Cost-benefit analysis as decision support for determining sound classification for new apartment buildings

Citation for the original published paper (version of record):
Cusumano, L., Olsson, N., Rempling, R. (2025). Cost-benefit analysis as decision support for determining sound classification for new
apartment buildings. Procedia Computer Science, 256: 1615-1622

Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 256 (2025) 1615–1622

Procedia Computer Science

www.elsevier.com/locate/procedia

CENTERIS – International Conference on ENTERprise Information Systems / ProjMAN – International Conference on Project MANagement / HCist – International Conference on Health and Social Care Information Systems and Technologies 2024

Cost-benefit analysis as decision support for determining sound classification for new apartment buildings

Linda Cusumano*, Nilla Olsson & Rasmus Rempling[a,b]

[a]*Chalmers Univeristy of Technology, Sven Hultins gata 8, 41296 Gothenburg, Sweden*
[b]*NCC Building Sweden AB, Drakegatan 10, 41250 Gothenburg, Sweden*

Abstract

The construction industry significantly contributes to the world's total carbon emissions and strives to reduce its climate impact. One strategy to reduce emissions in new buildings is to minimize the volume of material used in the structural system. However, aside from load-carrying, the structural system has other essential functions, such as providing sufficient sound reduction. The most common strategy for achieving better sound reduction is adding more structural material to floors and walls, which contradicts the aim of minimizing the material volumes to lower climate impact. Therefore, this project applies cost-benefit analysis to the structural system of new residential multi-floor concrete buildings to analyze the societal benefits and costs of choosing different sound classes. The objective is to explore whether buildings with better sound classes can be justified from a societal perspective, notwithstanding the increased climate emissions they may produce. The results show that constructing apartment buildings with better sound classification levels is justified from a societal benefit perspective, even though the choice increases carbon emissions.

Keywords: sound calssification; CBA; apartment buildings

---

* Corresponding author. Tel.: +46 70 288 91 45
E-mail address: linda.cusumano@chalmers.se

10.1016/j.procs.2025.02.298

1. Introduction

The construction industry significantly contributes to the world's total carbon emissions and strives to lower its carbon footprint. Considering the total emissions of carbon dioxide equivalents for a new multi-floor apartment building over its entire lifespan, at least 50% of the emissions come from the construction material used [1-2]. As a result, a common strategy to reduce emissions in new buildings is to optimize material usage and minimize the volume of material used in the structural system. However, aside from load-carrying, the structural system has other essential functions, such as providing sufficient fire safety and sound reduction. The most common strategy for achieving better sound reduction is adding more structural material to floors and walls, which contradicts the goal of minimizing the material volumes. Therefore, in reducing the construction industry's climate impact, the choice to design new buildings with higher sound classes than the minimum is questionable and motivates a broader investigation of overall benefits.

Research shows that living in buildings with better sound reduction properties generates health benefits, such as better sleep, improved productivity, and reduced risk of increased blood pressure and cardiovascular diseases [3-5]. In addition, many sustainability certification programs impose requirements on the indoor climate and acoustic parameters [6]. Therefore, the Swedish building regulations specify minimum sound requirements called sound class C [7]. The Swedish standards for building acoustics also specify two improved classes, B and A, where B corresponds to better sound conditions than C, and A corresponds to better sound conditions than class B [8]. The difference in sound reduction requirements between classes is presented in Table 1.

Table 1. Minimum sound reduction requirements for airborne sound between apartments.

Sound class	A (dB)	B (dB)	C (dB)
Reduction from space outside to inside the apartment.	60	56	52

2. Aim & Purpose

The purpose of this research project was to conduct a cost-benefit analysis (CBA) of new apartment buildings with concrete structures to evaluate the investment costs compared to the benefits of different sound classifications. The aim was to create an understanding of the societal benefits achieved by improving building sound properties. The proposed method can serve as an approach for supporting decision-making regarding the choice of sound classification requirements in new projects.

