and cooling of the supply air, and how the air is supplied in the occupied zone. The highest scores are given when the risk of draught is smallest hence ventilation systems with preheating of the air, air supply outside the occupied zone at low velocities, and no cooling of the air.

The parameter THER4 evaluates the occupants' possibility to adjust the thermal indoor environment. Many factors can influence the thermal indoor environment, however not all is possible to adjust by the occupant, therefore only criteria possible for the occupant to easily use and change is included. Criteria of adjusting the ventilation load is included based on how much they influence the thermal comfort included, as well as possibility for solar shading, cooling, and possibilities of controlling the heating and temperature during winter. For ventilation, possibilities of opening the windows, boosting the air flow and automatic control is assessed. For heating system control, the possibilities of control are assessed, and for solar shading and cooling, the types of elements present to utilise by the occupants is assessed. Depended on what possibilities are present different scoring is given. The greatest impact on possibility to adjust the indoor environment is for ventilation, heating control, and solar shading, as these will be utilised more than cooling.

### 3.2.4 Visual Comfort (VIS)

The visual comfort considers and evaluates the supply of daylight, Artificial lighting, View (in and out), and the occupants' possibility to adjust the external shading, as presented in Table 4.

*Table 4 - Parameters, criteria, and their weights for the assessment of the visual comfort*

| Parameter | | Parameter weights | Criteria | | Criterion weights |
|---|---|---|---|---|---|
| VIS1 | Daylight | 30 % | 1.1 | Daylight intensity and distribution | 50 % |
| | | | 1.2 | Colour rendering of windows | 20 % |
| | | | 1.3 | Direct sunlight | 30 % |
| VIS2 | Artificial lighting | 35 % | 2.1 | Lighting level from artificial lighting | 40 % |
| | | | 2.2 | Luminance distribution | 30 % |
| | | | 2.3 | Quality of the artificial light | 30 % |
| VIS3 | View | 20 % | 3.1 | View out (access and quality | 40 % |
| | | | 3.2 | View-in (exposure to passers-by) | 25 % |
| | | | 3.3 | Influence of view by external shading | 35 % |
| VIS4 | Occupants' possibility to adjust the visual IE | 15 % | 4.1 | External solar shading, adjustment | 50 % |
| | | | 4.2 | External solar shading window-by-window activation | 50 % |

Parameter VIS1 evaluates the amount and quality of daylight that enters the room, this is done through calculations and evaluations performed by the users' inputs of; room - and window area, type of glass, shadowing buildings, overhang, and other relevant correction factors the scoring allows for larger windows to get the highest score possible. VIS1 also considers the colour rendering of the of windows to assess the quality of the perceived sunlight, this is done with an empirical observation of the perceived colour, if no information of the colour rendering index of the glass type is available. The evaluation of VIS1.3 investigates how well the room is able to block out the disrupting sunlight, glare, whist allowing the non-disrupting sunlight to light up the room. These evaluations are based on assumptions and known facts about external and internal shading devices and how they handle the entering sunlight.

Artificial lighting, VIS2, is a parameter that is implemented with the adaptation of the tool from apartment buildings to school buildings. It investigates the lighting level, the luminance distribution and the quality of the installed light. The lighting level, as the name suggest, evaluates the level of the artificial light in the room, which can be investigated with the knowledge of the installed light in the room. The required light level is dependent on functionality and room type. Distribution and quality of the light is important so no discomfort that could expose the health and well-being of the occupants, can occur and cause, pupils and teachers to leave the school because of feeling sick. The distribution and quality are being evaluated by the user of the tool and is evaluated by answering case specific question that determines the score. The evaluated areas are, the colour rendering of the artificial lighting, since that is a replacement for the sunlight, and should have close to the same colours, and flickering of the lights, since flickering can cause discomfort and health issues for the occupants [26].

The parameter VIS3, view in and view out, take into consideration the positive effects of having a good view from the school, since teachers and pupils spent 20 % of their awaken hours inside the school it is important to allow them a change of view to the outside, which also improve the concentration of the pupils [1]. Regarding the view in, VIS3.2, school buildings are not exposed to the same loss of privacy as dwellings are. Therefore, does the focus lay in how the school can prevent distractions from the outside, so the occupants do not decrease the focus on the task at hand. This is evaluated with empirical questions the user must answer to score maximum points.

