DELIVERABLE 2.2.3

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CO	Confidential, only for the members of the consortium (including the Commission Services)	

Nature of Deliverable

R	Report	✓
P	Prototype	
D	Demonstrator	
O	Other	

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0 EXECUTIVE SUMMARY

0.1 OBJECTIVE OF THE DELIVERABLE

The objective is to contribute to the development of the noise score rating method for the indoor environment for residential buildings and is part of the WP 2.2 within the CityHush project.

In Sweden today, a standard sound insulation of $R'_w + C_{tr}$ = 25 dB is used in noise map analysis software when predicting annoyance caused by traffic noise indoors.

This report presents a method to improve the accuracy of noise map analysis when estimating the number of inhabitants disturbed by traffic noise. By examining the constructional designs of apartment buildings in Stockholm, Sweden, from the period 1880 to present time, two curves have been created, illustrating the sound reduction, $R'_w + C_{tr}$ of the exterior walls as a function of the year of construction for open and closed passive ventilation slots respectively. From literature, concerning constructional designs, it can be observed that buildings in residential areas in Stockholm constructed within the same period have similar exterior wall designs. Hence, the buildings from a certain period will have approximately the same sound reduction index {=SRI}.

In order to estimate the number of annoyed people within an apartment building a method to derive the number of one- or two-sided apartment flats in relation to the width of a building has also been a main goal within this deliverable.

The results of this study are only applicable to apartment buildings in the City of Stockholm, Sweden.

0.2 DESCRIPTION OF THE WORK PERFORMED SINCE THE BEGINNING OF THE PROJECT

From a literature survey, information on constructional designs during certain periods was compiled. For each period, information parameters such as

- the areas of the exterior walls
- the sizes of bedroom windows
- the height of bedrooms, floor to ceiling
- typical constructional designs for three components, i.e. walls, windows and ventilation

were added in a table. All these parameters differed between time periods and are of importance when estimating the sound insulation of exterior walls.

For each component the sound reduction index was calculated. To obtain the resulting sound reduction index {=SRI} of the exterior wall, all three partial surfaces were added logarithmically according to a standard equation.

A complementary field study was also performed in a residential area with apartment buildings close to Stockholm. Together with a study of the buildings within the area at the Stockholm City Administration Archives, the idea was to ascertain whether the width of a building has any relation to the incidence of one- or two-sided flats. Further a

3D-model of the area was provided by Stockholm City, where the year of construction for each property could be derived. The buildings were built between 1938 and mid-1990. The buildings constructed between 1938 -1959, were the ones of interest, since the buildings from this period are similar in shape and constitute a large part of buildings in Stockholm. From 1960 and onwards the shapes varies more and therefore are more difficult to use for estimations. For this reason these buildings have been excluded from this initial study concerning the width of the buildings.

0.3 MAIN RESULTS ACHIEVED SO FAR

Typical constructional designs for walls, windows and ventilation from different time periods have been identified and compiled in a table. The SRI was estimated for each component, as well as a resulting sound insulation index for typical exterior walls of the period, based on a window/wall ratio typical for the time period.

From the estimated SRI two curves were produced based on the most typical constructional designs of exterior walls as a function of the year of construction. One graph is for open passive ventilation slots and the other for closed passive ventilation slots. Trend lines were added, producing two polynomial equations.

From the field study and the city archives no standard width of the buildings related to a certain period could be derived. Also, it was not possible to separate different properties in the 3D-model within the noise map analysis software, and derive the width of the buildings this way.

0.4 POTENTIAL IMPACT AND USE

The equations of the trend lines may be of use if implemented in noise map analysis software. This would potentially result in more accurately estimated traffic noise levels indoors. Further the estimation of inhabitants annoyed by traffic noise indoors in an area would also be more correct.

0.5 CONCLUSIONS

The method described here; the estimated SRI of typical constructional designs as a function of construction year, gives a good view of how the SRI has changed but also been improved over the years.

In the study it was shown, as could be expected, that the contribution through the wall could be neglected. It is the dimensions and the construction of the windows and the ventilation system that determines the SRI of the exterior walls.