3. Method

Cost-benefit analysis is a technique used to evaluate projects and determine their impact on society [9]. CBA is grounded in traditional microeconomic principles and employs net present value (NPV) as a key metric for evaluation [9]. The NPV is calculated by summing all benefits and subtracting all costs associated with a specific action. CBA converts all costs and benefits into monetary terms based on the value they contribute to human well-being at a societal level [10]. This project uses CBA to assess the societal impact of constructing apartment buildings with varying indoor sound environments.

The analysis conducted in this research project was performed in five steps, as presented in Figure 1. The first step involved choosing a reference building and then using it to calculate material quantities, corresponding costs, and carbon dioxide emissions. The long-term societal benefits were subsequently estimated and quantified in monetary terms. For this study, a 50-year time horizon was chosen, reflecting the technical lifespan of an apartment building as defined by Swedish construction regulations [7]. The investment costs and societal benefits were then used to calculate the net present value. Finally, a sensitivity analysis was conducted to provide insights into how different parameters used in the calculations impact the results.

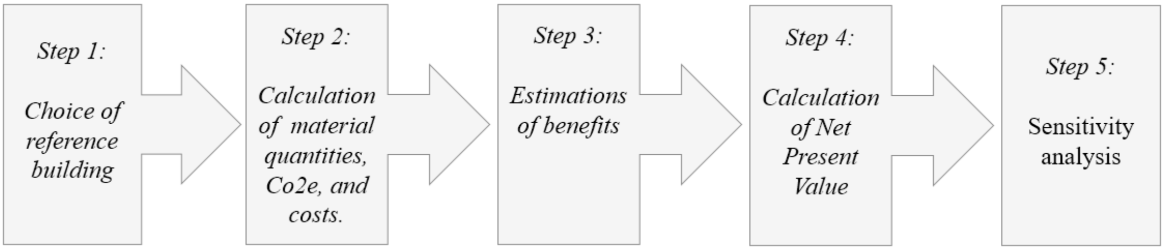

Fig. 1. The five steps used in the analysis.

3.1. Step 1: Choice of reference building

The study used a specific house as the reference building, chosen for its typical design, straightforward construction, and established technical standards. The reference building is a four-story apartment complex with a concrete structure and a floor height of 2.7 m. The floor plan illustrating the building's structural layout is shown in Figure 2. All inner walls, floors, and balconies are made of concrete. The inner walls are assumed to be of a semi-prefabricated structure, consisting of two 50 mm outer layers of prefabricated concrete and a middle layer of in-situ cast concrete. The façade walls are made of lightweight steel with plaster as the exterior surface. The floors are semi-prefabricated concrete, consisting of a bottom layer of 50 mm prefabricated concrete with an in-situ cast concrete layer on top. The fire safety requirement for the building is R60, both horizontally and vertically.