VIS4 evaluates the occupants' possibility to adjust the external solar shading devices on the façade. Because of the increased sizes of schools, compared to dwellings, the adjustable devices have been increased to a percentage of the total that can be controlled by the occupants. The scoring for VIS4.1 is, no possibility to adjust, lowest score, remote controlled, highest score. VIS4.2 scores the percentage of windows that can be adjusted from 0 % adjustable, lowest score, to all windows' shading devices can be controlled, highest score. In the case of occupants' possibility to adjust the comfort, the opportunities are very few and are often decided during the design process of the school. Which is why the weighting of the parameter VIS4 is relatively low compared to THER4

## 3.3 Criteria and weights

To obtain a combined score of the IEQ of the individual parameters and criteria evaluated for the rooms and building in the tool *IEQ-Compass: Schools*, weighting between the evaluation points is implemented to balance the parameters and criteria based on the importance and impact on the IEQ, size of the parameter, method of evaluation and other factors that may influence. There is implemented several levels of weighting, where the first is found among the 4 comforts: acoustic, atmospheric, thermal, and visual comfort. Equal weight among the four main areas is implemented as no significant data can be found on how their relative impact and importance compared to each other. Second level of weight is found in each of the comforts to balance the parameters within the comfort. This level of weighting among the parameters in the comforts are based on the impact the parameter has on the IEQ in schools. The third level of weighting is found among the criteria within each parameter, also based on the impact and importance the criteria has on the IEQ parameter as well as evaluation method. Lastly, it should be mentioned that there can be several scorings within each criterion, e.g. several components are evaluated and scored. The weighting among these in the criteria is handled by adjusting the scoring to fit the total score to avoid fourth level weighting.

## 3.4 Communication of Results

The vision of IEQ-Compass: Schools is to be able to show a IEQ label and a IEQ compass for the whole school and for each evaluated room and their potential to provide a good IEQ. Providing results on building and room level can help provide justifications for renovation proposals for existing buildings as well as different design ideas and how those changes may influence the IEQ during the design phase. A major change in the results is how the evaluations went from building level, down to room level, so each room will be evaluated for all parameters.

The objective of the IEQ-Compass: Residential is to provide the user of the tool with the potential IEQ label and design compass that can easily be communicated and understood by professionals and a broader audience. The results are communicated in two ways, one that illustrate the IEQ label and one that illustrates the IEQ design compass. The IEQ label, labels the building with an overall class, and the IEQ design compass shows how the building specifically are performing in all criteria in each parameter, which can, in turn, help identify potential IEQ problems and improve decision making in the early stages. IEQ-Compass: Schools utilises that setup and communication as a basis but more detailed so the design compass can show each evaluated room and with that help discover potential problems and renovation areas. The reason for keeping the overall communication is that it is easy to understand and generally showing a detailed view of the building. The solution IEQ-Compass: Schools uses is the implementation of a correction factor. Each room type is evaluated within four factors, Importance factor (how many criteria act upon room type, fixed value), Room area, Time of occupation (how much of the day is the room occupied, also fixed value), and Number of people. Each of these correction factors are evaluated in regard to importance and combined into a multiplication factor, that is multiplied with the score of that room type. The multiplication factor will ensure that the IEQ labelling for the whole school building is evaluated so secondary and tertiary rooms does not dictate the end results but are still being evaluated. In Figure 2 can an illustration of how it potential can look like in a school building and how the different rooms have an IEQ label associated with it, and in Figure 3 and Figure 4, how the IEQ Design Compass and IEQ label can go into a room to see how criteria's is distributed.

The user of the tool as mentioned, will be by a consultant professionally trained within the built environment, so the tool can be used for decision making, for the design phase or existing buildings. The tool is longer and more complex than IEQ-Compass: residential, and therefore it would not be advised for people with no background in the subject to conduct the evaluation.