By using the resultant curves, a more accurate estimation of the number of inhabitants annoyed by traffic noise indoors can be made, compared to using the standard value $R'_w + C_{tr} = 25$ dB. The curves shows that sound insulation of facades have been much improved over the years, especially since the 1970s until today, as an effect of the energy crisis and the ever increasing cost of heating.

The goal of finding a method to estimate the number of one- or two-sided flats in a building could not be accomplished. This was due to the fact that no connection could be established between a certain period and a standard width of buildings as well as the inability of the noise map analysis software to unambiguously separate the properties from each other in the provided 3D-model.

However, from the Swedish Tax office it is easy to derive the number of inhabitants in a property, but no information on how the inhabitants are distributed within the building is given. The question how many that are likely to be annoyed, still remains unanswered.

1 INTRODUCTION

This deliverable presents a method that improves the accuracy of noise map analysis when estimating the number of residents indoors annoyed by traffic noise. It is part of the WP 2.2 within the CityHush project.

In order to predict annoyance of traffic noise in apartment buildings, the sound reduction index {=SRI} of the construction is preferably required when estimating the noise levels indoors. The most established and reliable method to collect sound insulation data is by measuring the exterior wall. However, since measurements are both time-consuming and expensive, it is not feasible to do measurements for an entire city. So far it has been customary in Sweden to use the sound reduction of $R'_w + C_{tr} = 25$ dB within noise map analysis, when estimating the indoor traffic noise regardless of the constructional design. The same sound reduction is assumed for all types of buildings; apartments building in cities as well as one-family houses. The standard SRI-value varies between countries.

In order to improve the prediction of traffic noise levels indoors to be more accurate, a concept of estimating the SRI as a function of construction year was developed. It is difficult to gain constructional knowledge of exterior walls for buildings by observing them from the outside. However, the year of construction as well as the constructional design is often available in the city archives. From archives and literature studies, the constructional design periods were found. In this study, focus is on apartment buildings with construction year from 1880 to present time, since this is the period in Swedish history when most buildings were built in cities.

From the literature study, it was concluded that buildings in residential areas in Stockholm, constructed within the same period have a similar exterior wall design. Hence, the sound reduction, $R'_w + C_{tr}$, of the exterior walls would be alike during a specific period of time. In order to visualise the connection between the year of construction and the sound reduction of a wall, two curves depending on closed or open passive ventilation slots, were produced.

Due to the industrialization, the sound levels in cities have increased rapidly. As an outcome many older apartments are situated close to busy roads, where the exterior walls are not adequate to obtain noise levels inside that meet the Swedish Road Traffic Noise Regulations of today. In Stockholm, many buildings consist of one-sided apartments. If such an apartment is only orientated towards the busy street, the inhabitants are likely to be exposed to annoying traffic noise. In order to estimate the number of annoyed people within an apartment building, a method to estimate the number of one- or two-sided apartment flats in buildings in relation to construction year and width has also been a main goal within this deliverable.

The results of this study are only applicable to apartment buildings in the City of Stockholm, Sweden.

2 DESCRIPTION OF WORK

2.1 LITERATURE SURVEY

In many cities throughout Europe different styles of architecture co-exists side by side. It is not an unusual sight to see an 19th century building next to a 1970's steel and glass complex. The diversity of buildings in all European cities and suburb areas is just one obstacle to overcome when finding a comprehensive method to use for the noise score model.

Another obstacle, which is closely related to the former, is all the various types of constructional designs used in different countries and the constructional variations between cities within a country. In Sweden this is due to the diverse climate in the south and the north. Therefore this survey only includes apartment buildings in Stockholm, Sweden.

In order to collect information, a comprehensive literature survey was performed. Information about constructional designs was gathered at the following places:

- The Swedish Museum of Architecture, Stockholm
- Stockholm City Administration Archive
- Tyréns corporate library, Stockholm

Since there exist vast quantities of data on how buildings have been built during the centuries, it was important to define the scope of the study. For this reason information on building apartments has only been collected from the 1880's until present day. This is also the period in Swedish history when most buildings were built in cities [1].