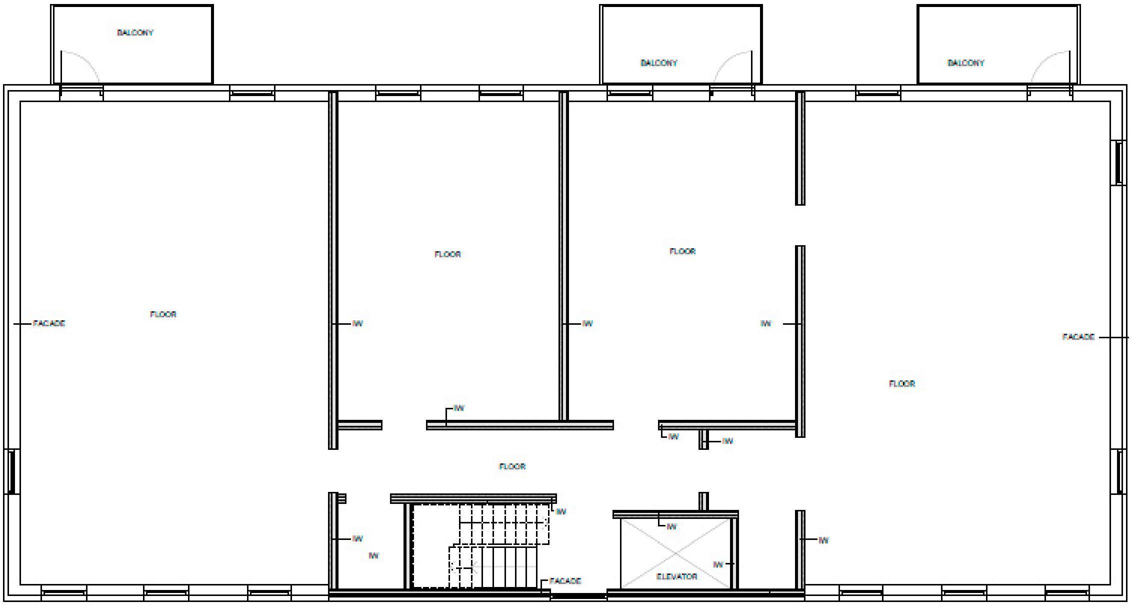

Fig. 2. A floor plan for the reference building. IW stands for Inner Wall, which, along with the floor slabs, are the main components affected by the sound classification.

3.2. Step 2: Calculation of material quantities, CO2e, and costs.

The material quantities were calculated using the AutoCAD model for measurements. Stairs and elevator shafts were excluded from the floor area. The material quantities for the building parts included in the analysis are presented in Table 2.

Table 2. The reference building's material quantities for floors, inner walls and façade.

Building part	Façade walls	Inner walls	Floors
Total surface area [m^2]	865	703	1125

This paper presents all prices in Swedish krona (SEK) for the cost calculation. When the research was conducted, 1 Euro corresponded to 11.7 Swedish krona. The prices for the different wall types and floors have been calculated by referencing a price database from a large Swedish contractor. The prices include both material and labor costs and represent mean values.

The calculation of the climate impact has been conducted according to guidelines of the Swedish National Board of Housing, Building and Planning, which became a requirement for new buildings in Sweden in January 2022 [11]. The calculations include factors A1-A5, where A1 represents emissions from raw material, A2 represents emissions from the transport of raw materials, A3 represents emissions from production, A4 represents emissions from transport to the construction site, and A5 represents emissions from the construction and assembly process [11]. Since this study uses a hypothetical reference building, only the generic climate impacts have been considered.

3.3. Step3: Estimation of benefits

The benefits included in the analysis are health improvements, fire safety improvements resulting in reduced insurance costs, and productivity improvements for individuals working from home.

3.3.1. Health improvements

The monetary value of health improvement from reduced noise disturbances was calculated using ASEK 7.1 Chapter 10 [4], which follows a hedonic approach. The method relies on individuals' willingness to pay (WTP) to avoid noise derived from property price differences in various sound environments. Since ASEK focuses on indoor noise caused by outdoor sources, a benefit transfer was made by considering the differences in sound classes from the Swedish Standard [8], as outlined in Table 1. The difference between sound classes C and B, and B and A, is 4 dB. Therefore, the WTP difference for a 4dB reduction derived from ASEK has been used.

WTP varies depending on the initial noise level, with higher initial levels prompting larger payments for reductions. As a reference value, 30 dB was used, the equivalent acceptable sound level for indoor apartments specified in FOHMFS 2014:13 [3]. Using ASEK's data, the WTP for transitioning from sound class C to B was estimated by comparing sound levels at 30 dB and 26 dB and from C to A by comparing 30 dB and 22 dB.

ASEK provides WTP values for 2017 and 2040. Therefore, estimates for 2023 were derived, assuming a linear correlation between these years. This linear model was also utilized for projecting WTP values beyond 2040, accounting for potential real-term increases in benefits. Given that ASEK provides the willingness to pay per individual per year, an estimate of the number of residents in the reference building was necessary. This was done assuming one adult in each one-room apartment and two adults in each two-room and three-room apartment, resulting in 26 adults.

