AALBORG UNIVERSITY
STUDENT REPORT

INDOOR ENVIRONMENT IN MULTI-STOREY RESIDENTIAL BUILDINGS

Thermal and Visual Comfort Using IV20

MASTER THESIS

4th Semester MSc. Building Energy Design

AALBORG UNIVERSITY
STUDENT REPORT

SYNOPSIS

TITLE: INDOOR ENVIRONMENT IN MULTI-STOREY RESIDENTIAL BUILDINGS (THERMAL AND VISUAL COMFORT USING IV20)

SEMESTER: 4th Semester MSc. Building Energy Design

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GROUP: 1.242-03

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The purpose of this report is to analyze several apartments score regarding placement and orientation using IV20 tool.

The apartments chosen for this experiment are sorted and registered according to their condition, in order to obtain a grade for 2 evaluation areas, Thermal Comfort and Visual Comfort, as well as a general grade for the entire building.

These apartments are located in Allborg and will be included in a building catalog. The aim is to make a comparison between the overall score, parameter and criteria using the IV20 tool.

REPPORT: 58 Pages

APPENDIX: 97 Pages

PREFACE

This report is part of 4th semester Master of Science Program in Building Energy Design at Aalborg University, department of Civil Engineering. This project is done by a group of 1 student from Group 1.242-03.

The project period is from September 2017 to January 2018. Report delivery date is 10th of January. The completion of the report and examination based on the research is equivalent to 30 ECTS point. The supervision was done by Associate Professor Rasmus Lund Jensen and PhD Fellow, Lasse Engelbrecht Rohde, from Aalborg University.

The aim of this project is to test the IV20 tool on different multistory residential buildings and to analyze how scores are influenced by different location and solar orientation, within the same building. After testing and analyzing the apartments according to their orientation, a total score for the building should be obtained.

The chapters of this report are recommended to be read consecutively. The list of reference for figures, graphs, tables and literature can be found in the end of the report. If references are used directly in the text, the referred text is written with Italic. The Appendix is separate from this report and contains additional information for the research.

The author would like to thank to her supervisors Rasmus Lund Jensen and Lasse Engelbrecht Rohde, for the help and guidance throughout the process of completing this report. In addition, gratitude will be expressed to group 1.242-04 for the help during the registration and testing period.

GROUP 1.242-03

JANUARY 2018

Table of Contents

1. Introduction

1.1. Background information and description of the subject

The location of an apartment or house is one of the major aspects that should not be ignored in a world that is more and more attentive to what makes a home efficient energetically and indoor climate wise. The comfort of the occupants can be significantly improved and equally save money by taking advantage of natural light and heat.

The title of this project is “Indoor Environment in Multi-Storey Residential Buildings”. The objective is to investigate a number of apartments provided by Himmerland Boligforening by testing them in IV20 to analyze the link between the location within the same building, its’ orientation and the scores of the evaluation criteria. Another objective of this report is to analyze how many apartments are relevant to test in order to obtain a building label and apartment label.

1.2. IV20

IV20 is part of the REBUS project in collaboration with other partners. The purpose of this project was to create a tool which can evaluate and score Indoor Environment, with the aim that in the future this will become a part of the Building Regulations. Another purpose for this new evaluation tool would be that when the analysis and report for the Energy Label will be performed, an Indoor Environment analysis and report will also be made. The scale might be similar to the Energy Label scale, giving an easy understanding to the users.

Buildings' primary function is to protect against the outside environment and create a comfortable and healthy indoor climate for the inhabitants. The physical indoor climate of the building is influenced by how is designed, by materials, interior design and possibility of ventilation, but the indoor climate is equally dependent on the building's use, for example, by venting, cleaning and building activities.

People spend up to 90% of the time in buildings; at work, at school, in institutions at leisure or at home, therefore, it is important to have a good and healthy indoor climate that supports the activities that take place in that building.

There is a growing demand for comfort, as well as a good and healthy indoor climate in buildings. This is because research results substantiate that a good indoor climate can reduce the number of sick days and provide better productivity or better learning. Therefore, there may be great gains also socio-economically by improving the indoor climate in Danish buildings. Human comfort in buildings also depends on the indoor climate conditions in the four evaluation areas of the indoor climate assessment tool, IV20; thermal, acoustic, atmospheric and visual indoor climate. The user experience of comfort is also closely linked to the possibilities of self-governing the indoor climate, and this is also an important element in the assessment of the indoor climate of buildings. All indoor climate evaluation areas are measurable, and in the long term, the increased focus can be expected to create meaningful measurable requirements for each evaluation area.

The tool is identifying and evaluating a residence's possibility of reaching a good indoor climate by establishing the potential through observations and identification of problems. The tool was initially developed for housing, but it will be developed further for other types of buildings. It can also be used to compare the results before and after renovation.

IV20 evaluates 4 main criteria:

- Thermal: temperature in the summer, temperature in the winter and draught
- Acoustic: outside noise, noise from neighboring apartments, noise from inside the apartment
- Atmospheric: impact from outdoor air, impact from building materials, impact from activities
- Visual comfort: daylight, direct solar radiation, view, inside and outside view

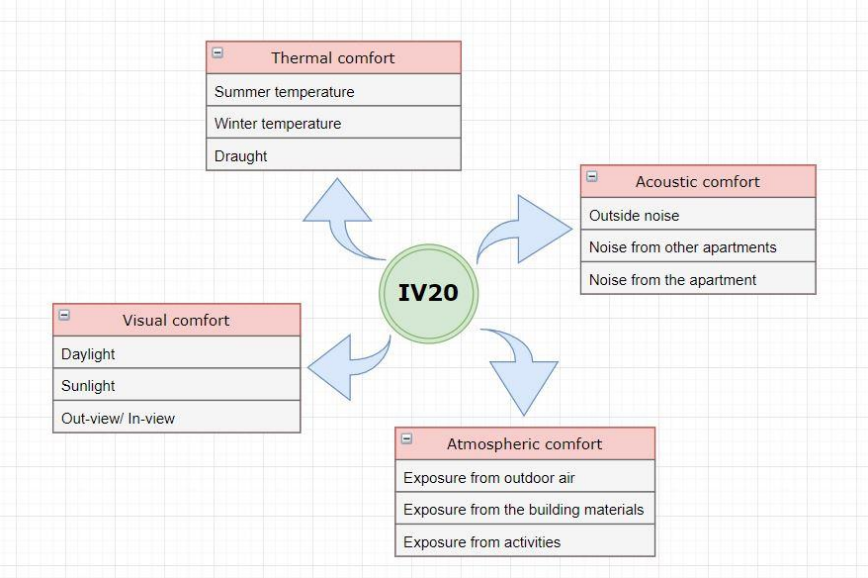

Figure 1.1. - IV20 Evaluation area

The results are structured so that they can be communicated widely and in an easy understandable language, so the overall indoor climate classification can be understood by constructors and building users, while advisors and experts can get a more detailed information about the partial results of the parameters in the 4 evaluation areas.

During the development of the tool, several approaches to assessments were used. In some cases, calculated values are used, and it is assumed that it is possible to work with ideal constructions so that the calculations made, for example, in terms of silencing of structures, are based on design constructions that have been performed without any errors in the construction. These assumptions are also normally used for energy calculations in relation to the calculation of U-values. This will give an uncertainty about the result, and therefore it is expected that the calculated potential will be higher than what can actually be achieved in the building. The indoor climate assessments are independent of the users, thus showing the potential of the building.

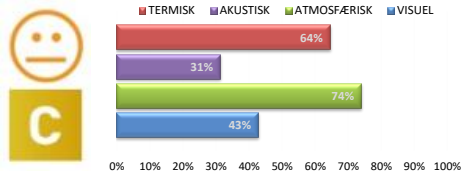

Figure 1.2. - IV20 Grading Scale

A total score is given presented as an overall indoor class rating varying from A to G, similar to the scale used for energy labeling. Concomitantly, an overall score in numbers is providing additional information for each of the four evaluation areas indicating the total score of an apartment (0-100%). The detailed result for each evaluation area can also be accessed, which can help users see where potential improvements can be made. The results for each parameter is based on the detailed calculation of each criteria evaluated on a scale from 0 to 10, determined on a predefined assessment basis, for example calculations, registrations, checklists or a combination of these. This creates a clear overview, and it can easily go from the assessment of individual criteria to the bigger picture in terms of the final IV20 score.

A comfort rating could change the equation because the tenants will be able to compare the rating on the buildings, giving owners an incentive to ensure their buildings are attractive.

...luerings-...lade	Parametre		Kriterier		Kriterie score		Parameter-score		Område score	Samlet score
	Nr.	0% /---------/ 100%	6 /-------/ 10	Kriterie vægt	Kriterie sum	Kriterie max	Score	Vægtning	[A - G]	ABCDEFG
TERMISK	TER1	Temp. sommer			**10.0**	**10**	**100%**	33%	B	C
			1.1 Beregning: Sommerkomfort		10.0	10				
	TER2	Temp. vinter		**2**	**20.0**	**20**	**100%**	33%		
			2.1 Overfladetemperatur	1	10.0	10				
			2.2 Varmekilder	1	10.0	10				
	TER3	Træk		**3**	**18.5**	**30**	**62%**	33%		
			3.1 Utætheder	1	8.5	10				
			3.2 Kuldenedfald	1	10.0	10			0% /---------/ 100	
			3.3 Ventilation	1	0.0	10			87%	
AKUSTISK	AKU1	Støj - fra omgivelser		**1**	**1.0**	**10**	**10%**	50%	F	
			1.1 Trafikstøj	0.9	0.0	10				
			1.2 Orientering af åbninger	0.1	10.0	10				
	AKU2	Støj - fra byggeri			**2.2**	**10**	**22%**	25%		
			2.1 Luftlyd		2.2	10				
			2.2 Trinlyd		3.8	10				
	AKU3	Støj - fra bolig			**7.5**	**10**	**75%**	25%	% /---------/ 100	
			3.1 Tekniske installationer		7.5	10			29%	
MOSFÆRISK	ATM1	Påvirkning fra udeluft			**4.0**	**10**	**40%**	20%	C	
			1.1 Partikler		4.0	10				
	ATM2	Påvirkning fra bygning og materialer		**1**	**9.4**	**10**	**79%**	40%		
			2.1a Ventilations-system/serviceaftaler	0	0.0	10				
			2.1b Naturlig ventilation	0.5	10.0	10				
			2.2 Udsugning i badeværelse	0.3	8.0	10				
			2.3 Lav-emitterende materialer	0.2	10.0	10				
	ATM3	Påvirkning fra aktiviteter		**1**	**10.0**	**10**	**100%**	40%		
			3.1 Tørringsmuligheder	0.28	10.0	10				
			3.2 Emhætte	0.28	10.0	10				
			3.3 Komfur/ovn	0.38	10.0	10			0% /---------/ 100	
			3.4 Brændeovn	0.06	10.0	10			80%	
VISUEL	VIS1	Dagslys		**2.0**	**9.0**	**10**	**90%**	50%	C	
			1.1 Intensitet og fordeling	1	10.0	10				
			1.2 Kvalitet	1	-1.0	0				
	VIS2	Direkte sollys			**10.0**	**10**	**100%**	20%		
			2.1 Solskinstimer		10.0	10				
	VIS3	Udsyn, indkig og afskærmning		**0.3**	**1.5**	**6**	**25%**	30%		
			3.1 Udsyn	0.15	6.7	30				
			3.2 Indkig	0.1	0.0	10			0% /---------/ 100% /---------/ 10	
			3.3 Afskærmning	0.05	10.0	10			73%	67%

Figure 1.3 - IV20 Score

1.3. IV20 – Evaluation areas

Thermal

The thermal indoor climate includes the criteria that affect human balance. It is the air and radiation temperature, air velocity and turbulence intensity and a smaller extent the humidity. A good indoor climate aims to make inhabitants comfortable which is defined by the state of satisfaction of the thermal environment. Discomfort can be created due to too cold or hot conditions for the body as a whole, or it could be unwanted heating or cooling on individual body parts like cold feet or too warm temperature for the head.

In early 20th century, the first focus was on thermal indoor climate, in the "Comfort Equation and the Predicted Mean Vote (PMV)", which expresses the condition that a normal person will feel thermal comfort. Fanger defined also the PPD index (Predicted Percentage Dissatisfied), which indicates how high is the percentage in a group of people that feel discomfort due to thermal indoor comfort. These trials showed that everybody is different and has a different perception of the thermal indoor climate, so there cannot be only one thermal that will satisfy everyone. This is one of the main reason for which the IV20 results are based on the actual condition of a building and not on the users' level of comfort.

Surveys of indoor climate in homes have shown that there is often dissatisfaction regarding parts of thermal indoor climate. IV20 pays attention to temperature in the summer and winter, and draught. In the summer, the temperature inside an apartment can be uncomfortably high due to lack of sun protection, large windows and insufficient ventilation which can make the temperature go up, beyond the limits specified in BR15. In the winter, the temperature can become uncomfortably low due to the cold from outside that penetrates through leaks, poor insulation and because of a poor heating system. Draught is unwanted local cooling of the body resulting from air movement, causing discomfort.

- thermal comfort during summer - TER 1
- thermal comfort during winter – TER 2
- draught – TER 3

Acoustic

The acoustic indoor climate describes how the sound moves in the building and in the rooms, both in relation to sound scattering and sound absorption in space and materials. It is another important part when looking at indoor comfort and health in terms of concentration, sleep and stress level. The acoustic requirements are given by DS490 in the Sound Classification of buildings, where in some cases the minimum requirement is C and in other cases can be D, in case of renovation when the conditions are not optimal.

The noise from surroundings is about the physical location of the building in relation to traffic noise, which is one of the most disturbing sound nowadays and therefore an extremely important parameter to assess and evaluate in relation to acoustic indoor climate.

The sound from the building is constituted by the airborne isolation between partition walls and staircase insulation. Air sounds are sound waves that propagate in the air.

Noises from the apartment refers to the building's technical installations, such as elevators, ventilation, toilet, which is perceived as extra disturbance and might be harder to isolate. The sound can happen randomly and at the wrong times.

- noise from surroundings – AKU 1
- noise from the building – AKU 2
- noise from apartment – AKU 3

Atmospheric

The atmospheric indoor climate indicates the quality of the air, and it is another important aspect that can have a major impact on health and comfort. The quality of the air depends on the content of oxygen, moisture, odors and pollutants such as particles and chemical substances.

Generally, in Denmark the pollution in the air is not so high and could always improve the indoor climate by venting, however it still not 100% clean. An important role is played by the location of a building whereas an apartment located in an urban area can be more polluted when compared to an apartment located outside the city.

The indoor air quality it is also influenced by the building, through building materials, which emit chemical substances, depending on the type and age of the construction.

Another way by which the quality of the air is lowered is through everyday activities that take place in the building. Activities can add moisture or smoke in the air, and can increase the chances of mold growth that may cause health problems.

The score for the atmospheric part of IV 20 is given by the following categories:

- impact from outdoor air – ATM 1
- building materials – ATM 2
- activities (clothes drying, kitchen extraction, stove and oven and fire place) – ATM 3

Visual

Light has a great impact on work, learning ability and general wellbeing and it is another important parameter evaluated in IV20.

The visual indoor climate is affected by light distribution, intensity of light, contrasts, color properties and glare. Functionality, aesthetics and energy aspects of light must be combined in order to create the best possible qualitative framework for inhabitants and related activities.

Windows are an important part of a building, being able to connect the indoor and outdoor environments, increase ventilation, give light and heat. There is close connection between visual and thermal indoor climate and energy consumption in buildings.

Daylight is a quality parameter in rooms where people normally spend a significant amount of time, such as living rooms, where light distribution and intensity are very important.

Sunlight and glare are closely related as sunlight in building is often the source of glare or through reflective surfaces.

Another category evaluated and scored in IV20 is the in and out view and shadows on the building/apartment.

1.4. Problem statement

The objective of this report is to perform tests on the IV20 tool and focus on the level of calculation and how positioning of different apartments can affect the weighting parameters.

Through the analysis, a building catalog will be made containing all the tested apartments located in Aalborg, Denmark and the results in two evaluation areas. Another objective of this report is to analyze how many apartments need to be tested in order to have a building label and apartment label.

1.5. Research questions

- How the IV20 score for Thermal and Visual evaluation are is influenced by different orientation and location of the apartments?
- How many apartments should be tested to go from individual apartment labeling to building labeling?

1.6. Delimitation

The main focus of this project is placed on testing and analyzing different apartments. A limited investigation of apartments and rooms will be conducted in order to see if these can be labeled.

A few assumptions are made when performing the tests in IV20, due to lack of apartments and information. Detailed input information will be explained in the following chapters and in the appendix.

Some of the information about the apartments was received from Himmerland Boligforening, therefore the analysis of the building is based on drawings and registrations, with a few reasonable assumptions, which will be explained in the corresponding chapter.

1.7. Research methodology

Research methodology is referring to the process of collecting information and data, in order to evaluate a project. For this report, several information and data sources were used.

Firstly, information regarding the buildings, drawings, plans were provided by Himmerland Boligforening. The staff has been very helpful in providing detailed description of the building, and systems. Additionally, registrations were conducted in at least two apartments in each building that will later on be tested and analyzed. The focus during the registrations was on the sizes of the apartments, location, orientation, condition of the construction (including windows) and conditions of the systems.

IV20 manuals and case studies, internet research and literature, helped in completing this report.