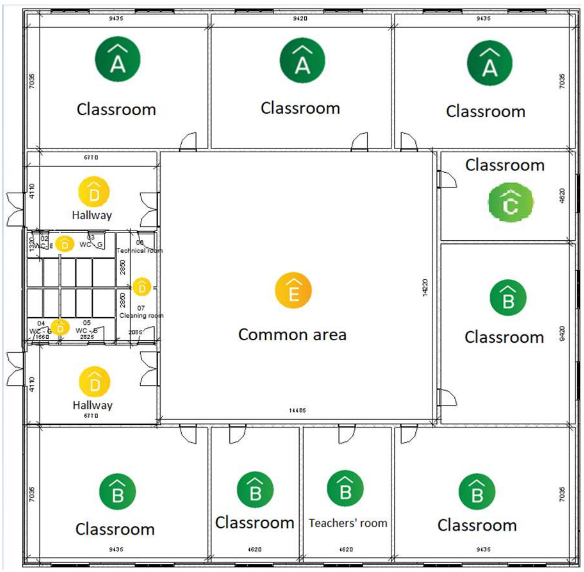


*Figure 2 - An example of how a schools IEQ label can look like for each room.*

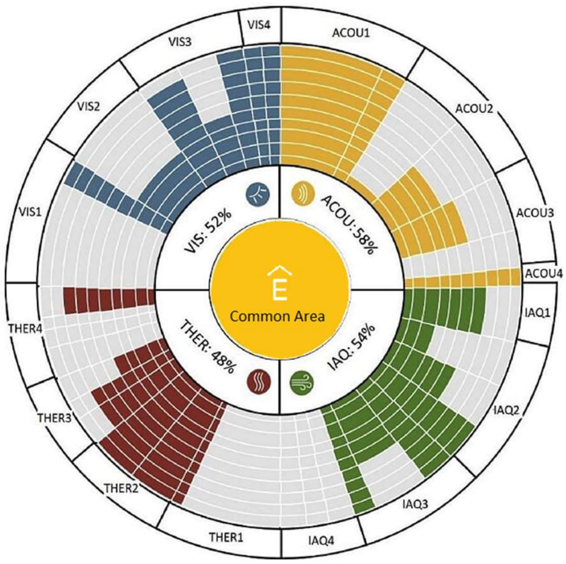


*Figure 3 - An example of IEQ Design Compass that shows the criteria and how the room is graded.*

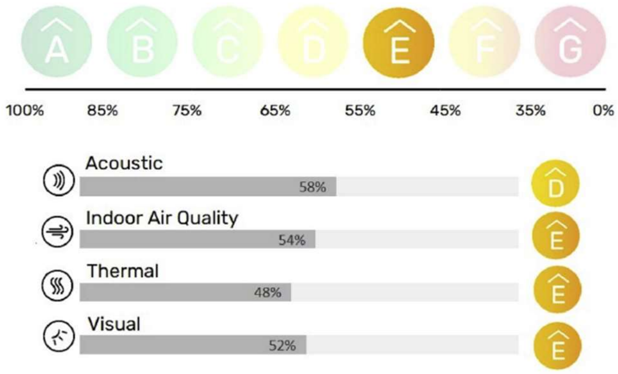


*Figure 4 - An example of how the percentage of each parameter.*

# 4 Discussion

The purpose of developing the IEQ-Compass: Schools were to assess the indoor environmental quality potential of school buildings. When presenting the results of the IEQ potential of schools it is important to consider the different types of rooms evaluated. Compared to the IEQ-Compass: Residential tool, IEQ-Compass: Schools have a greater variety of room types that all should be graded and presented in the IEQ labelling in a sensible way that does not degrade the importance of other rooms. Hence not all rooms are used for occupation, have different area, and different time of occupation, a simple and fair weighting system among the rooms cannot be implemented. IEQ-Compass: Residential secures the IEQ labelling score with not allowing an overall score two grades higher than the lowest one of an individual room. That would not be sufficient for IEQ-Compass: Schools If all types rooms of the school are included in the evaluation; giving secondary and tertiary rooms like hallway and toilets the same weight as classrooms would not give a representative score of the school building. However, the same method of IEQ-Compass: Residential could be applied, if only occupied rooms are included, as e.g. classrooms, laboratories, and common areas.

To accommodate renovation cases of schools, where demands for indoor environment is too ambiguous to achieve, renovations projects to improve the indoor environment are in some cases rejected and not included [27]. To target renovation cases of schools, the purpose of the tool could be changed to include a “Renovation Class” to give incentive to include the improvement of the indoor environment of schools, where the requirements for the IEQ is lowered where it is not possible to achieve in old buildings. However, this will not take the comfort and well-being into account and the general standard of IEQ is lowered, however as it does give initiative to improve the indoor environment, the IEQ of the existing school buildings could change for the better with achievable goals.

# 5 Conclusion

The research shows that there is a general problem with the Indoor environmental quality in schools in Denmark and have shown that for a long time [1, 2]. It also shows that with the continued focus on energy savings the comforts will not get better. The development of the tool *IEQ-Compass: Schools* demonstrates the possibility of holistic evaluation of the indoor environmental quality of school buildings. The tool provides possibility to evaluate the IEQ potential of each room for a detailed evaluation, and considers the indoor air quality, thermal, visual, and acoustic indoor environmental quality. The tool performs simulation and calculation of the IEQ potential based on the user inputs of building information and is designed and developed to be quick and easy to use without making time-consuming measurements. The current tool is not fully developed and is intended to be developed in a more user-friendly and commercial tool than the existing, as the prior tool for residential. The tool should be able to provide results that present data on the room and building level in varied levels of detail; the tool produces two graphical illustrations to present the results, IEQ label and IEQ design compass. IEQ label illustrates general overview of the room and building that is easily communicated to the users, whereas IEQ design compass goes into depth with the rooms and building present a detailed score of each IE parameter and criteria. With the presentation of the two kinds of results, it allows consultants in the municipality and construction companies for an overview of the whole school and for the specific rooms. The process thereby allows for small renovations and design changes, for existing and future buildings, to be conducted on the room level, so the overall IEQ of the school can be improved without the use of expensive measurements and observations.

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