3.3.2. Fire-safety improvements

Enhancing the soundproofing between apartments often involves using more structural materials, which also improves the building's fire safety, leading to societal benefits. These benefits were quantified by estimating reduced property insurance costs. According to Lundin & Olsson [12], installing a sprinkler system, a known fire safety enhancement, can lower insurance costs by 10%. A sprinkler system allows for reduced fire safety requirements. For instance, if floors are required to withstand fire for 90 minutes, they can be designed for 60 minutes because sprinklers provide an additional 30 minutes of protection. Therefore, it has been assumed that the reverse logic holds; improving fire resistance by 30 minutes could lead to a similar 10% reduction in insurance costs.

Data from Svensk Betong [13] was used to assess the impact of sound classification changes on fire resistance for concrete walls. Changing from sound class C to B increases fire resistance by 20 minutes, and from B to A adds another 20 minutes. If a 30-minute increase corresponds to a 10% insurance cost reduction, a 20-minute increase would imply approximately 6%. However, to avoid overestimation, this study assumes a 5% insurance cost reduction for sound class B and 10% for sound class A.

A major Swedish insurance company estimated the annual property insurance cost to be 22,000 SEK. This cost was then adjusted yearly based on a projected 1.8% increase in GDP per capita, following ASEK's guidance in chapter 5.6 [4].

3.3.3. Productivity increase

Thicker walls and floors not only reduce noise but also improve the working environment for home workers and students. Statistics Sweden reports that since the COVID-19 pandemic, about 22% of Swedish adults continue to work from home more than half of the time but less than all the time [14]. Given the trend toward returning to the office, this study assumed that 22% of the 26 residents in the building work from home two days a week.

A study by Jahncke & Hallman [15] found a linear correlation between noise reduction and productivity in office workers in Sweden. According to their research, each 1 dB reduction in noise level correlates with a 0.9% increase in productivity. Given that the noise reduction difference between two sound classes is 4 dB, the estimated productivity gain is 3.6% (4 x 0.9%).

Assuming an annual workload of 2,080 hours per employee, Ekonomifakta [16] data was used to estimate the monetary value of productivity improvements. It was assumed that those working from home primarily held service-producing occupations, where remote work is more prevalent. Therefore, the monetary value of productivity in Sweden, defined by Ekonomifakta as the ratio between value-added and worked hours, was specifically applied to service jobs, amounting to 680 SEK per hour in 2023 [16].

3.4. Step 4: Calculation of Net Present Value

As a reference scenario, the building was designed for sound classification level C, the minimum level accepted for new apartment buildings in Sweden. The comparison between the reference scenario and the scenarios where the building is designed and built in sound classes B and A was made using the net present value. The NPV for alternatives A and B was calculated as follows:

$$\sum_{t=0}^{T} \frac{B_i}{(1+r)^t} - I$$

where T is the total number of years, in this analysis 50 years, corresponding to the building's technical lifetime.
r is the discount rate, as a standard put to 3.5% in this analysis [4].
B_i is the monetary value of benefits.
I is the initial investment cost, in this case, construction materials and CO2e. The initial investment occurs at t=0 and is not discounted in the calculation.
t is the year when a specific benefit occurs.

3.5. Step 5: Sensitivity analysis

Since the NPV depends on multiple factors that can vary, a sensitivity analysis was conducted to evaluate the impact of these variables. The default time horizon was 50 years, but supplementary analyses were performed for 20 and 100 years. The initial discount rate was set at 3.5%, but additional scenarios were calculated with 2% and 5% discount rates.

The price of carbon dioxide equivalents has been set to 7 SEK/kg according to ASEK 7.1, Chapter 12 [4]. However, this price significantly affects the NPV, and alternative analyses tested 2 SEK/kg [17] and 12 SEK/kg.

For productivity, the base assumption was that home workers worked from home two days a week. Sensitivity analyses were also conducted for one and three weekly home-working days.

Since the health benefits were estimated using a hedonic approach, it cannot be excluded that productivity effects are already accounted for or partially included. Therefore, an analysis was conducted under a scenario without considering productivity benefits. An additional "worst-case" scenario was assessed, setting the discount rate at 3.5%, the CO2e cost at 12 SEK/kg, removing all productivity gains, and shortening the time horizon to 20 years.