1.8. Abbreviations

IV20	Indoor Environment Evaluation
REBUS	Renovating Buildings Sustainably
St.tv	Ground Floor to the Left
St.th	Ground Floor to the Right
BR15	Building Regulations 2015

Table 1.1 - Abbreviations

2. Case studies

This chapter constitutes of tests and analysis of the scores obtained. Two evaluation areas of IV20 will be investigated: Thermal Comfort and Visual Comfort.

Thermal Comfort consists of the following parameters and the weighting factor is mentioned in the brackets:

- Summer comfort (33%)
- Surface Temperature and Radiators (33%)
- Airtightness, Draught and Ventilation (33%)

Visual comfort consists of the following parameters and the weighting factor is mentioned in the brackets:

- Daylight intensity (50%)
- Sun-Hours (20%)
- View-Out, View-In, Shadows (30%)

All the above sub-criterias consist of 10 points each.

Acoustic Comfort and Atmospheric comfort will be briefly mentioned, but it is not the main focus of this chapter, since it was observed that the criteria score has minor changes when testing different apartments and do not influence the overall score.

The investigation started by selecting the residential building analysed by the author in the 1st semester, because there was a lot of documentation about constructions. The building is located in Aalborg at Henning Smiths Vej. The next step was to work with the first version of IV20 (V0) and analyze the scores obtained and find errors in the tool. Several tests were made on 18 apartments situated in ground floor, 1st, 2nd and 3rd floor. When looking at the test results, errors have been found for both above mentioned evaluation area, and together with group 1.242-04 some of them have been corrected.

Another version of IV20 was released in medio August 2017, V1, and the process was the same as for V0. The test for the first building were redone, and other errors have been found. Some of the errors have been corrected, but more were found along the way, and due to lack of time, V1 still has errors that will be later on added and corrected for V2. More information about the errors encountered on the way can be found in Appendix A.

V1 was used to analyze the cases from Magisterparken, Steen Billes Gade and Otte Ruds Gade from Aalborg. The process started by making registrations on 2 apartments from each building to later be able to make assumptions based on them and on drawings received from Himmerland Boligforrening to start the tests.

2.1. Henning Smiths Vej

The blocks at Henning Smiths Vej were built between 1948-1950 and has been in use ever since. There has not been any major renovation in 50 years therefore the general condition of the building does not fulfill the current requirements. The building consists of 2 and 3 rooms apartments of around 60-70 square meters.

In 2001 was carried an extensive renovation in which:

- the roof had been improved;
- the gables were insulated;
- all the windows and doors have been changed with two panes thermo glass in aluminum and wood frames;

The building has 3215 gross m² of living space and 643 m² of basement with technical room, bicycle racks, laundry room and storage rooms. The construction is typical for that period. The building elements can be described as concrete foundation and basement walls, massive brick outer walls plastered on the inner face and brick partition walls.

The building has been a part of the main project for 1st Semester, BED 2016. For each floor (groundfloor, 2nd, 4th) 6 tests were made in order to see the condition of the apartments and how is the score influenced. All tests were made based on assumptions, information and drawings used during the semester.

This building was used at the initial start when the IV20 tool was released, to get familiar with the program and also to check if there were any errors in the program. During the analysis of the tool and the test, mistakes and errors have been found. Some of the errors were corrected on the way, but mistakes were found further on, and due to lack of time not all have been corrected. Therefore, the results for these tests are right when looking at some of the criteria results, but it might not reflect the actual case in real life.

Figure 2.1 - Henning Smiths vej, Tested Block

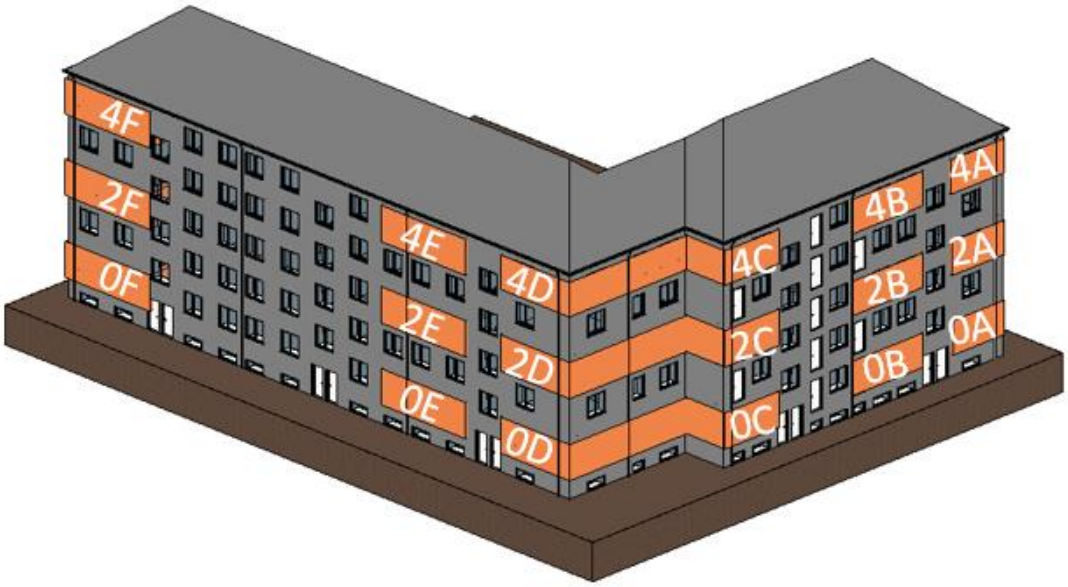

Figure 2.2 - Henning Smith Vej 3D Model

Figure 2.3 - Henning Smiths Vej Ground Floor Plan

2.1.1. IV20 results

Thermal

When analyzing the summer comfort, it was observed that all the apartments located in the 2nd floor are affected by overheating due to window sizes and orientation (S-N) (E-W), and building components. On the south side of the building the rooms that have overheating are the living rooms and bedrooms while on the east side the rooms affected by overheating are the bedrooms and closets.

The thermal comfort during winter for some of the apartments scores maximum (10 points) because the radiators are placed under windows whereas in other cases there is a minimum score of 9 points, because the radiators are not placed on the same walls as the windows (kitchen, living room).

The criteria Falling Draught accounts the condition of the windows to approximate if there are any leakages and if the air is preheated by mechanical ventilation (0). The scores in this category are low because the windows are old, and the quality level is low.

Buildings nowadays are at risk of overheating and especially old buildings where the quality of the windows it is not good and where passive cooling does not have a well-defined strategy. The risk is higher in city centers for multi-residential buildings, where internal solar gains can be more significant.

This problem could be improved by installing proper shading and having an effective ventilation strategy to allow buildings to cool naturally at no cost.

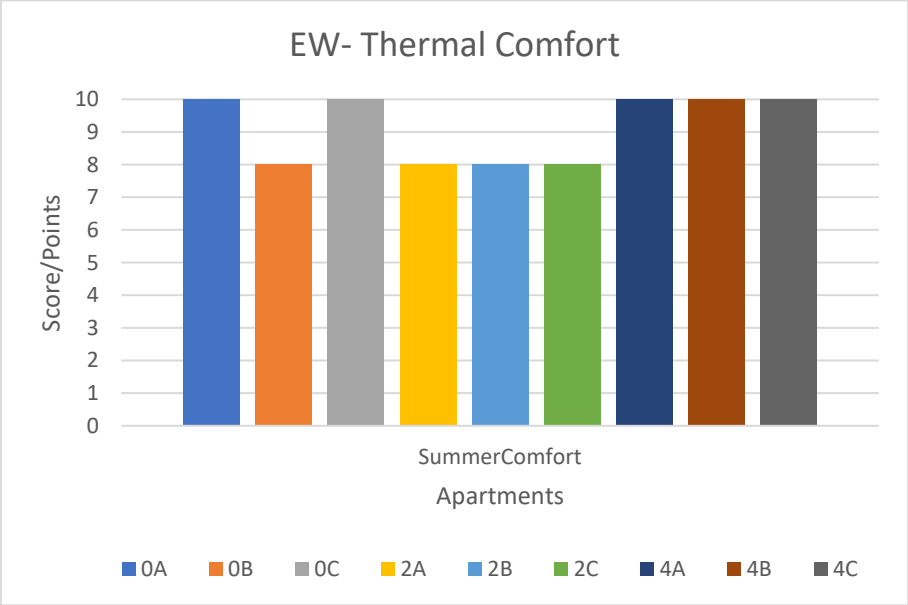

Figure 2.4 - Thermal Comfort Scores, East-West Orientation

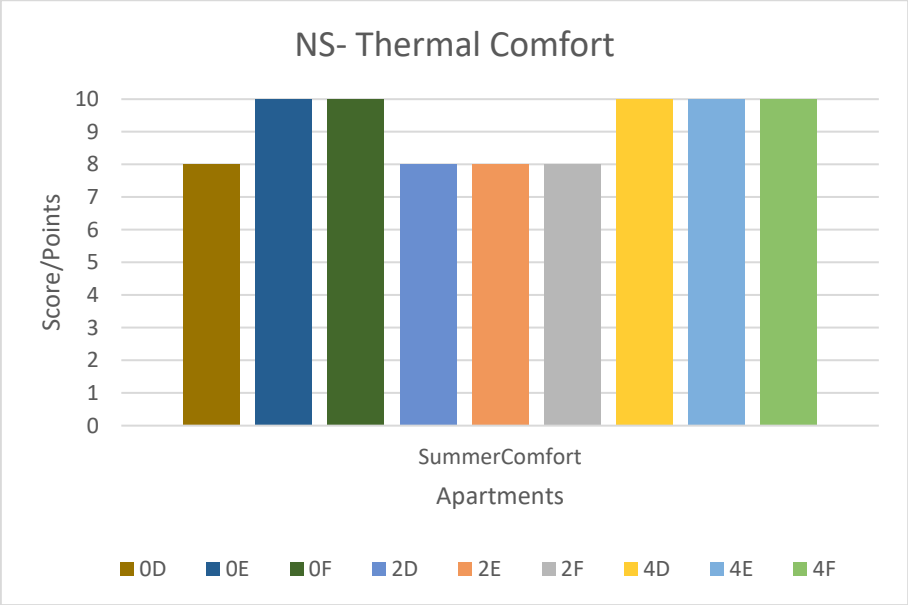

Figure 2.5 - Thermal Comfort Scores, North-South Orientation

Acoustic

The general score is low (E) because the building was erected in 1950, as brick construction and does not have enough insulation, therefore the transmissions of the impact sounds and airborne sounds are high. (2,2 points out of 10). Moreover, the apartments get the highest score for the outside noise (pink noise) which is low since the area where the building is located, it is quiet.

The noise coming from technical installations is also low because the apartments only have mechanical extraction in the bathrooms.

Atmospheric

The atmospheric score for the apartments is 61 out of 100 percent's, due to the fact that the impact from outdoor air, building materials and activities is the same on all of them.

When observing the impact from the outdoor air all the apartments score 4 points out of 10. There is also a low score for the emission from the building and materials, because there is the possibility for cross ventilation but there are no trickle vents in the windows.

For the 3rd category, Activities, the maximum score it is obtained.

Visual

When looking at the visual criteria, the building receives the best score compared to the other categories. After analyzing the scores, it was observed that the intensity and distribution of the daylight is optimal in relation to the location and orientation of the building, as well as the number of hours with sunlight. The only disadvantage in this category comes from the view-out

and view-in. The building is surrounded by other apartment buildings that have the same height, therefore the tenants do not have so enough privacy.(Visual area parameters- VIS 1, VIS 2, VIS 3)

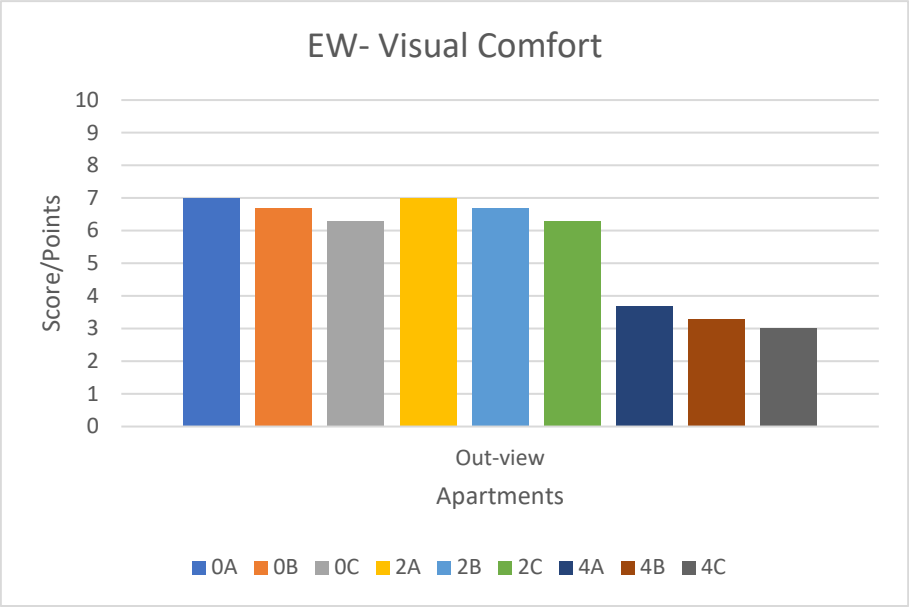

Figure 2.6 - Visual Comfort Scores, East-West Orientation

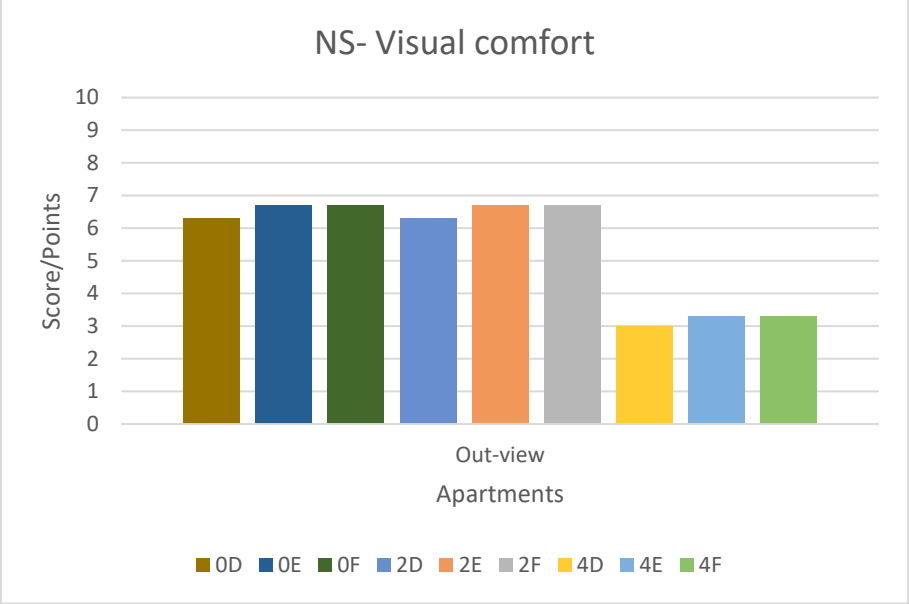

Figure 2.7 - Visual Comfort Scores, North-South Orientation

The tests on Henning Smiths Vej were made using V0, which had a lot of errors. It can be concluded that when looking at the thermal comfort results, some of them are conclusive while in the visual part, the results do not reflect the cases in real life.

2.2. Magisterparken

Afdeling 16 was built in 1963 and consist of 3 or 4 room apartments (70-80 m²). It can be described as a traditional brick construction. In 2012 the buildings have been renovated, including better insulation of the external walls and new windows for all the rooms and balconies.

Registrations were conducted in 2 apartments at Magisterparken (427,2nd floor to the left and 431,ground floor to the left) as showed in Figure 2.8. Other four apartments were artificially tested based on the measurements and investigations done in the first 2. In order to test the apartments assumptions were made with the information obtained during registrations and drawings from Himmerland Boligforening. The constitution of the building components was based on the authors own investigation. The u-values used for terrain deck and roof were taken from Energi Handbog based on the time period the building belongs to (roof-0,25 / floor- 1,3).

The registration was done in 3 steps:

- Measurement of the entire apartment (lengths, widths and heights of rooms)
- Measurements of windows, window sills and doors
- Investigation of the condition of the apartment including components and systems
- Pictures (components and HVAC systems)

Figure 2.8 - Magisterparken, Tested Block, view from South

Figure 2.9 - Magisterparken, Surrounding Buildings

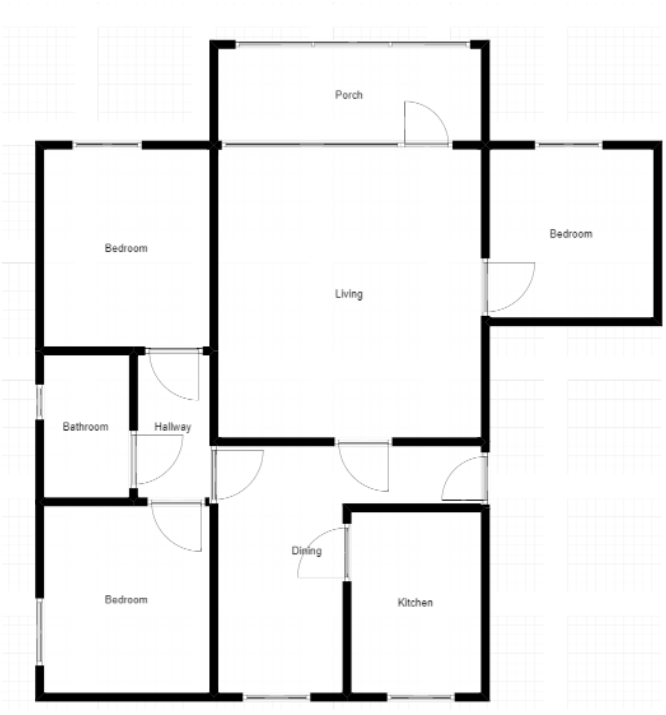

Figure 2.10 - Apartment 431, st.tv.