Further, as the aim has been to collect information concerning the SRI of the exterior walls, the literature survey focused on finding information about:

A. The construction of the walls
B. The construction of the windows
C. Type of ventilation

Regarding Swedish building designs, a great deal of information was found in the Swedish Building Regulations [2] – [5], which since 1946 has been a guideline to Swedish building designers. In addition, several studies about Swedish design throughout the last century [6] – [16] gave input on how the exterior walls were constructed related to specific construction periods. In Appendix 1 the constructional data are compiled.

2.2 FIELD STUDY

Aiming at complementing the literature survey a field study was performed in a residential area, Hammarbyhöjden, in Stockholm during the spring 2011, see Appendix 2a and 2b. The City of Stockholm provided a 3D-model of the selected area, where the year of construction of each building could be derived. Also studies at the City Administration Archives of the selected area were performed.

The architectural concept for this area throughout its development from 1938 to the mid-1990's, has been to insert long narrow three storey buildings into the natural surroundings. Most of the buildings in Hammarbyhöjden were built during the Second World War. The idea was to maintain the natural steepness as intact as possible. This resulted in an airy and spacious feeling between the buildings. This idea dominated architecture in Stockholm throughout the 1930's to the 1950's.

From the study it was revealed that approximately 5 % of the buildings had obtained a secondary exterior insulation. At the City Administration Archives it was also revealed, by studying the actual constructions of the building as well as the planning permissions for this specific area that only a few buildings had been refurbished since they were built. Further, no information on exchanged windows could be found in the city archives.

From the City Administration Archives, the width of the buildings was found, which is closely related to the existence of one- or two-sided flats in an apartment building. This information is of great interest when refining the noise score model for the number of residents that are exposed to exceeding traffic noise levels indoors. In the Archives it was also found that the stock of buildings, built between 1938 and 1950, is very homogenous in width and shows little or no variety at all, whereas the buildings from 1950 and onward to 1959 are slightly broader, giving the opportunity to small one-sided flats with one room and a kitchen. As for the buildings built after 1959 to the mid-1990's no information regarding any connection between the width of the building and two- or one-sided flats could be obtained.

3 ANALYSIS

Data from both literature and field studies were then examined. From the literature study several different constructional designs could be recognized and by categorising the different types of constructions by construction year for walls, windows and ventilation a pattern emerged. From the pattern it could be concluded that buildings in residential areas in Stockholm, constructed within the same period have approximately a similar exterior wall design. Hence, the sound reduction, $R'_w + C_{tr}$ of the exterior walls would be alike during a specific period.

From the late 19th century until now, depending on different circumstances such as economic crisis, war and the cost of energy, the constructional designs of the exterior walls have changed over time. For example during and just after the Second World War the availability of construction material decreased. As a result the SRI of the walls was reduced. Further, the energy crisis in the mid 1970's resulted in better window and ventilation systems. In addition, different architectural design ideas also added to the constructional differences. Further due to the diverse climate in the south and the north of Sweden the constructional designs in the north differ from the designs in southern Sweden.

Below, each component i.e. wall, window and ventilation is presented. Estimates by calculations of the sound insulation were performed for both walls and windows and were carried out in Insul 6.3 from Marshall Day Acoustics [17], see section 4 Calculations and Assumptions.

Data concerning extracting one- or two-sided apartments in relation to construction year and width of the building was also analysed and is presented below in section 3.4.

3.1 WALLS

From the literature survey, it was possible to draw general conclusions regarding the constructions of the walls. It is well documented which materials that have been used in Stockholm in the last 120 years. In buildings constructed before 1945, approximately 50 % of the walls are masonry. Between 1945 and 1960, light concrete and concrete were the most common materials. Until 1950 masonry was used as a load bearing material but after that it has only been used as a cladding material. From 1880 to the 1960's most buildings were completed with plaster as cladding layer.