3.6. Limitations

The cost analysis only includes structural components affected by sound classification changes, such as external façade walls, interior apartment walls, staircase-separating walls, and floors. It does not consider elements like the roof, balcony slabs, stairs, or foundation, as changes in sound classification do not impact these.

Some inner walls don't separate apartments, allowing for thinner construction, but for simplicity in production, these are generally built to the same thickness as other internal walls. Since these walls comprise just 5% of the total wall length, they were assumed to have the same thickness as other interior walls.

In the calculation of CO2 equivalent emissions, only the production phase (stage A1-A5) has been included. This analysis does not include emissions from usage, maintenance, or demolition phases.

This study assesses the benefits of reducing airborne noise disturbances from neighbours and the outdoor environment. Though measures to reduce airborne sound also reduce impact noise, this aspect is not considered in the analysis.

4. Results

4.1. Investment costs

The investment costs for constructing the reference building with different sound classes are presented in Figure 3. As expected, the costs rise with higher sound classes due to greater material use. Upgrading from sound class C to B adds 0.34 MSEK to the total cost, which is approximately 23 KSEK per apartment. Changing from sound class C to A results in a 0.66 MSEK increase, equivalent to approximately 44 KSEK per apartment.

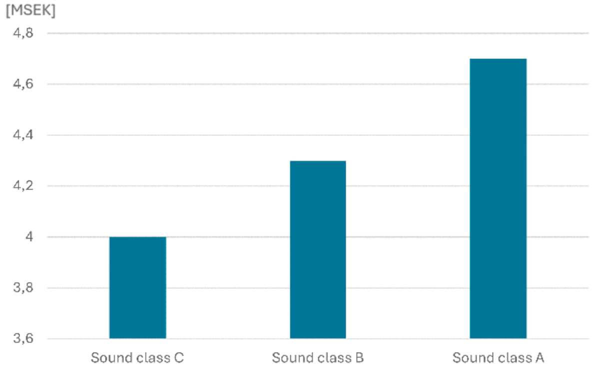

Fig. 3. Investment costs for construction materials and compared to carbon emissions for different sound classes.

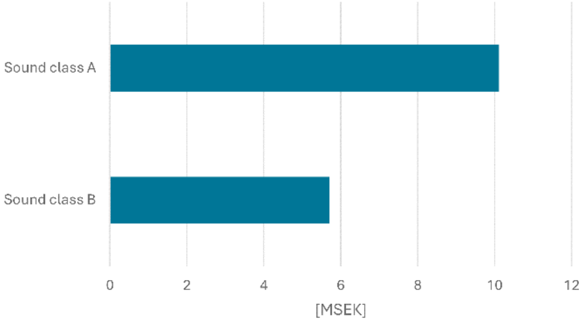

Fig. 4. NPV difference between buildings in sound class A or B the reference scenario in sound class C.

4.2. Net Present Values

Figure 4 presents the NPV results for buildings in sound classes A or B, compared to the reference scenario in class C. The results demonstrate that constructing buildings with higher sound classes provides greater societal value. The results show that for sound class B, every 1 SEK invested yields an NPV return of 4.8 SEK. For sound class A, the return is 9.1 SEK for every 1 SEK invested. This highlights the benefits of building to higher sound standards.

4.3. Sensitivity analysis

The reduced insurance cost due to fire safety improvements had a low impact on the NPV. With a 50-year time horizon, the benefit was 36.4 KSEK for sound class B and 72.9 KSEK for sound class A, compared to investment costs of 4.3 and 4.7 million SEK, respectively. This suggests excluding fire safety improvements from the analysis would not significantly affect the results.

Key factors that strongly influence NPV are the time horizon and discount rate. Table 3 shows how NPV varies with changes in time horizon, carbon emission costs, discount rate, and home-working days. Sensitivity analysis results are also presented in Figure 5.