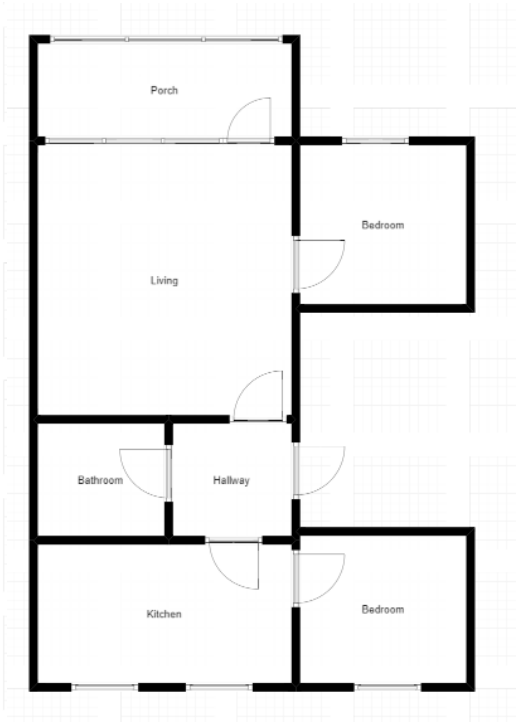

Figure 2.11 - Apartment 427, 2tv

2.2.1. IV20 results

Thermal

When looking at the scores for thermal comfort during summer, it was observed that all tested apartments are affected by overheating. The rooms experiencing overheating in all the cases are the living rooms, which is due to the orientation and window floor ratio, see Table 3.2, page38. The apartments located in the 1st floors score lower for the thermal comfort because the overheating is higher in between floors when compared to the ground floor and 2nd floor. Resembling the ground and top floor, the apartments located in between suffer from overheating because of window sizes and orientation. It must be mentioned that the software doesn't account the transmission losses through the ceiling and terrain deck for the intermediate floors.

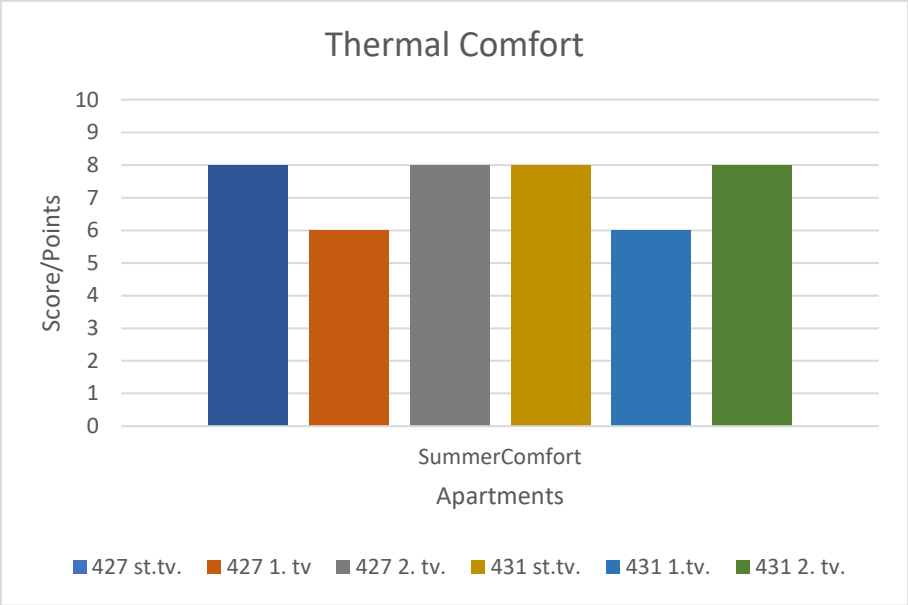

Figure 2.12 - Magisterparken, Thermal Comfort Results

Evaluerings-område	Parametre		Kriterier		Kriterie score		Parameter-score		Område score
	Nr.	0% |--------| 100%	0 |--------| 10	Kriterie vægt	Kriterie sum	Kriterie max	Score	Vægtning	[A - G]
TERMISK	TER1	Temp. sommer			6.0	10	60%	33%	D
			1.1 Beregning: Sommerkomfort		6.0	10			
	TER2	Temp. vinter		2	20.0	20	100%	33%	
			2.1 Overfladetemperatur	1	10.0	10			
			2.2 Varmekilder	1	10.0	10			
	TER3	Træk		3	14.8	30	49%	33%	
			3.1 Utætheder	1	4.8	10			
			3.2 Kuldenedfald	1	10.0	10			0% |--------| 100%
			3.3 Ventilation	1	0.0	10			70%

Figure 2.13 - Apartment 427, 1tv, Thermal Comfort Score

In the case of the thermal comfort during winter, all the apartments score the maximum of 10 points because the radiators are placed under windows.

From the research, it was observed that the condition of the windows in the 2 registered apartments was not the best: not closing evenly and having poor condition weather stripping. The following 4 tests were based on the premises mentioned in the sentence before. The condition of the windows affects the score for the criteria and the overall score for Thermal comfort, together with the Summer Comfort score. Out of a maximum of 10 points, the criteria Air Tightness can only obtain 4,8 points.

Visual

The score for the daylight are different for the apartments located in different sections of the building, Figure 1.17. It was observed for Magisterparken 427 that the score for daylight is rising when moving from ground floor to top floor. Therefore when the altitude is increasing, the quantity of daylight that enters the apartment is increasing. The same trend was observed for the apartments located at Magisterparken 431, except the fact that the score for this address are not so high compared to 427. The section has more shadow from other buildings, thus reducing the score obtained for daylight.

Another difference between these 2 sections is that the apartments on the left side (blue, orange and grey) are 3 rooms apartments and the ones on the right section (yellow, blue and green) have 4 rooms. IV20 tool has a limited room input (max. 4), so in the left case the rooms accounted are both North and South oriented, while the right case has South and East oriented rooms. The scores in real life for both sections should be the same, when all the rooms in the apartments are accounted, including the kitchen (North façade).

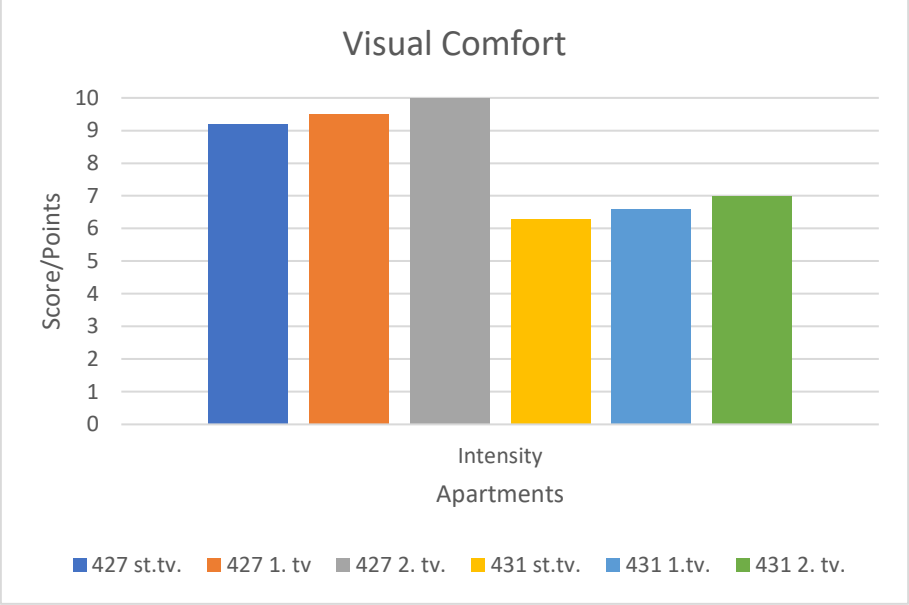

Figure 2.14 - Magisterparken, Visual Comfort Results

The first 3 left columns in the graph represent scores of apartments which has the kitchen in the software. The last 3 columns represent the scores of the apartment without the kitchen because of lack of available space in the software.

VISUEL	VIS1	Dagslys		2.0	6.6	10	66%	50%	D
			1.1 Intensitet og fordeling	1	6.6	10			
			1.2 Kvalitet	1	0.0	0			
	VIS2	Direkte sollys			10.0	10	100%	20%	
			2.1 Solskinstimer		10.0	10			
	VIS3	Udsyn, indkig og afskærmning		0.3	1.5	6	25%	30%	
			3.1 Udsyn	0.15	6.7	30			
			3.2 Indkig	0.1	0.0	10			0% |--------| 100%
			3.3 Afskærmning	0.05	10.0	10			61%

Figure 2.15 - Apartment 431, 2tv, Visual Comfort Score

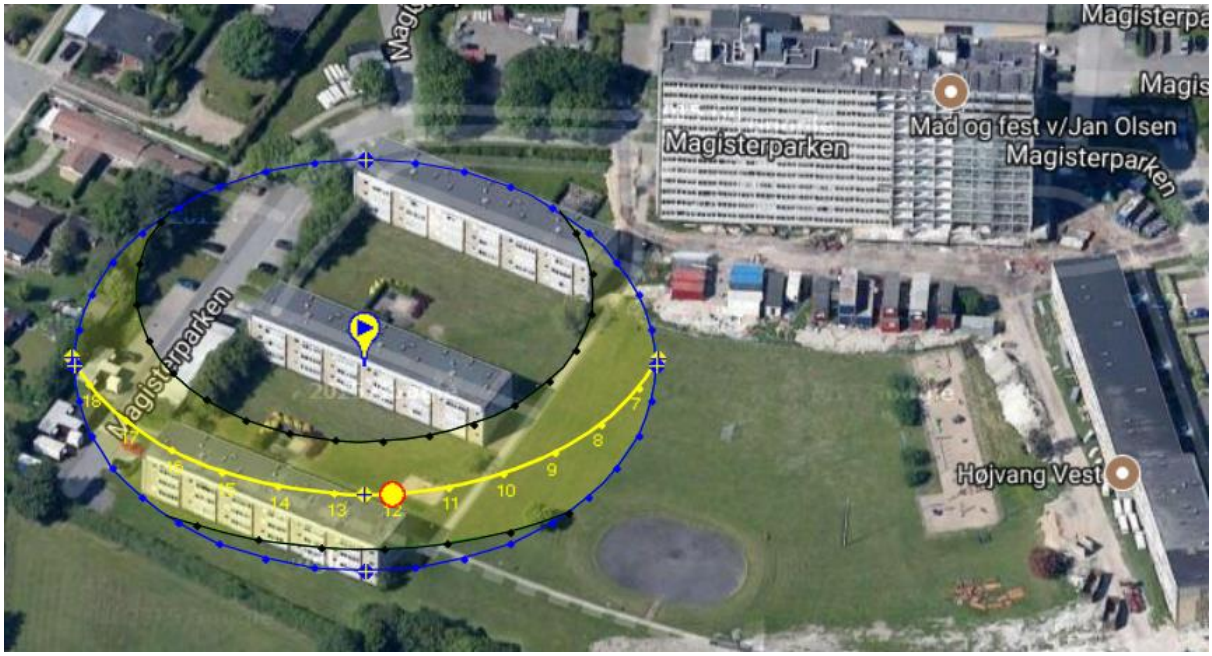

Figure 2.16 - Sun Path at Equinox

As seen in the Figure 2.16, the apartments are in the sun path at equinox, thus obtaining a maximum score for sun hours in IV20 (max.10 points).

The score is changing when looking at the View-Out criteria with 6,7 points for all the apartments, out of 10 maximum point. The building is in a close surrounding of blocks of the same height, as well as another block which is 28m taller.

When analyzing the View-In criteria it was observed that no points are obtained. The buildings surrounding the apartments are very close and have the same height, therefore the tenants do not have enough privacy, unless curtains are used.

Since the building receives maximum amount of Sun Hours (10 points), the same score is obtained also for the Shadows criteria.

2.3. Steen Billes Gade

Afdeling 8 located in Aalborg was built in 1950 and has mostly 2 and 3 rooms apartments of around 73 m2. The building has not been under any major renovation; however, the windows have been changed but the year it is unknown. The building is oriented to East-West and is surrounded by buildings of the same height from all the sides.

Registrations were conducted in 2 apartments at Steen Billens Gade as shown in Figure 2.17 represented as red boxed.

Other 16 apartments (orange boxes) were artificially tested based on the measurements and investigations done in the first 2 apartments. In order to test the apartments assumptions were made based on the registrations and drawings from Himmerland Boligforening.

The registration was done in 3 steps:

- Measurement of the entire apartment (lengths, widths and heights of rooms)
- Measurements of windows, window sill height and doors
- Investigation of the condition of the apartment including components and HVAC systems
- Pictures (components and systems)

Figure 2.17 - Steen Billes Gade, Tested Block

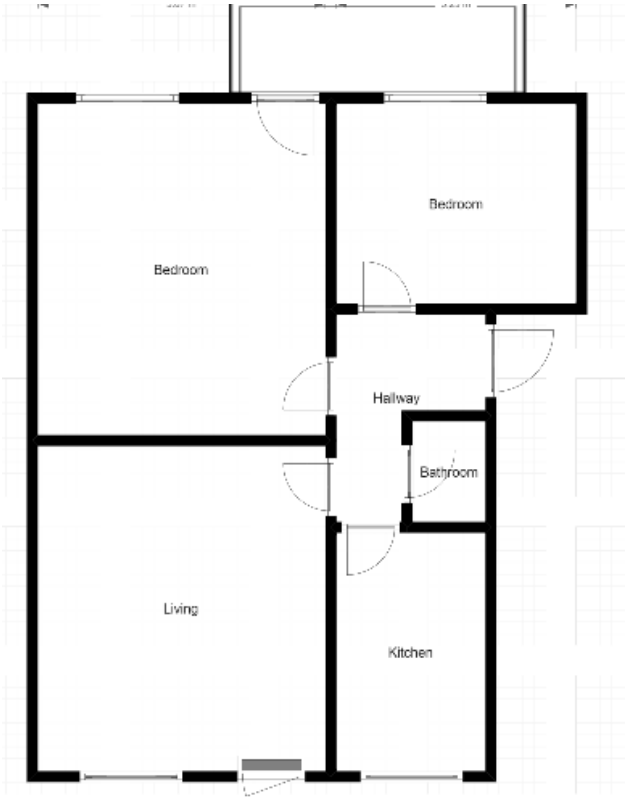

Figure 2.18 - Apartment 22, 1th, Red Box

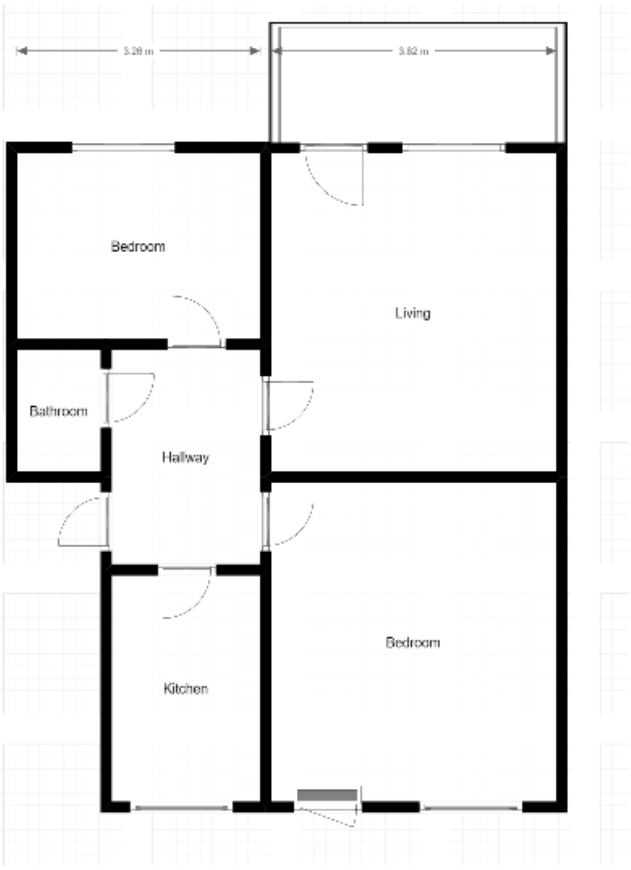

Figure 2.19 - Apartment 22, st.th, Red Box

2.3.1. IV20 Results

Thermal

The Thermal Comfort in IV20 gets the grade C (78% out of 100%). The grading is influenced by scores from the Summer Comfort criteria, Surface temperatures, Radiators criteria, Air tightness criteria and Ventilation Criteria.