Table 3. NPV variation in MSEK for different time horizons, carbon emission costs, discount rate, and home-working days. The grey zone represents the base case. All results shown are compared to the base case in sound class C.

Sound Class	50 years, 3.5%, 2 days/week 7 SEK/kgCO2e	20 years	100 years	2 SEK /kgCO2e	12 SEK /kgCO2e	2 %	5 %	1 day /week	3 days /week
B	5.6	2.7	8.0	5.7	5.5	8.1	4.1	3.7	7.6
A	10.0	4.8	14.2	10.2	9.8	14.3	7.3	6.1	13.9

The productivity of home-workers strongly influenced the NPV. Therefore, an additional analysis was conducted, excluding productivity benefits. The results in the fourth set of bars in Figure 5 still indicate that constructing apartment buildings with improved sound properties is societally beneficial. The "worst-case scenario" is presented in the last two bars on the right in Figure 5. This analysis, which uses a 20-year timeframe, a 12 SEK/kg carbon price, and no productivity gains, still demonstrates that improved sound properties are socially advantageous.

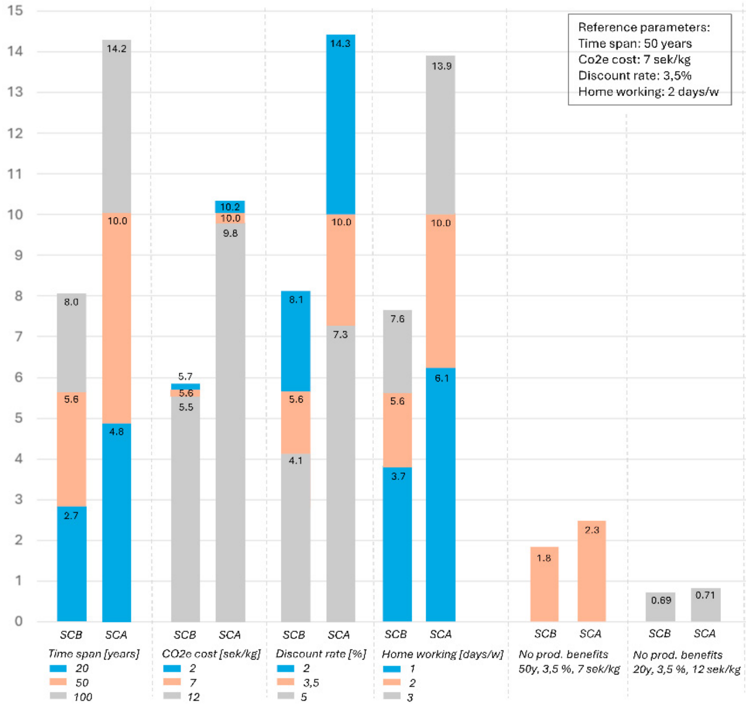

Fig. 5. How various factors influence the NPV. The y-axis shows the NPV in [MSEK] compared to the reference scenario.

5. Discussion & conclusions

Given the NPV results and the sensitivity analysis, building apartment complexes with better soundproofing than the minimum required by Swedish building regulations is justified from a societal perspective. The analysis suggests that designing to sound classification B is advantageous, but aiming for class A is even better.

Choosing to design according to sound class B has become standard practice in Sweden, and this practice can be motivated. However, it is uncommon to choose sound class A, which theoretically is an even better choice. The reason for this can be a lack of benefit studies, restricted budgets, and property developers being less interested in societal benefits if they cannot be used for marketing purposes.

Several factors motivate the choice to build with a better sound classification level than the minimum. The NPV is positive for classes A and B in a shorter time than the building's technical lifetime. The break-even point for sound class A is 17 years; class B is 31 years. The NPV is also positive even with a low carbon price. Increased productivity for people working from home is a parameter highly influencing the outcome of the NPV. However, if productivity is removed from the analysis, the results still indicate considerable benefits with better sound properties.

A probabilistic CBA using Monte Carlo simulations would be a valuable extension to this study, offering more comprehensive insights into likely outcomes, which is helpful for decision-making and risk assessment.