Evaluerings-område	*Parametre*		*Kriterier*		*Kriterie score*		*Parameter-score*		*Område score*
	Nr.	*0% |--------| 100%*	*0 |--------| 10*	*Kriterie vægt*	*Kriterie sum*	*Kriterie max*	*Score*	*Vægtning*	*[A - G]*
TERMISK	**TER1**	Temp. sommer			**10.0**	**10**	**100%**	33%	**C**
			1.1 Beregning: Sommerkomfort		10.0	10			
	TER2	Temp. vinter		**2**	**18.3**	**20**	**91%**	33%	
			2.1 Overfladetemperatur	1	10.0	10			
			2.2 Varmekilder	1	8.3	10			
	TER3	Træk		**3**	**14.0**	**30**	**47%**	33%	
			3.1 Utætheder	1	4.0	10			
			3.2 Kuldenedfald	1	10.0	10			*0% |--------| 100%*
			3.3 Ventilation	1	0.0	10			79%

Figure 2.22 - Apartment 22, st.th, Thermal Comfort Score

When looking at the score for thermal comfort during summer it was observed that all the apartments located in the last floor are affected by overheating. Considering that the apartments from the last floor should suffer from a higher transmission loss than the apartments bellow, the scoring from IV20 is surprising in the condition that the orientation of the building is towards East and West (100-285 degrees). The other 2 lower floors get a

maximum score for Summer Comfort. In real life the result might be different because the software does not account the transmission losses through the ceiling and terrain deck for the floors in between the ground and roof. All the results for summer comfort for ground, 1st and 2nd floor are similar. The only difference can be noticed between ground and 3rd floor, therefore they were included bellow.

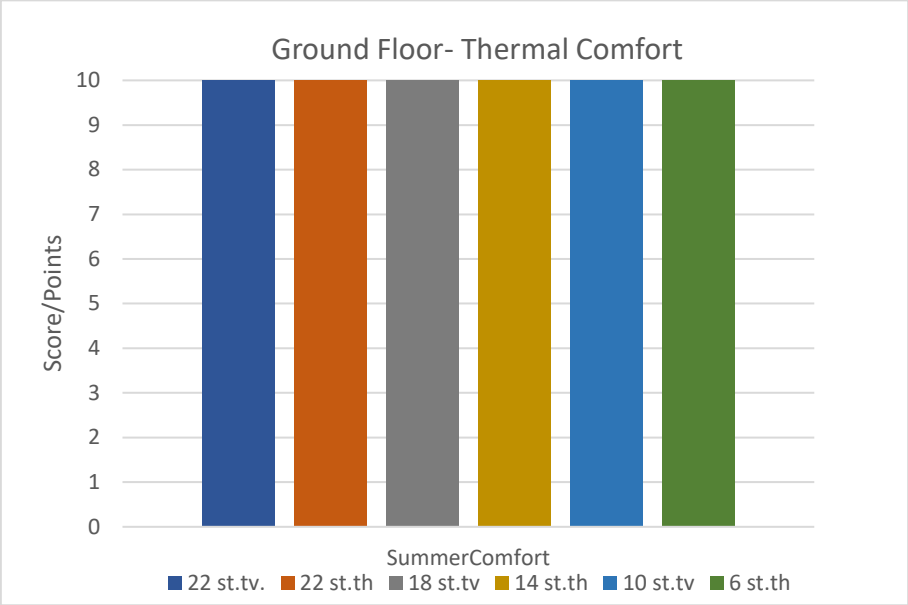

Figure 2.20 - Ground Floor and Second Floor, Thermal Comfort Results

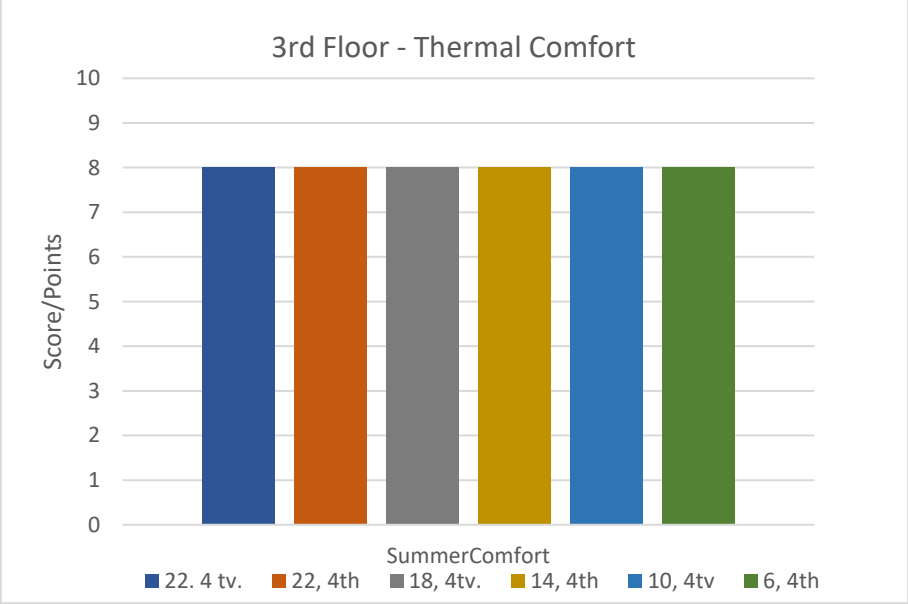

Figure 2.21 - 3rd Floor, Thermal Comfort Results

For the thermal comfort during winter, all apartments score between 8,3 and 10 points, because in some of them all the radiators are placed under the windows and in other cases are placed on opposite walls (kitchens).

It was observed that the condition of the windows in the 2 registered apartments was not the best. The same was assumed for the other artificially tested apartments. The low-quality windows affect the overall evaluation area score as well as the criteria score, Air-tightness. A score between 3,3 and 4 points it is obtained.

No points are obtained for the Ventilation criteria, since there is no heat recovery unit in any of the apartments, which normally would be installed in a ventilation system.

Visual

As mentioned before, the orientation of the building is towards East and West. In the graph bellow can be observed that the apartments in the ground floor have a score between 4 and 6 points for Daylight criteria. As in the Magisterparken case before, the building is in a closed surrounding, with dwellings of the same height which make it a bit difficult to receive the maximum score. The surroundings affect the score for more than one criteria. Beside the amount of daylight received, also the Sun Hours, View-Out, View-In are affected.

VISUEL	VIS1	Dagslys		2.0	5.8	10	58%	50%	D
			1.1 Intensitet og fordeling	1	5.8	10			
			1.2 Kvalitet	1	0.0	0			
	VIS2	Direkte sollys			10.0	10	100%	20%	
			2.1 Solskinstimer		10.0	10			
	VIS3	Udsyn, indkig og afskærmning		0.3	1.5	6	25%	30%	
			3.1 Udsyn	0.15	6.7	30			
			3.2 Indkig	0.1	0.0	10			0% |--------| 100%
			3.3 Afskærmning	0.05	10.0	10			56%

Figure 2.21.1 - Apartment 22,1tv, Visual Comfort Score

Since the orientation is towards East and West, the score for Sun-Hours criteria is between 8,5 and 10 points.

The score is also changing when looking at View-Out criteria, with 6,7 points for all the apartments, and for the View-In with a score of 0 points.

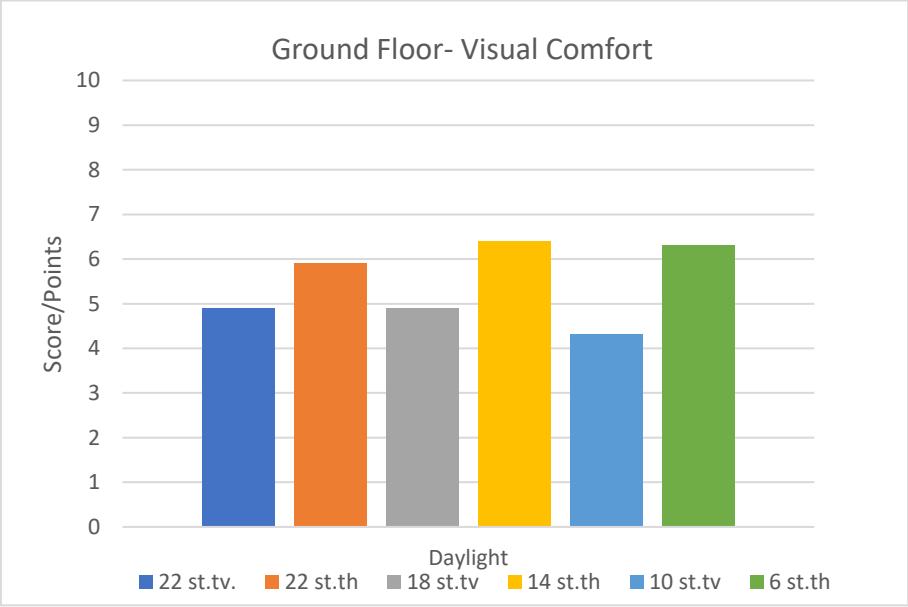

Figure 3.23 - Steen Billes Gade, Ground Floor Visual Comfort Results

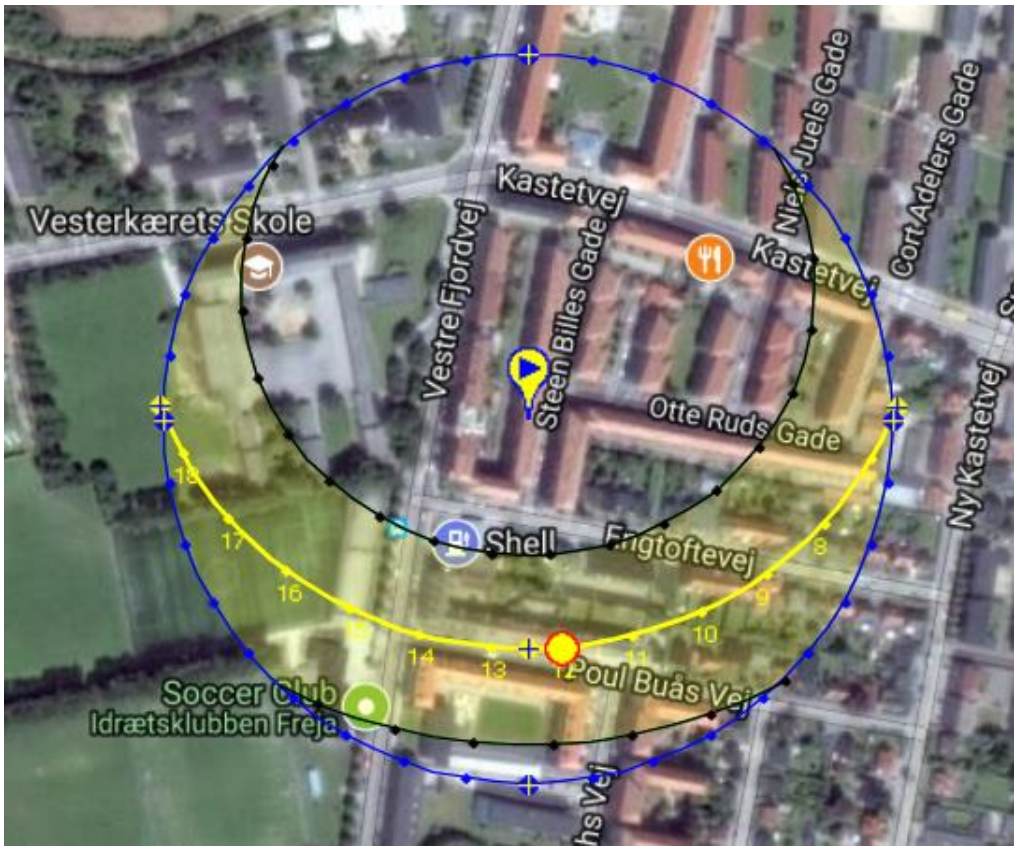

Figure 2.24 - Sun Path at Equinox

When moving from the ground floor apartments to the top floor apartments, it can be seen in the graphs bellow that the score for daylight is rising, so when the height is increasing, the quantity of daylight that enters the apartment is increasing. Once reaching the top floor, the score is between 9-10 points.

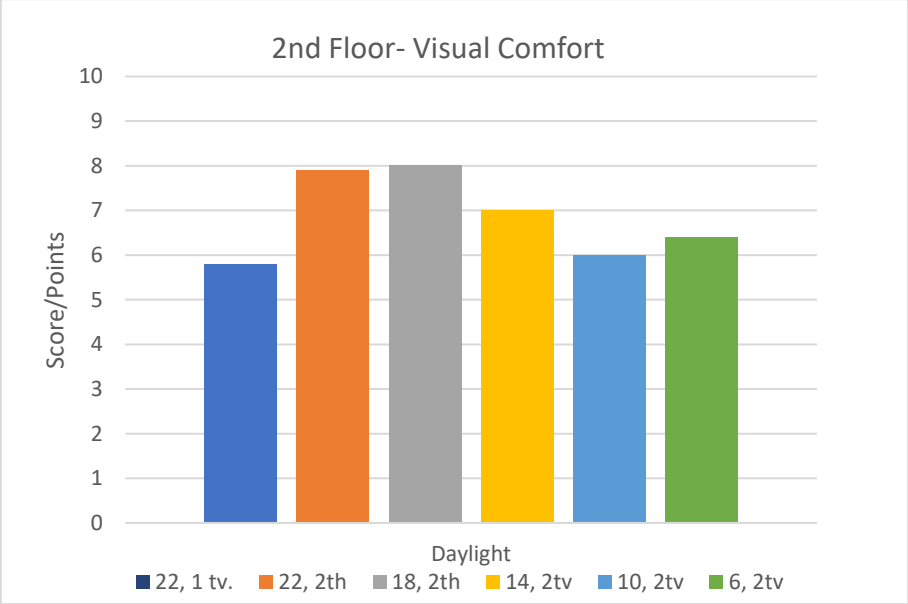

Figure 2.25 - Steen Billes Gade, 2nd Floor, Visual Comfort Results

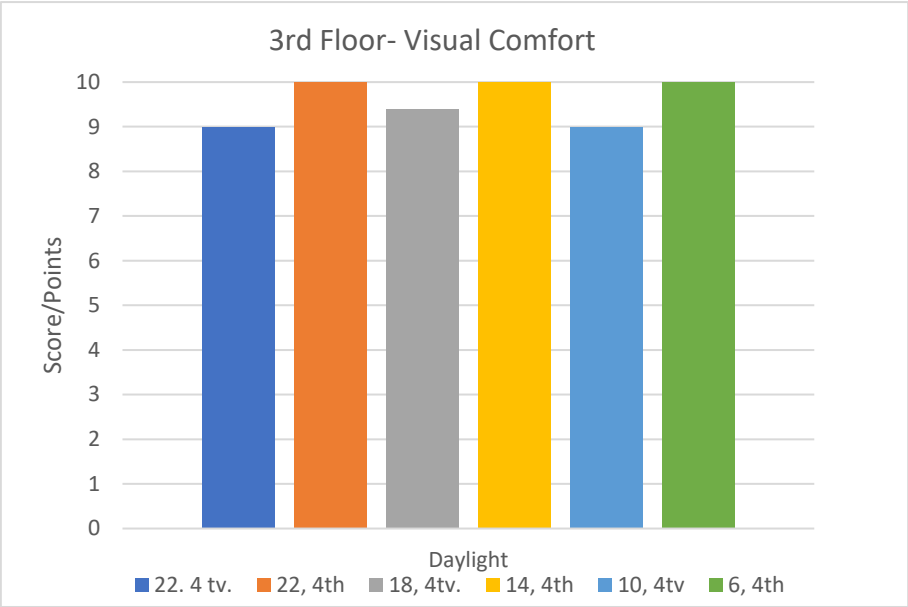

Figure 2.26 - Steen Billes Gade, 3rd Floor, Visual Comfort Results

2.4. Otte Ruds Gade

Otte Ruds Gade is a part of Afdeling 8, together with Steen Billes Gade. It was built in 1950 and has mostly 2 and 3 rooms apartments of around 73 m². The orientation of the building is towards South for living rooms and bedrooms and North for kitchens and bedrooms.

The building has not been under any major renovation; however, the windows have been changed but the year is unknown.

Registrations were conducted in 2 apartments (red Boxes) at Otte Ruds Gade as shown in Figure 2.27, 27, st.tv and 17, 3th. The other 16 apartments (orange boxes) were artificially tested based on the measurements and investigations done in the first 2. In order to test the apartments assumptions were made.

The registration was done in 3 steps:

- Measurement of the entire apartment (lengths, widths and heights of rooms)
- Measurements of windows, window sills and doors
- Investigation of the condition of the apartment including components and HVAC systems
- Pictures (components and systems)

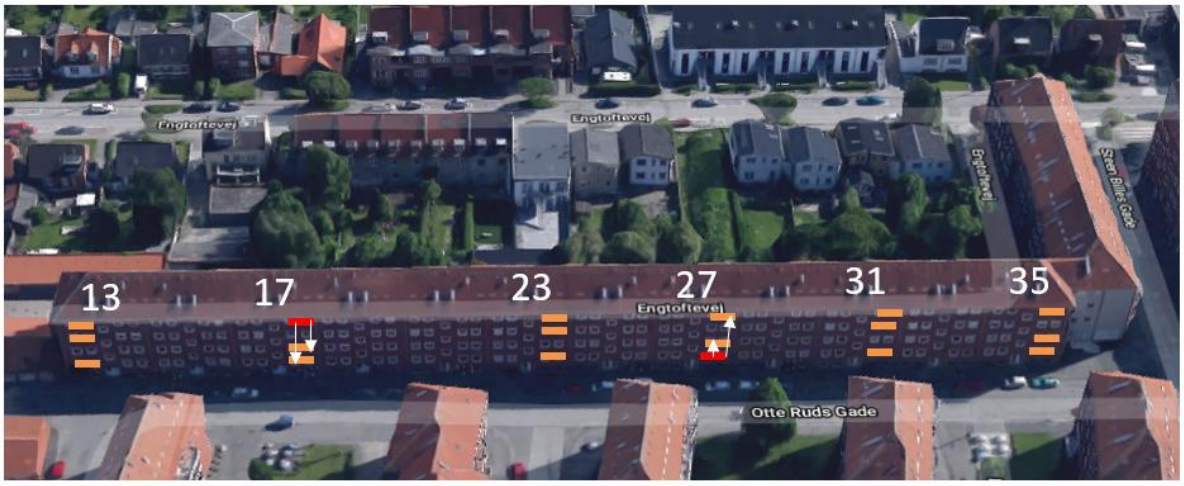

Figure 2.27 - Otte Ruds Gade, Tested Block

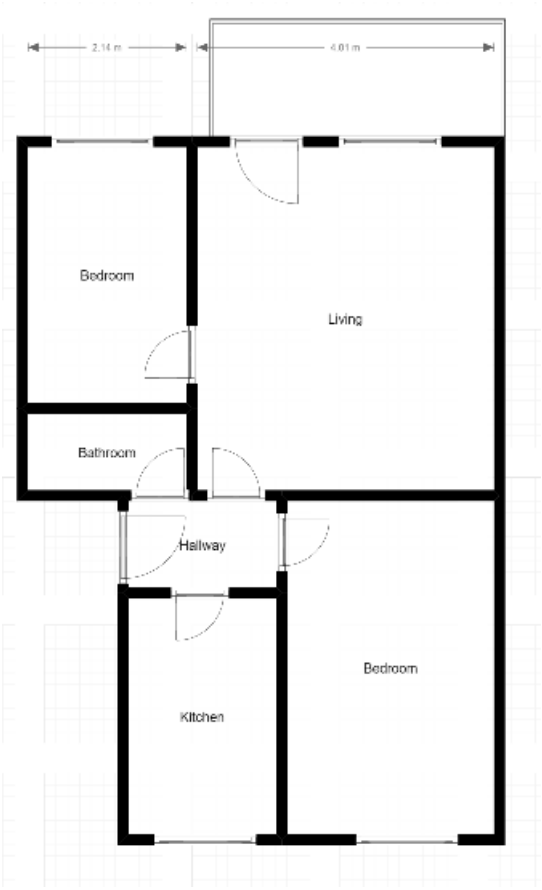

Figure 2.28 - Apartment 27, st.th, Red box

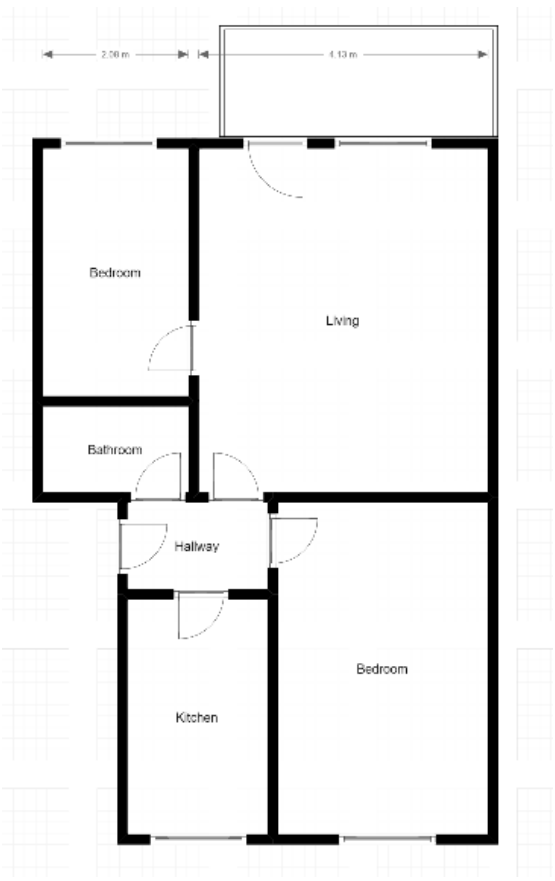

Figure 2.29 - Apartment 17, 3th, Red box

2.4.1. IV20 Results

Thermal

When looking at the score for thermal comfort during summer it was observed that all tested apartments are affected by overheating of more than 100 hours of 26° and obtain the same score of 8 out of 10 maximum points, as showed in Figure 2.30. The building is oriented towards South (living rooms and bedrooms) and towards North (bedrooms and kitchen). The rooms experiencing overheating in all the cases are the living rooms, which is due to the orientation and window sizes.

TERMISK	TER1	Temp. sommer			8.0	10	80%	33%	C
			1.1 Beregning: Sommerkomfort		8.0	10			
	TER2	Temp. vinter		2	18.8	20	94%	33%	
			2.1 Overfladetemperatur	1	10.0	10			
			2.2 Varmekilder	1	8.8	10			
	TER3	Træk		3	13.3	30	44%	33%	
			3.1 Utætheder	1	3.3	10			
			3.2 Kuldenedfald	1	10.0	10			0% |--------| 100%
			3.3 Ventilation	1	0.0	10			73%

Figure 2.28.1 - Apartment 17, 3th, Thermal Comfort Score

For the thermal comfort during winter, all the apartments score 8,8 out of points 10 points because not all the radiators are placed under the windows.

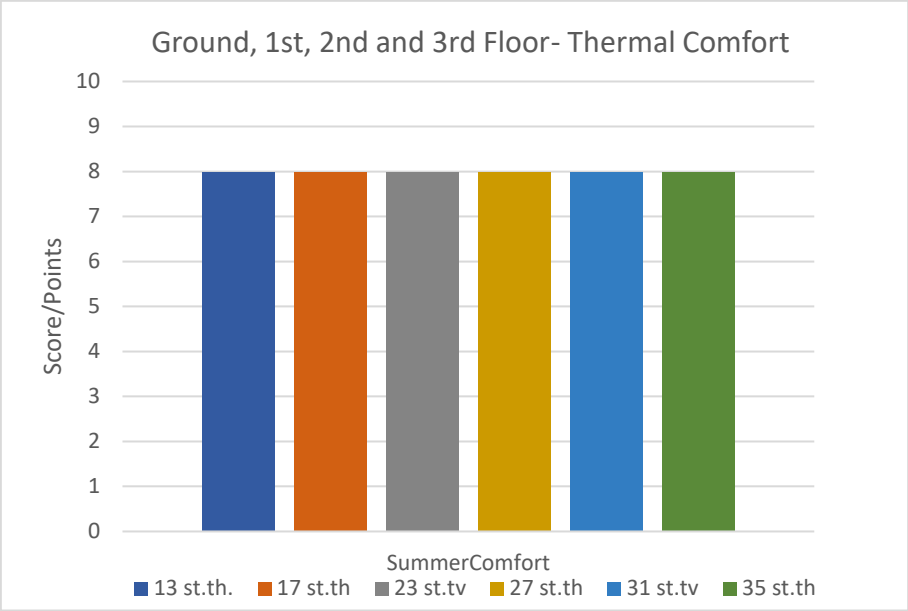

Figure 2.30 - Ground Floor, 1st, 2nd and 3rd Floor, Thermal Comfort Results

When investigated, it was observed that the condition of the windows in the 2 registered apartments were not good. The same conditions for windows were assumed for the rest 16 tests. The condition of the windows affects the score for the Air Tightness criteria and the overall score for Thermal comfort.

Due to a poor condition of the windows the Air Tightness criteria can only obtain between 1 and 3 points.

No points are obtained for the Ventilation criteria, since there is no mechanical ventilation system installed.

The results from the test can be found in APPENDIX D.

Visual

As in the previous cases, one of the lowest score for daylight is in the ground floor. The score is variating between 3 and 9 points. The worst condition is in apartment number 35 and 31, due to the fact that these apartments are the closest to the corner. The grading is improving when moving towards the West, where the neighboring buildings are placed in front and behind.

The apartment in number 27 is the one with the highest score, and this could be because it has an open path perpendicularly, and the buildings situated in front of it on the South side are low.

When analyzing the results for number 13, 17 and 23, it could be observed how they are influenced by the buildings in front.

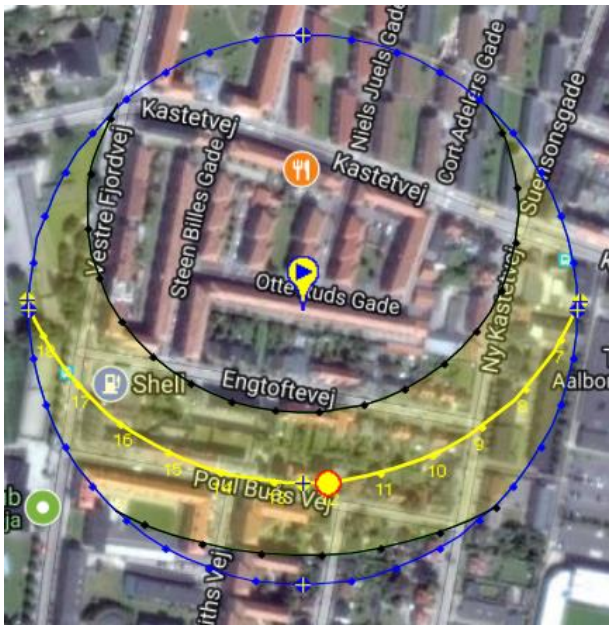

Figure 2.31 - Sun Path at Equinox

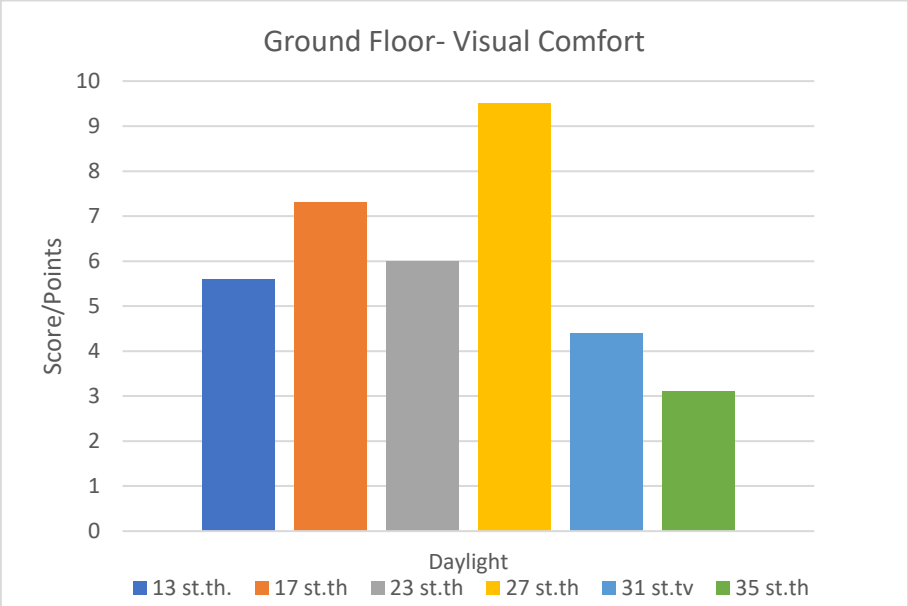

Figure 2.32 - Ground Floor, Visual Comfort Results

VISUEL	VIS1	Dagslys		2.0	8.5	10	85%	50%
			1.1 Intensitet og fordeling	1	8.5	10		
			1.2 Kvalitet	1	0.0	0		
	VIS2	Direkte sollys			10.0	10	100%	20%
			2.1 Solskinstimer		10.0	10		
	VIS3	Udsyn, indkig og afskærmning		0.3	1.6	6	27%	30%
			3.1 Udsyn	0.15	7.0	30		
			3.2 Indkig	0.1	0.9	10		
			3.3 Afskærmning	0.05	10.0	10		

C
0% |--------| 100%
71%

Figure 4.34.1 - Apartment 17,3th, Visual Comfort Score

In the apartments located at the 2nd floor can be observed that the scoring follows the same pattern as the ones in the ground floor. Once the height of the apartments is increasing, the score is also increasing with 0,5 and 1 point.

When moving to the last floor, apartment number 31 and 35 keep the same trend-line as in ground floor and 2nd floor, so the apartments are highly influenced by the corner building regardless of the height.

As a result of South orientation, the Sun-Hours criterion has a maximum score for all the apartments (10 points).

The score is changing when looking at View-Out criteria, with 6,7 points for all the apartments, and for the View-In with a score of 0 points in some cases, and 0,9 in other cases.

When moving from the ground floor apartments to the top floor apartments, it can be seen in the graphs below (Figure 2.33, Figure 2.34) that the score for daylight is rising, so when the height is increasing, the quantity of daylight that enters the apartment is increasing. In the case for the tests from the top floor, the score is between 9-10 points.

Based on the results from the 4 buildings tested it can be concluded, that all apartments facing South suffer from overheating of over 100 hours of 26 degrees and in some cases of over 100 hours of 27 degrees, dependent on the buildings' orientation while in Steen Billes Gade case, where the building is oriented towards East and West the situation is better. The block suffers from overheating only at the last floor apartments, and with no more than over 100 hours with 26 degrees.

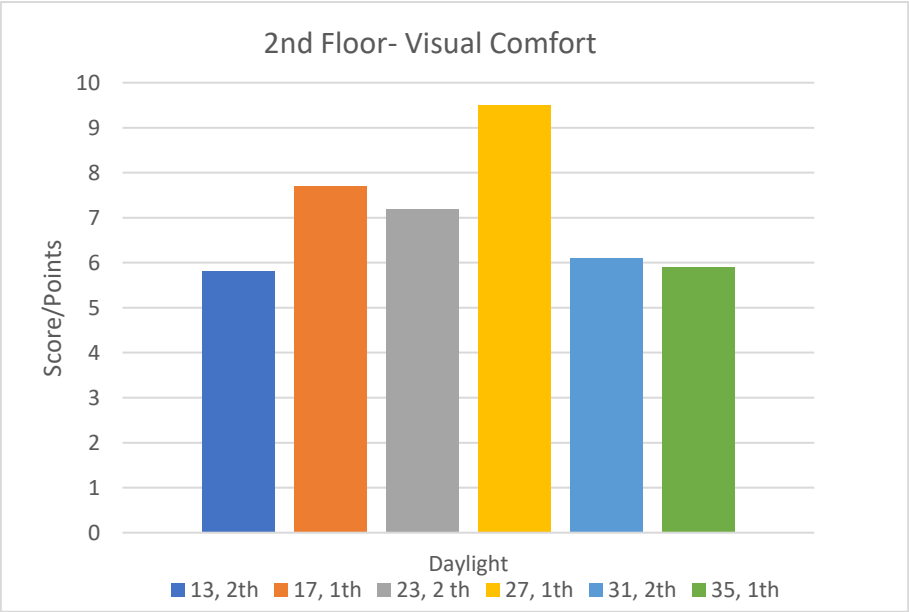

Figure 2.33 - 2nd Floor, Visual Comfort Results

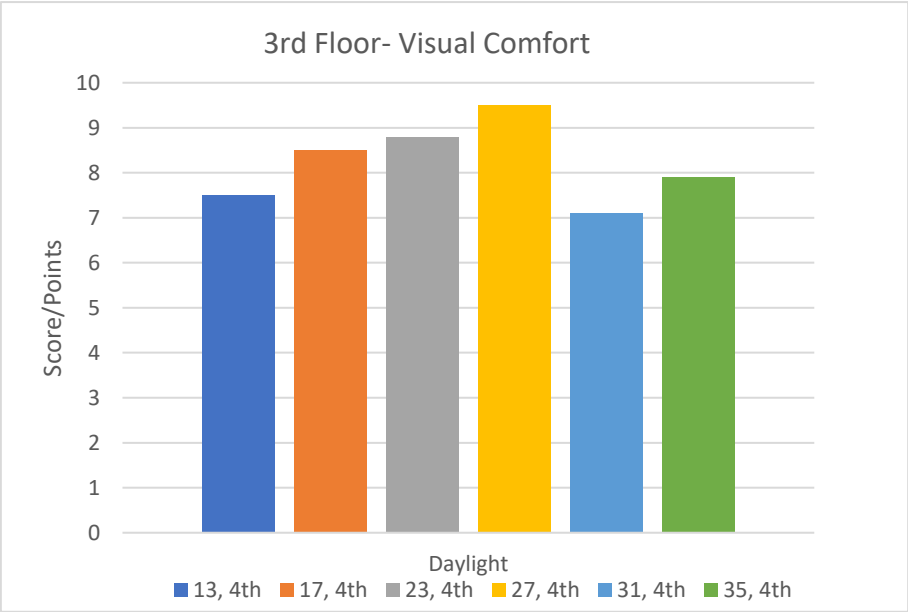

Figure 2.34 - 3rd Floor, Visual Comfort Results

In the Visual Comfort evaluation area, for the cases tested with V1, the score follows a trend line, improving as the height of the apartments increased. It can be concluded that buildings are highly influenced by height of the surrounding building.