While the NPV calculations suggest that better sound classes offer a positive return, these choices also increase carbon emissions. Given the construction industry's emphasis on reducing its carbon footprint, the study's findings highlight that improved indoor acoustics can offer societal benefits that outweigh the added emissions.

It is important to note that the study does not consider other potential advantages, such as encouraging more people to work from home, which could reduce emissions from commuting.

Most projects focus on direct benefits, investment costs, and project-related carbon emissions. This narrower view can lead to different conclusions from a broader societal perspective. The common practice in the industry to build with sound class B seems to be a practical compromise, balancing project goals with broader societal benefits.

Acknowledgements

This research was enabled by a grant from the Development Fund of the Swedish Construction Industry (Grant number 13949) and NCC Sweden AB.

References

[1] Houriuchi, C., Webster, M., Gryniuk, M. and Stringer, M. (2021) "Structural Engineers and the Climate Crisis: Reducing Embodied Carbon through the SE2050 Commitment." *Structural Carbon*, July, 2021.

[2] Hung, C. C. W., Hsu, S-C. & Cheng, K-L. (2019) Quantifying city-scale carbon emissions of the construction sector based on multi-regional input-output analysis. *Resour Conserv Recycl*. 149: 75-85.

[3] Folkhälsomyndigheten (2014). *Folkhälsomyndighetens allmänna råd om buller inomhus (*FoHMFS 2014:13). Solna, Folkhälsomyndigheten.

[4] Trafikverket (2023). *Analysmetod och samhällsekonomiska kalkylvärden för transportsektorn:* ASEK 7.1. Version 2023-02-01.

[5] WHO (2018). *Environmental Noise Guidelines for the European Region*. Word Health Organization, Copenhagen.

[6] SGBC (2022). *Miljöbyggnad 4.0*, Swedish Green Building Council.

[7] Boverket (2020a, March 4). *Boverkets byggregler, BBR*. https://www.boverket.se/sv/om-boverket/publicerat-av-boverket/publikationer/2020/boverkets-byggregler-bbr/

[8] Svensk Standard (2024). SS25267: *Acoustics – Sound classification of spaces in buildings – Dwellings.* SS25267:2024. Svenska institutet för standarder. Stockholm.

[9] Johansson, P-O. & Kriström B. (2018). *Cost-Benefit Analysis*. Cambridge Elements, Public Economics.

[10] Söderqvist, T., Brinkhoff, P., Norberg, T., Rosén, L., Back, P.-E., Norrman, J. (2015). Costbenefit analysis as a part of sustainability assessment of remediation alternatives for contaminated land. *J. Environ. Manag.* 157, 267–278.

[11] Boverket (2023, March 4). *Klimatdeklarationens omfattning*. Website: https://www.boverket.se/sv/klimatdeklaration/gor-sa-har/omfattning/

[12] Lundin, J., & Olsson, F. (2000). *Kostnadseffektiv utformning av brandskydd*. (LUTVDG/TVBB--3110--SE; Vol. 3110). Lunds University.

[13] Svensk Betong (2024, March 6). Website: "*Tabeller för betongelementkonstruktioner*". www.svenskbetong.se/om-betong/prefab/brand/tabeller-for-betongelementkonstruktioner

[14] SBC 2022b. *Hemarbete under pandemin. Arbetskraftsundersökningar Januari 2021 till maj 2022*. Statistiska centralbyrån, Stockholm.

[15] Jahncke, H. & Hallman, D. (2020). Objective measures of cognitive performance in activity based workplaces and traditional office types. *Journal of Environmental Psychology*, 72:101503.

[16] Ekonomifakta (2024a, March 7). Website: www.ekonomifakta.se/Fakta/makroekonomi/Produktion-och-Investeringar/Produktivitetsutvecklingen-i-naringslivet/?graph=/25105/1,2,3/all/

[17] Rennert et al. (2022). Comprehensive evidence implies a higher social cost of CO2. *Nature*, vol 610, p687, October 2022.