Based on the test results from these multistory residential buildings it can be concluded that almost all the apartments suffer from overheating in summer, always dependent on orientation. Two of the buildings are oriented towards South resulting in lower summer comfort for all the tested apartments while the building with East and West orientation, is the closest one into obtaining the highest score for summer comfort, not being affected by overheating in all the apartments.

When looking at the Visual comfort, for all 3 cases, the score follows has a trend line improving as the height of the apartments is increasing. The influence on the score for all the tests is given by the surrounding buildings.

In order to narrow the research, the focus in the next chapter will be on analyzing apartment grading and to see how many apartments are relevant to test in order to get a building label.

3. Apartment and Building Labeling

This chapter is describing how the apartments and buildings tested were chosen based on the condition, orientation and location and how an overall score for the building can be reached starting from apartment scoring.

The first case study tested and analyzed was the 1st semester project building, Henning Smiths Vej. This was the start into getting to know the IV20 tool (V0) and work with it. Due to corrupted test results due to errors in the software it was decided not to be included in the analysis for this chapter. The conclusion will be based only on valid results.

Indoor environment label could provide users with information on the quality and condition of an apartment. Being able to label an apartment as it is nowadays the Energy Label, would be a big step for all home owners, buyers and tenants, it could give a great overview over what people are buying/renting, in regards to what the condition is when looking at thermal comfort, acoustic comfort, atmospheric comfort and visual comfort, and even greater overview for the owners in knowing how can they improve their properties make it more attractive on the market. Needless to say, the impact this would have on inhabitants' health, if people would start focusing more on how can the indoor environment in their homes can be improved.

Comparison labels would allow customers to compare the quality of different apartments over a period into their purchasing decision. The indoor environment label would allow people to understand what is the value of their venues together with the Energy labeling. It is a great initiative to encourage users into paying more attention when investing into a building and also to raise awareness to the impact of indoor environment on health.

The IV20 evaluation tool offers an overall score over an apartment which is marked as a letter as well as score represented in percentage. Moreover, an individual score (both as letter and as percent) for each evaluation area and criteria it is obtained.

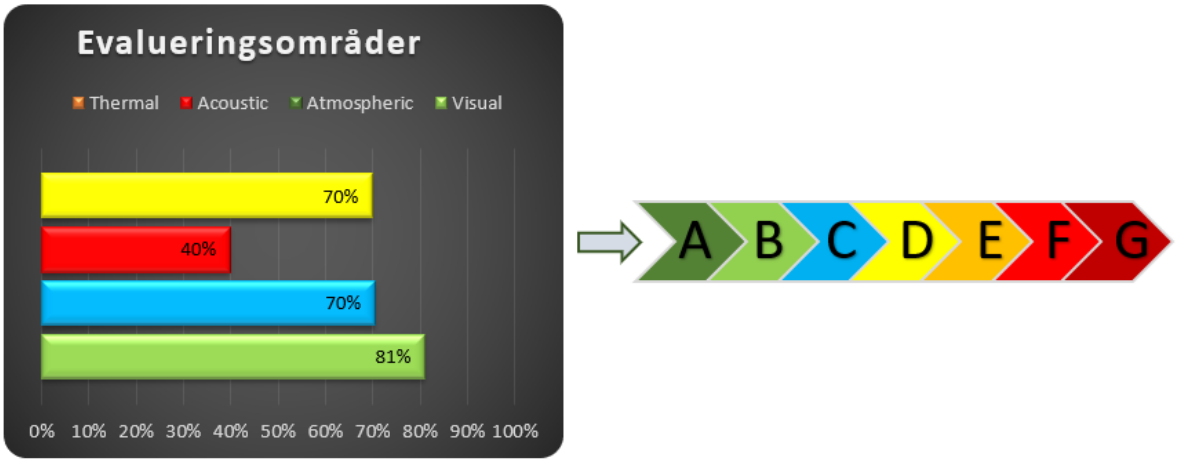

Figure 3.1 - IV20 Scaling

Users understanting

- The choice of label design is of great importance in influencing choices for users where the quality is not the key
- Studies have shown that scales which include letters over numbers are better understood by users
- Scales from A to G offer a good understanding
- Most users are able to correctly identify the weighting of grading and quality of a product
- Understanding of the scale is important to determine users' choices
- Studies made on the Energy Labeling scales showed that scales from A to G lead to better choices compared to scales from A+++ to D
- The choice of label design is of great importance in influencing choices for users where the quality is not the key

When making the Energy Label, a report is received with detailed description and energy consumption for the building envelope and installations, regardless if there is information on the actual energy consumption. The target is that together with the Energy Label, an Indoor Environment label to be made in the same way, offering the users a report on what is the actual condition, how this can be improved and a price estimation.

By analyzing different apartments in a building, the process could go from apartment label to building label if all the important parameters are considered. The table below represents all the criteria and what can be critical in each phase.

	Thermal	**Acoustic**	**Atmospheric**	**Visual**
1	Orientation	Building Envelope	Pollution from outside	Orientation
2	Window Sizes	Internal walls	Pollution from building materials	Windows Sizes
3	Ventilation system	Location/Orientation	Ventilation system	Room Size
4			Type of Stove and Oven	Location
5			Washing and Drying Clothes	Shadows

Table 3.1. - Critical Criteria

3.1. Magisterparken

Magisterparken is part of Afdeling 16 owned by Himmerland Boligforrening. It was one of the first building registered and tested and consists of 3 and 4 rooms apartments, divided on 2 floors.

Registrations were conducted in 2 empty apartments from which, further on, 6 tests were made. For the registration, the apartments were not chosen, but when making the test, both building and apartments have been analyzed to decide which apartment is more exposed and to what, and what is critical when looking at all the evaluation areas (thermal, acoustic, atmospheric and visual) and criteria.

Figure 3.2 - Magisterparken, Tested Block

Initially the registered apartments were in the last block which had the living room view to the green spaces, but later on it was decided to switch to the middle block, to see what is the impact on the visual evaluation area when the building is facing another block from both North and South side, assuming that the condition and plans are the same as in last block.

Apartment Number	Room Name	Room Size m²	Window Size m²	Orientation
Apartment 427, 2 tv	Living Room	20,3	4,92	S – 210
	Bedroom 1	7,2	1,31	S – 210
	Bedroom 2	7,8	1,31	N – 30
	Kitchen	10,4	2,62	N – 30
Apartment 431, st.tv	Living Room	22	4,9	S – 210
	Bedroom 1	9,4	1,31	S – 210
	Bedroom 2	8	1,31	S – 210
	Bedroom 3	8,9	1,39	E – 120

Table 3.2 - Registration Overview, Apartments Sizes and Orientation

Thermal

When looking at the thermal comfort for apartment 427, 2tv, the critical part can come from the orientation of the building, the sizes and quality of the windows, and lack of a ventilation system. The orientation in this case is towards South for the living room and bedroom 1, which due to windows sizes gives overheating during summer and affecting the thermal comfort score, and towards North for bedroom 2 and kitchen which might make the rooms not warm enough.

The same applies for apartment 431, but in this case, IV20 can only account 4 rooms, so the kitchen which has North orientation is missing from the table and analysis.

When the orientation of the building is towards South, it is important to test the apartments that has rooms on that side, especially if it is a living room with big windows with a risk of overheating.

The registered apartments do not score more than C, and D due to overheating problems and poor quality of windows.

Figure 3.3 - Living Room Windows

Figure 3.4 - Bedroom 1 Windows

Acoustic

Another important aspect that can be critical, is the Acoustic Comfort. In this case the quality and thickness of the building envelope is very important. If external and internal walls are too thin the inhabitants can easily be bothered by noise coming from outside or from the neighboring apartments.

The location of the building also plays an important role, where a block located in a highly populated urban area can have problems with the noise coming from outside, while a block located in a rural area can get almost maximum score.

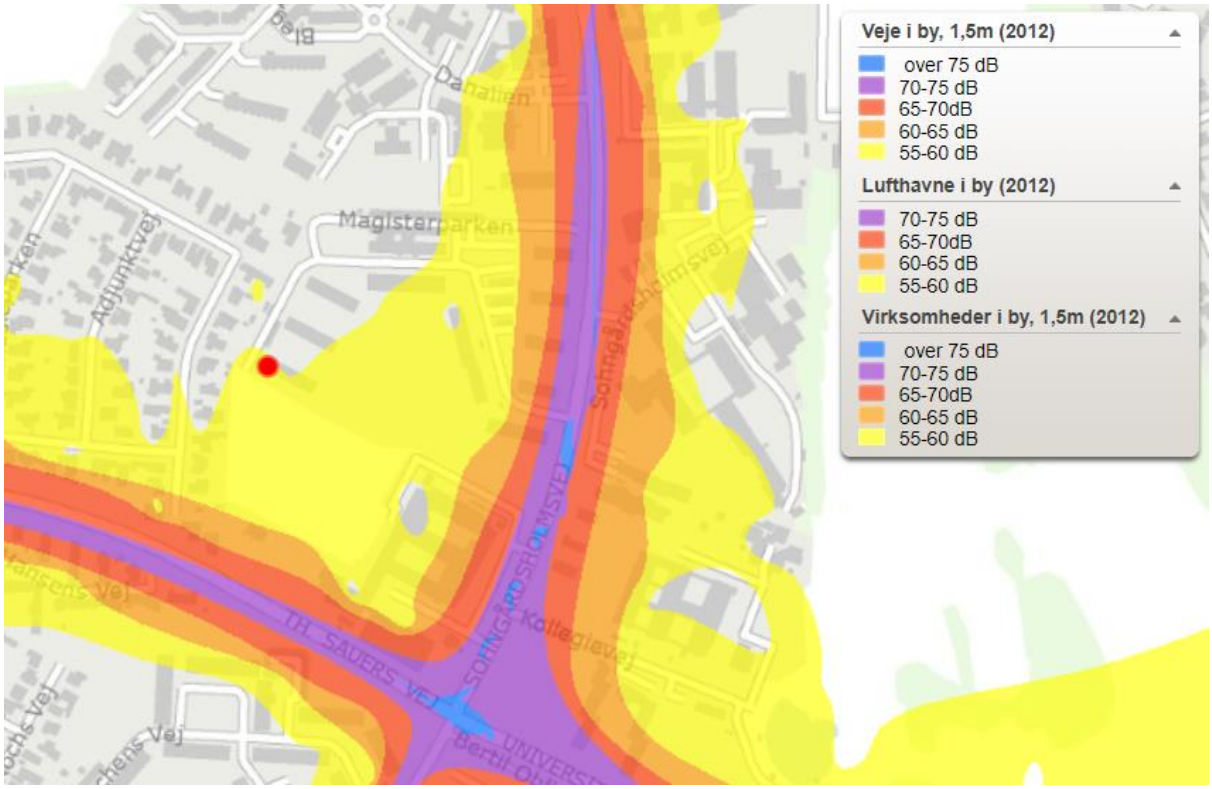

Figure 3.5 - Acoustic Map

Both apartments score between 35 and 40 point (F), due to traffic noise (60 dB), and poor building components.

Atmospheric

When looking at Atmospheric Comfort, independent from user behavior or choices, location and orientation is an important aspect of this category. Living in a high polluted area, can make a difference when looking at the score. Another important part is the building materials which can release a certain amount of pollution if the building is less than 2 years old, or renovation took place less than 2 years ago.

Users can also have an impact on indoor environment regarding atmospheric comfort, when choosing the power source for their stove and oven, where a gas stove or oven can have a higher impact on comfort compared to the electrical ones, or when choosing the way to wash and dry clothes.

In the Magisterparken case, the score for Atmospheric comfort is 70 (C), being influenced by the lack of a ventilation system.

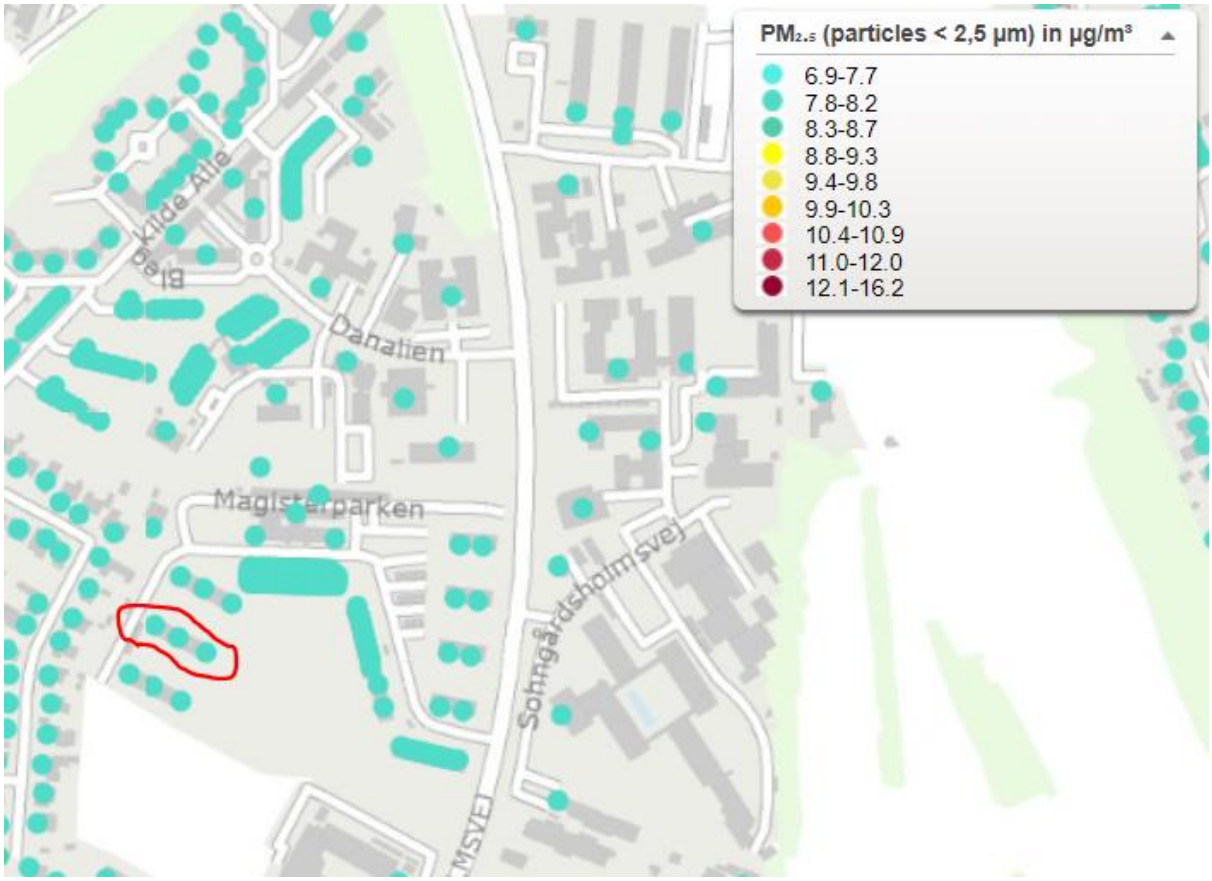

Figure 3.6 - Pollution Concentration Map

Visual

Similar to Thermal comfort, when looking at Visual comfort, orientation plays an important role. The amount and quality of daylight received by the rooms is tightly connected to whether the building is South or North oriented and can influence the score. The distance and height of neighboring buildings is also important, because they can block the light. The same condition applies for shadows.

The results for the 2 registered apartments are different, due to the limited number of rooms the tool has. In the left case apartment (427, st.tv.) the rooms accounted are both North and South oriented, while the right case has South and East oriented rooms. In real life the scores for both sections should be the same, when all the rooms in the apartments are accounted, including the kitchen (North façade). Being conditioned by the software, number 427 scores 81 points while 431 scores only 59 points.

Based on the registered apartments and on the analyzed criteria it was decided to artificially test the apartment on the ground floor and 1st floor located on the same section as the one in the 2nd floor. The floor plans, sizes and windows do not change when moving from one floor to another. The difference is given in the case of Thermal Comfort, by the IV20 tool, which does not account the transmission losses through ceiling and floor.

Another difference was noticed for the visual part, where the height of the apartments and surrounding building has an impact.

For Magisterparken 6 apartments out of 18 have been tested. During the selection and testing it was concluded that all critical parts have been covered, whereas 3 apartments (431) located on the corner are influenced by the building envelope and the other 3 in number 427 cover for building envelope, center section of the building and different heights.

Based on the results for Atmospheric Comfort, it was observed that nothing is changing from apartment to apartment, since the conditions are the same.

After looking at the acoustic part, it can be concluded that the apartments located in the center of the building score better than the ones locate on the corner, due to a lower number of square meters on the external side.

Apartment	Thermal	Acoustic	Atmospheric	Visual	Total
427, st.tv	C-77	F-40	C-70	C-72	C-65
427, 1tv	D-70	F-40	C-70	C-75	C-64
427, 2tv	**D-70**	**F-40**	**C-70**	**B-81**	**C-65**
431, st.tv	**C-76**	**F-35**	**C-70**	**D-59**	**C-66**
431, 1tv	D-70	F-35	C-70	D-61	C-59
431, 2tv	C-76	F-35	C-70	D-63	C-61
Average	**C-73,1**	**F-37,5**	**C-70**	**C-68,5**	**C-63,3**

Table 3.3 – Magisterparken, Overall Score

The best choice in labeling a building would be to test all the apartments, but due to lack of time this must be narrowed to what is believed and proven to be critical for the 4 parameters. Magisterparken comprises 18 apartments, out of which 6 have been tested based on 2 registrations and other assumptions. From the 6 results a conclusion can be drawn, where the overall building label is C.

3.2. Steen Billes Gade

Steen Billes Gade is part of Afdeling 8 owned by Himmerland Boligforrening, consists of 2 and 3 rooms apartments in 3 floors building. The orientation is E-W.

Registrations were conducted in 2 empty apartments from which, further on, 16 tests were made. For the registration, the apartments were not chosen, but when making the test, both building and apartments have been analyzed to decide which apartment is more exposed and what is critical when looking at all the evaluation areas (thermal, acoustic, atmospheric and visual) and sub-criteria.

Figure 3.7 - Steen Billes Gade, Tested Block

Apartment Number	Room Name	Room Size m²	Window Size m²	Orientation
Steen Billes Gade 22, st.th.	Living Room	16,1	3,75	W – 280
	Bedroom 1	8	1,92	W – 280
	Bedroom 2	16,1	3,75	E – 100
	Kitchen	6	1,92	E – 100
Steen Billes Gade 22, 1tv	Living Room	17	3,75	E – 100
	Bedroom 1	17,3	3,75	W – 280
	Bedroom 2	8,7	1,92	W – 280
	Kitchen	6,5	1,92	E – 100

Table 3.4 Registration Overview, Apartment Sizes and Orientation

As in the previous case, the critical part for Thermal Comfort can be due to building orientation, sizes and quality of the windows and lack of ventilation system. The orientation of the building is towards East and West. Unlike from Magisterparken case, overheating does not happen in between floors, but only at the last floor, which faces the roof. Even though the window quality is not the best, the apartments can still obtain a good score, this happening in the condition where summer comfort weights more in the scaling than Air Tightness.

Acoustic

As mentioned before, the quality of the building envelope and the location of block is very important. The test results showed a score of 38 points (F), which comes from the poor quality of the envelope that dates from 1950.

It can be observed in the picture below that the building is located in a quiet area, not reaching an outside noise level over 60 dB.

Also from the author's experience, it can be acknowledged that the area where Steen Billes Gade is located, is very quiet.

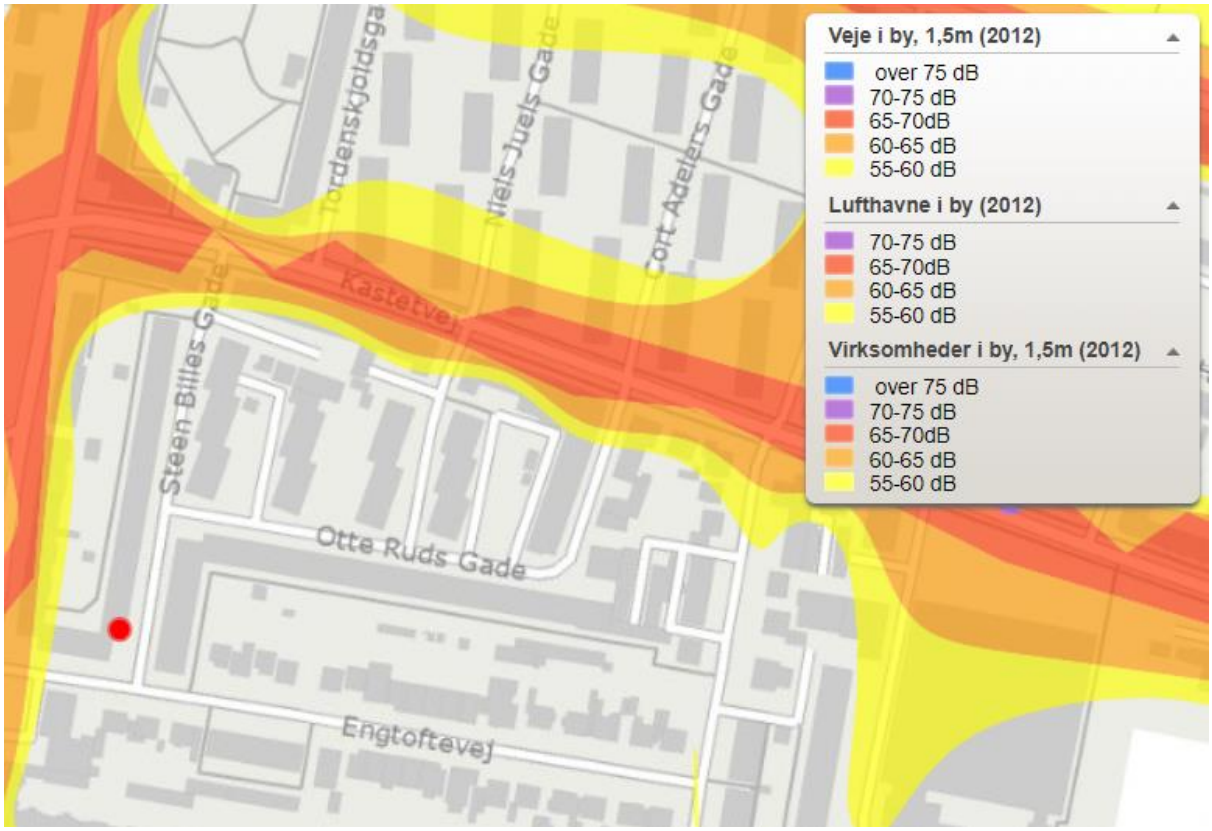

Figure 3.8 - Acoustic Map

Atmospheric

The block has not been under any major renovation. Windows were changed, but the year is unknown. Building materials can have a big impact on atmospheric comfort since they can release a certain amount of pollution, up to 2 years from installation.

In this case, the low score D (56-67) comes from the lack of a ventilation system and outside pollution.

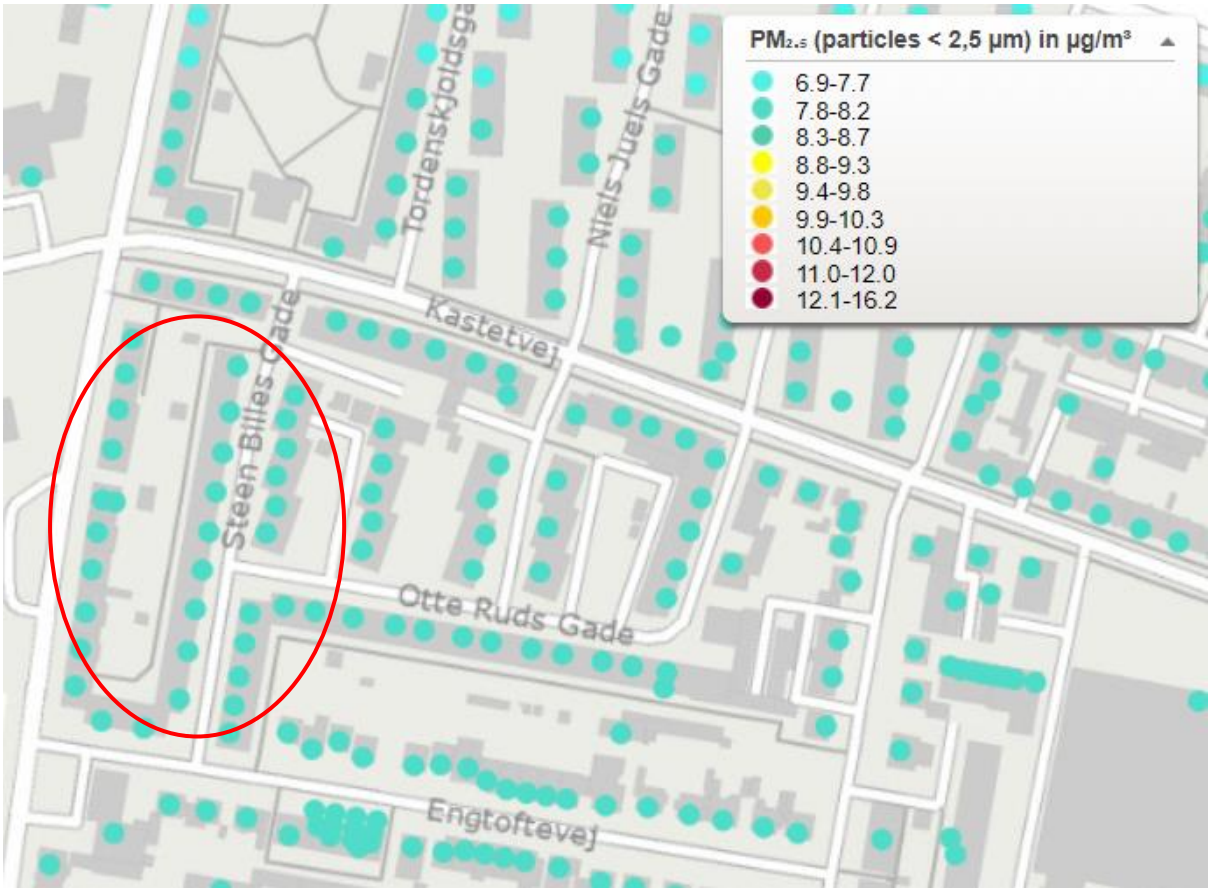

Figure 3.9 - Pollution Concentration Map

Visual

Visual comfort is strictly dependent on orientation by the quality and quantity of daylight and sun hours. In the 2 registrations the results were not so different, however some changes could be observed when artificially testing the ground floor apartment 22, st.tv. When comparing it with the apartment 22, st.th. it can be easily observed how neighboring blocks can impact the surrounding buildings through height and distance.

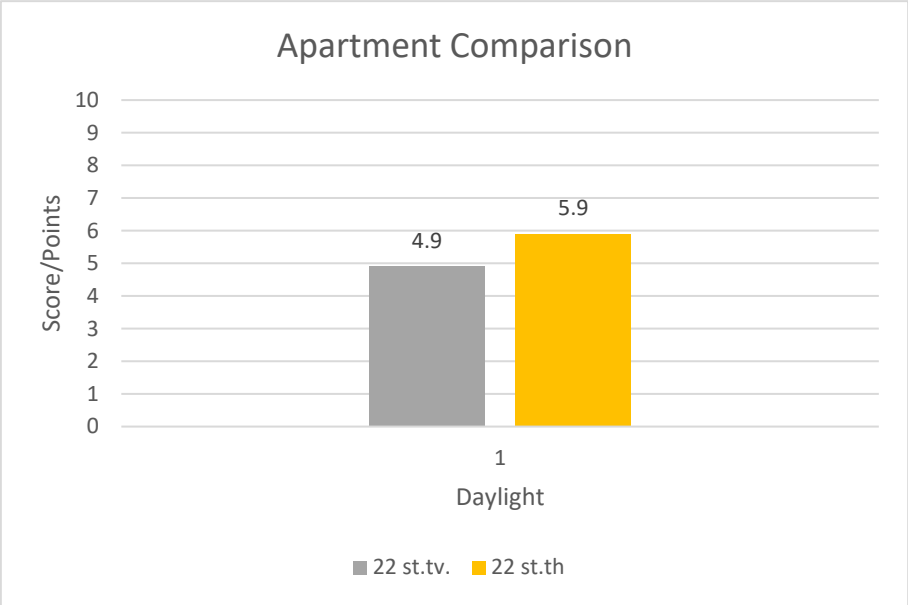

Figure 3.10 - Apartment Comparison, 22, st.tv and 22, st.th

Based on the 2 registrations and analyzed parameters it was decided to artificially test 2 apartments in the ground floor at each corner, to see the impact of the building envelope, and another 3 apartments located in the center of the building to conclude the influence terrain deck can have.

The same as in the ground floor, also in the 2nd floor 5 apartments were tested, under the same condition. The only difference when moving to 2nd floor comes from the software, which does not account for transmission losses through ceiling and floor.

For the last floor, 6 apartments have been tested simulating the conditions for corners, center section of the building top floor in relation to the building envelope.

From the test results it was observed that the building envelope does not have a big impact on the ground floor and 2nd floor, but it is influencing the last floor which should suffer from higher transmission loss than the apartments bellow. The score comes as an interesting fact in the condition that the orientation of the building is mainly towards East and West.

The Visual Comfort score is changing from floor to floor, improving as the height of the apartments increases.

- Ground Floor **E**
- 2nd Floor **D**
- 3rd Floor **C**

Apartment	Thermal	Acoustic	Atmospheric	Visual	Total
22, st.tv	B-81	F-38	D-67	E-52	C-59
22, st.th	**B-81**	**F-38**	**D-56**	**E-54**	**C-57**
18, st.tv	B-81	F-38	D-67	E-52	C-59
14, st.th	B-81	F-38	D-56	E-50	C-56
10, st.tv	B-81	F-38	D-67	E-46	C-59
06, st.th	B-81	F-38	D-56	D-58	C-58
22, 1tv	**B-81**	**F-38**	**D-67**	**D-56**	**C-60**
22, 2th	B-81	F-38	D-56	D-64	C-58
18, 2th	B-81	F-38	D-56	D-67	C-58
14, 2tv	B-81	F-38	D-67	D-60	C-61
10, 2th	B-81	F-38	D-67	E-54	C-60
6, 2tv	B-81	F-38	D-56	D-60	C-58
22, 4tv	C-73	F-38	D-56	C-77	C-61
22, 4th	C-73	F-38	D-56	C-77	C-61
18, 4tv	C-75	F-38	D-67	C-74	C-63
14, 14	C-73	F-38	D-56	D-58	C-56
10, 4tv	C-75	F-38	D-67	C-72	C-63
6, 4th	C-73	F-38	D-56	C-78	C-61
Average	**C-78**	**F-38**	**D-60**	**D-61**	**C-59**

Table 3.5 - Steen Billes Gade, Overall Score

Steen Billes Gade consists of 72 apartments, but due to limited amount of time 18 test have been made simulating all the critical conditions based on 2 registrations, investigations and assumption.

The table above shows the total score for each evaluation area and the overall score for the building. Even though the construction is old, without any major improvements, the score for Thermal Comfort is good, leading to an overall building label C.

3.3. Otte Ruds Gade

Otte Ruds Gade is part of Afdeling 8 owned by Himmerland Boligforrening, consists of 2 and 3 rooms apartments divided on 3 floors.

Registrations were conducted in 2 empty apartments (27 st.th, 17 3th) from which, further on, 18 tests were made. For the registration, the apartments were not chosen, but when making the test, both building and apartments have been analyzed to decide which apartment is more exposed and what is critical when looking at all the evaluation areas (thermal, acoustic, atmospheric and visual) and criteria.

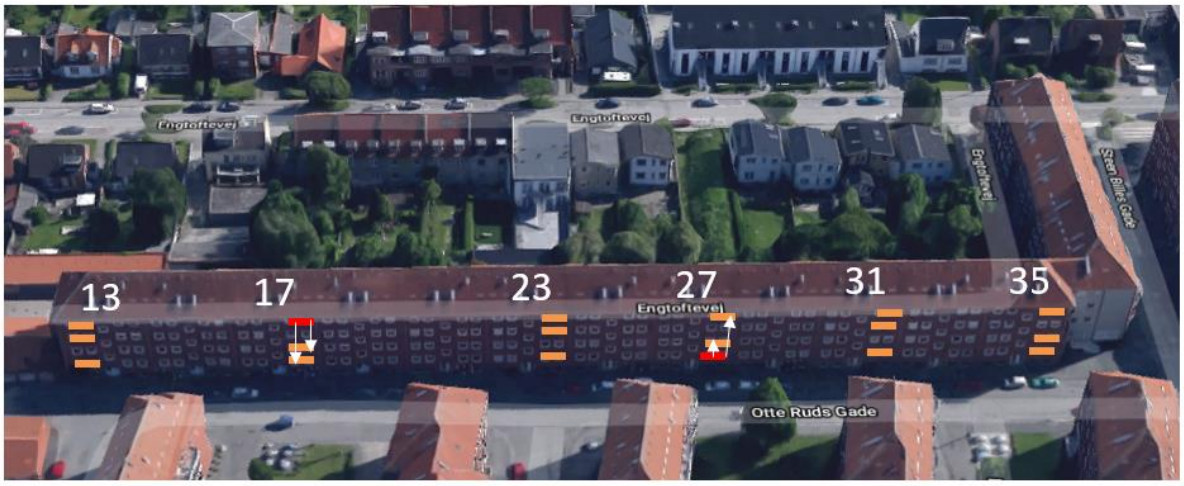

Figure 3.11 – Otte Ruds Gade, Tested Block

Apartment Number	Room Name	Room Size m²	Window Size m²	Orientation
Apartment 27, st.th	Living Room	18,6	3,75	S – 185
	Bedroom 1	7,4	1,92	S – 185
	Bedroom 2	12,6	1,92	N – 5
	Kitchen	10,4	1,92	N – 5
Apartment 17, 3th	Living Room	20,3	3,75	S – 190
	Bedroom 1	7,4	1,92	S – 190
	Bedroom 2	14,2	1,92	N – 10
	Kitchen	6,7	1,92	N – 10

Table 3.6 - Registration Overview, Apartment Sizes and Orientation

After making the test for the 2 registered apartments it was observed that the score (C) is given by the building orientation, sizes of the windows and lack of ventilation system. The orientation of the building is towards South and North, creating overheating problems in all the floors.

Acoustic

The critical part when looking at the acoustic comfort is the quality of the building envelope, location of the building, as well as orientation. In this case Otte Ruds Gade is not in the vicinity of any main street, as it can be seen in the figure below. Resembling Steen Billes Gade case, the score obtained is low (F) due to low quality construction of external and internal walls dating from 1950.

It can be observed in the picture bellow that the building is located in a quiet area, not reaching an outside noise level over 60 dB.

Figure 3.12 - Acoustic Map

Atmospheric

For Atmospheric Comfort orientation and location can be critical, aswell as building materials. Otte Ruds Gade is situated in a low polluted area, and have not undergone any renovation in the past 5-10 years, therefore there is a small risk of pollution from the upper mentioned categories.

During the registrations it was noticed that one of the apartments had a gas stove and oven instead of the electrical one. This is one of the aspects that influence the score, together with the lack of a ventilation system. The apartment with electrical stove scored 64 in terms of atmospheric comfort, and the other apartment with the gas connection scored 57 points.

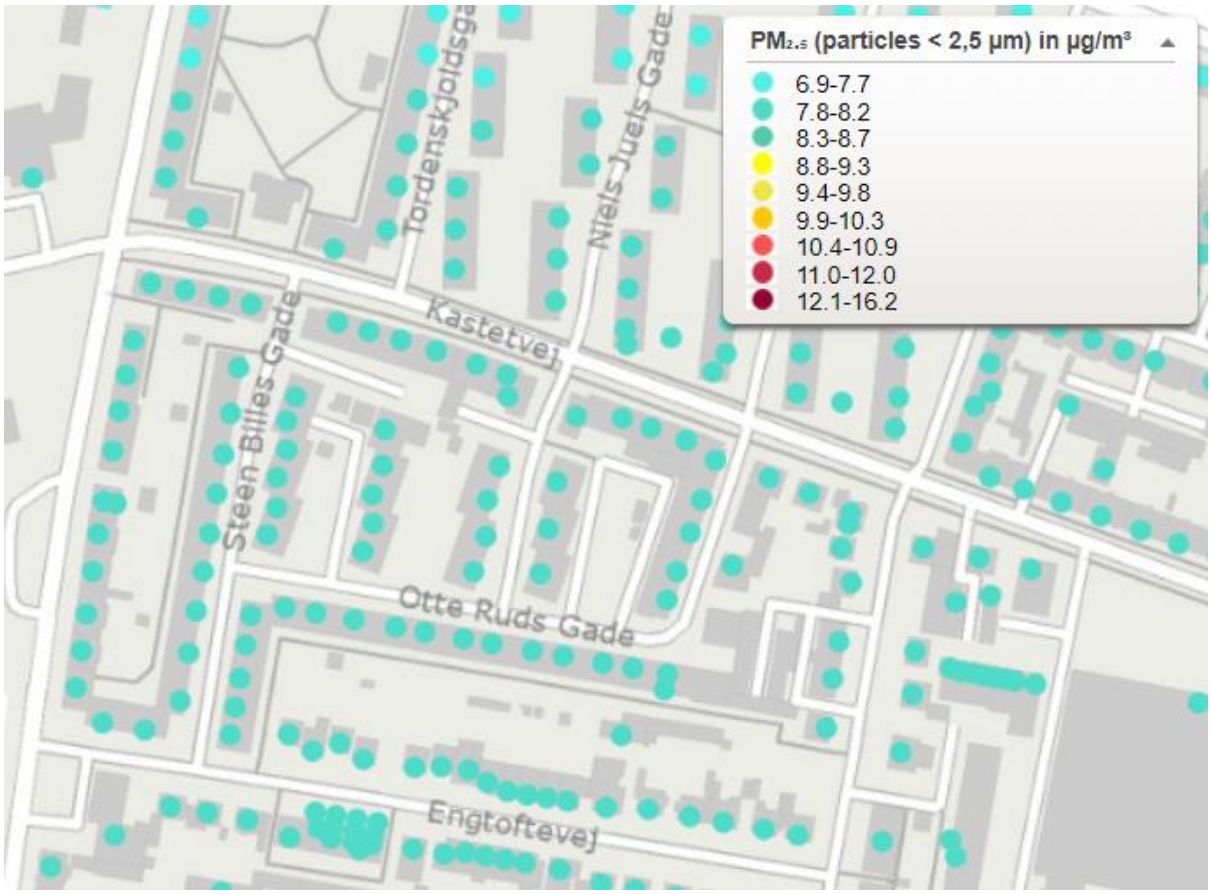

Figure 3.13 - Pollution Concentration Map

Visual

Otte Ruds Gade is N-S oriented and surrounded by other apartment blocks from North and West side, and by houses from South and East side ranging from 12 to 16 m height. The score for the apartments was not so different even though one apartment is located at 3rd floor and the other one in ground floor. When looking at the 3rd floor, the plus comes from the South side where the height of the houses in front are low, while for the apartment registered in ground floor the good score is due to the fact that on the South side the apartment does not face any building perpendicularly.

Based on the 2 registrations and the analyzed parameters, it was decided to test 16 apartments, covering the ground floor, 1st, 2nd and 3rd floor.

14 apartments in the ground, 3rd floor and corners were tested to see the influence of the envelope on the result. Thereafter, other 4 apartments were tested to see the difference between the ones located at the extremities and the ones in the center sections of the building.

After analyzing all the test results, it was concluded that all apartments suffer from overheating due to orientation and window sizes, regardless the height of the apartments or placement.

For the acoustic part, Otte Ruds Gade scores the same as the case above (Steen Billes Gade), since the buildings were erected in the same period and have similar construction. The impact on the score comes mainly from the construction which have not been renovated.

The results for Visual comfort are changing from floor to floor, improving from good to better, however the influences of the surrounding buildings can be clearly observed, especially when looking at the corner apartments number 35 and 31.

Apartment	Thermal	Acoustic	Atmospheric	Visual	Total
35, st.th	C-73	F-38	D-57	E-44	E-53
31, st.th	C-73	F-38	D-57	E-50	E-54
27, st.th	**C-70**	**F-38**	**D-64**	**C-75**	**C-62**
23, st.th	C-70	F-38	D-64	D-58	C-57
17, st.th	C-73	F-38	D-57	D-65	C-58
13, st.th	C-73	F-38	D-57	D-56	C-56
35, 1th	C-73	F-38	D-57	D-58	C-56
31, 2th	C-73	F-38	D-57	D-59	C-57
27, 1th	C-70	F-38	D-64	C-75	C-62
23, 2th	C-70	F-38	D-64	D-64	C-59
17, 1th	C-73	F-38	D-57	D-67	C-58
13, 2th	C-73	F-38	D-57	D-57	C-56
35, 4th	C-73	F-38	D-57	D-65	C-58
31, 4th	C-73	F-38	D-57	D-61	C-57
27, 4th	C-70	F-38	D-64	C-75	C-62
23, 4th	C-70	F-38	D-64	C-71	C-61
17, 4th	**C-73**	**F-38**	**D-57**	**C-71**	**C-60**
13, 4th	C-73	F-38	D-57	D-66	C-58
Average	**C-72**	**F- 38**	**D-59,3**	**C-66**	**C-58**

Table 3.7 - Otte Ruds Gade, Overall Score

After testing 18 apartments out of a total of 72, it can be concluded that the remaining apartments would score the same after covering all the critical issues for each evaluation area. Based on the registrations, investigations and assumptions the label received is D, due to poor construction and issues due to orientation.

Starting from apartment label a building label have been reached for all the tested dwellings, by pointing out and covering all the critical areas. Moreover, it was observed when looking at Steen Billes Gade case and Otte Ruds Gade case, which are similar by the construction year, layout and construction types, that when the orientation is towards East, the thermal score obtained is close to maximum, and when orientation is towards South, the thermal score suffers due to overheating. The opposite applies when analyzing the results for visual comfort, where in the South case, Otte Ruds Gade, obtains a better score due to orientation when compared to the results for Steen Billes Gade which is oriented towards East.

4. Conclusion

IV20 is part of the REBUS project in collaboration with other partners. The purpose of this project was to create a tool which can evaluate and score Indoor Environment, with the aim that in the future this will become a part of the Building Regulations. Another purpose for this new evaluation tool would be that when the analysis and report for the Energy Label will be performed, an Indoor Environment analysis and report will also be made. The scale might be similar to the Energy Label, giving an easy understanding to the users.

To evaluate the tool and to discover errors, several groups of testers were made, each having different target.

This report is part of IV20 testing process in terms of evaluation of Thermal and Visual Comfort and apartment labeling. The investigation started by finding an apartment building, the 1st Semester block located in Aalborg at Henning Smiths Vej, work with V0 and analyze the scores obtained and find errors in the tool. Several tests were run for 18 apartments situated in ground floor, 1st, 2nd and 3rd floor. When looking at the test results, errors have been found for both above mentioned evaluation areas, and together with group 1.242-04 some of them have been corrected.

Another version of IV20 was released, V1 and the process was the same as for V0. The test for the first building were redone, and other errors have been found. Some of the errors have been corrected, but more were found along the way, and due to lack of time, V1 still has errors that will later on be added and corrected for V2 which have not been released until now.

V1 was used for the tests on Magisterparken, Steen Billes Gade and Otte Ruds Gade. The process started by making registration in 2 apartments for each building to later be able to make assumptions based on them and on drawings received from Himmerland Boligforrening to start the test.

The registration was done in 3 steps, where measurements of the entire apartment were taken, including windows and doors, since the windows are the most important part for Visual Comfort, continuing with investigation of the condition of the apartment including components and systems and ending with pictures of rooms, windows, components and systems.

The focus of the first part was to test some apartments in each building to see how the overall score and the score for Thermal Comfort and Visual comfort is changing when moving from one apartment to another (corners and center of the buildings) and from floor to floor (ground floor, 1st, 2nd and 3rd floor), depending on orientation and height. The Acoustic and Atmospheric comfort was briefly described because it was observed that the results were dependent on the construction type, systems and surroundings and do not change when testing different apartments in the same building.

Based on the test results was found that almost all the apartments suffer from overheating, independent of the height the apartments, except the Steen Billes Gade case, where overheating happens only in the apartments at the 3rd floor.

It was observed that when looking at the Visual Comfort for all 3 cases, the score follows a trend line, improving as the height of the apartments increased. However, the buildings are highly influenced by height of the surrounding buildings.

The second part of this report was to see how is it possible to go from an IV20 score for each apartment to a building score and how many apartments is relevant to test in order to get a building label without testing all the apartments in the building. The indoor environmental evaluation areas from the tool have been analyzed to see what can be critical for each part. Based on the results of this tests it was concluded that the apartments should be sorted by the impact with the outside air, center section of the building as well as different heights and orientations in order to have relevant result that can lead to a building label.

The cases received the following grades: Magisterparken (C), Steen Billes Gade (C), Otte Ruds Gade (D). For the first case the plus came from an early renovation in 2010 that improved the condition of the building, but when comparing Case 2 with Case 3, that have the same construction year and same type of components and thicknesses, it was clearly observed something that can be used as a guideline for other future cases. Case 2 (Steen Billes Gade) is E-W oriented, while Case 3 (Otte Ruds Gade) is S-N oriented.

When the building is oriented towards East and West the thermal comfort can score up to 81 points (B) while in the other case with South and North orientation the building cannot score more than 73 points (C).

When looking at the Visual Comfort, according to the orientation, a South oriented building will have a better visual score than an East oriented building.

Finally, it can be concluded that based on the authors' research and analysis, the Thermal Comfort and Visual Comfort are changing when moving from one apartment to another, and that these two evaluation areas are strictly related to the orientation and height of the buildings and apartments. Moreover, obtaining an overall Building Label it is possible if all the critical areas are covered however, the number of the apartments that need to be tested variates from case to case.

5. Reference List

BOOKS and ARTICLES

- DS-EN 15251 – Input-parametre til indeklimaet ved design og bestemmelse af bygningers energimæssige ydeevne vedrørende indendørs luftkvalitet, termisk miljø, belysning of akustik
- HB 2016 – Håndbog for Energikonsulenter

LECTURE NOTES AND PRESENTATIONS

- Jensen, RL. (2016) - Acoustic Comfort – Indoor Environmental Analysis and Measurements
- Liu, M. (2016) – Thermal Comfort - Indoor Environmental Analysis and Measurements
- Liu, M. (2016) – Atmospheric Comfort - Indoor Environmental Analysis and Measurements
- Liu, M. (2016) – Daylight – Integrated building design
- Rohde, L.E., Mikkelsen, S.F. (2017)- Oplæg – Intro til testere
- T.S. Larsen, H.N. Knudsen, Lektor Aalborg Universitet, Seniorforsker SBI Aalborg Universitet, A. Heebøll, Konsulent Teknologisk Institut (2017) – Brugerkommunikation – Vejen til et bedre Indeklima
- T.S. Larsen, H.N. Knudsen, Lektor Aalborg Universitet, Seniorforsker SBI Aalborg Universitet, A. Heebøll, Konsulent Teknologisk Institut (2017) – Indeklimaparametre
- L.E. Rohde, F.S. Mikkelsen (2017) – Case Akustisk
- L.E. Rohde, F.S. Mikkelsen (2017) – Case Atmosfærisk
- L.E. Rohde, F.S. Mikkelsen (2017) – Case Generelt
- L.E. Rohde, F.S. Mikkelsen (2017) – Case Termisk
- L.E. Rohde, F.S. Mikkelsen (2017) – Case Visuelt
- L.E. Rohde, F.S. Mikkelsen (2017) – Manual Akustisk
- L.E. Rohde, F.S. Mikkelsen (2017) – Manual Atmospærisk
- L.E. Rohde, F.S. Mikkelsen (2017) – Manual Generelt
- L.E. Rohde, F.S. Mikkelsen (2017) – Manual Termisk
- L.E. Rohde, F.S. Mikkelsen (2017) – Manual Visuelt

WEBPAGES

- http://www.rehva.eu/publications-and-resources/rehva-journal/2013/022013/thermal-and-acoustic-comfort-requirements-in-european-standards-and-national-regulations.html
- https://www.designingbuildings.co.uk/wiki/Thermal_comfort_in_buildings
- http://casepractice.ro/asezarea-casei-in-functie-de-punctele-cardinale/
- https://nabers.gov.au/public/webpages/ContentStandard.aspx?module=21&template=3&include=IndoorEnvironment.htm&side=new-IE-docs.htm
- https://escholarship.org/uc/item/5ts7j0f8#page-4
- https://books.google.dk/books?id=8jXdNFwdzv8C&pg=PA135&lpg=PA135&dq=weighting+factors+in+indoor+environment&source=bl&ots=jd-eDyym3c&sig=K4HuMW_O6Wy6O5f6EFx75fn94wU&hl=da&sa=X&ved=0ahUKEwjtj5H8zpz

WAhVFEpoKHey5DJEQ6AEIYDAL#v=onepage&q=weighting%20factors%20in%20indoor%20environment&f=false
- https://www.bre.co.uk/filelibrary/Briefing%20papers/116885-Overheating-Guidance-v3.pdf
- https://floorplanner.com/projects/51498829-new-floorplan/viewer
- https://www.dingeo.dk
- http://afd9008.abhim.dk/Boligoversigt
- https://www.sunearthtools.com/dp/tools/pos_sun.php?lang=en
- http://www.sciencedirect.com/science/article/pii/S2212670814002115
- https://ec.europa.eu/energy/sites/ener/files/documents/Impact%20of%20energy%20labels%20on%20consumer%20behaviour.pdf
- http://danskebygningsmodeller.dk
- http://danskbyggeskik.dk
- https://www.weblager.dk/app
- https://boligejer.dk
- https://ois.dk
- http://godetage.dk/Sider/default.aspx
- http://miljoegis.mim.dk/spatialmap?&profile=noise
- https://www.latlong.net/
- http://lpdv-en.spatialsuite.dk/spatialmap?

6. Figure List

Figure 2.34	3rd Floor, Visual Comfort Results	Self-generated
Figure 3.1	IV20 Scaling	Self-generated
Table 3.1	Critical Criteria	Self-generated
Figure 3.2	Magisterparken, Tested Block	Google Maps
Table 3.2	Registration Overview, Apartment Sizes and Orientation	Self-generated
Figure 3.3	Living Room Windows	Self-taken
Figure 3.4	Bedroom 1 Windows	Self-taken
Figure 3.5	Acoustic Map	http://miljoegis.mim.dk/spatialmap?&profile=noise
Figure 3.6	Pollution Concentration Map	http://lpdv-en.spatialsuite.dk/spatialmap?
Table 3.3	Magisterparken, Overall Score	Self-generated
Figure 3.7	Steen Billes Gade, Tested Block	Google Maps
Table 3.4	Registration Overview, Apartment Sizes and Orientation	Self-generated
Figure 3.8	Acoustic Map	http://miljoegis.mim.dk/spatialmap?&profile=noise
Figure 3.9	Pollution Concentration Map	http://lpdv-en.spatialsuite.dk/spatialmap?
Figure 3.10	Apartment Comparison, 22, st.tv and 22, st.th	Self-generated
Table 3.5	Steen Billes Gade, Overall Score	Self-generated
Figure 3.11	Otte Ruds Gade, Tested Block	Google Maps
Table 3.6	Registration Overview, Apartment Sizes and Orientation	Self-generated
Figure 3.12	Acoustic Map	http://miljoegis.mim.dk/spatialmap?&profile=noise
Figure 3.13	Pollution Concentration Map	http://lpdv-en.spatialsuite.dk/spatialmap?
Table 3.7	Otte Ruds Gade, Overall Score	Self-generated