During the 1960's and 1970's the constructions were mainly made of aerated concrete masonry. However, from mid-1960 and onwards prefabricated element systems began to take shares on the construction market and during the 1980's and onwards, prefabricated elements were commonly used. The prefabricated elements are mainly made of one outer and one inner concrete slab with an insulation core in between the slabs. Styrofoam as an insulation core is common. During the 1980's several different constructions became popular, for example cavity walls with an air gap and outdoor gypsum on a crossed stud system which prevents a thermal bridge.

From 1990 and onwards it became common to use load bearing studs with a layer of outer gypsum and hard insulation with a finish of thin layered plaster. On the inside of the studs, there is a layer of plywood. Transverse studs and gypsum were also common. From mid-1990 plaster as a façade material started being replaced by other materials such as horizontal wooden panels.

See Appendix 1, for more detailed descriptions of general constructions dated to a certain period.

3.2 WINDOWS

From the 1880's to approximately 1910, the windows were made of two separately hinged window sashes. This created a relatively good sound insulation even though the thickness of the glass was only 2 mm. Since then, coupled sashes, i.e. a 2 + 1 system with a glass thickness of 2–3 mm have replaced most of these windows, with decreased SRI as a result.

From 1910 and onwards the most common construction was the coupled sashed windows, i.e. a 1+1 system, with 2-3 mm glass [16], [18, 19]. The space between the panes varied depending on period.

The SRI for couple sashed windows with a glass thickness of 2 mm was calculated to approximately 25 dB. Depending on the distance between the panes, the SRI changed.

Due to the mid 1970's oil and energy crisis throughout the world, a new standard on windows was introduced in Sweden. The triple-glazed 2+1 system, with a glass thickness of 3 mm, offers a better sound insulation. The SRI for such windows was calculated to 29 dB.

From mid-1990 2+1 system with glass of 4 and 6 mm becomes standard with an even better sound insulation of the exterior wall as a consequence. Such a system gives an SRI of 31 dB according to Insul.

See Appendix 1 for more detailed descriptions of windows.

3.3 VENTILATION

It is easy to forget the impact the ventilation system has on the SRI. There is a difficulty in finding typical a construction design for ventilation system associated to a certain period. However, from literature and archives, it has been derived that draft ventilation was common between 1880 and 1910.

Though connected sashes replaced the original windows during the 1980's, the ventilation did not undergo a similar transformation. Natural draft ventilation maintained by leaving a certain amount of weather sealing out on the exterior sash.

From 1930 and onwards to approximately 1980, passive ventilation slots were used. From then on, it is common with active ventilation using "soundproof" ventilation cassettes.

The field study showed that passive ventilation slots are situated underneath the window and has an opening area of approximately 30 cm^2. This ventilation can manually be closed or open. With an open ventilation slot the total insulation of the window decreased approximately 4 dB. See Appendix 1. However, there still remain uncertainties about what ventilation systems are in use in buildings and how large the opening area is.

3.4 ONE- OR TWO-SIDED FLATS

From the literature survey and from the City Archives the widths and heights of the buildings within the selected area of the field study were compiled, in particular the buildings built between 1938 and 1958, where the shapes of the buildings were most similar.

It was found that the storey height varied in apartment buildings according to period. From the literature a typical value for square meters and number of rooms in each apartment for the limited period could be derived. As for the buildings in the selected area the two-sided flats, two on each level, consists of 2 to 3 rooms with kitchen. The average square meter ranges from 47 – 60. For bedrooms approximately 9 m^2 were a standard size.

By using the provided 3D-model of the selected area, within noise map analysis software, efforts were made that from the model get information about the width of the buildings so as to extract one-sided apartments.

4 CALCULATIONS AND ASSUMPTIONS

Estimates by calculations of the SRI were performed for both walls and windows. All calculations were performed by using Insul version 6.3 from Marshall Day Acoustics [17]. For walls and windows, the most typical constructional design during a certain period was chosen. In Appendix 1 the calculated $R'_w + C_{tr}$ is compiled for each element.

In Stockholm it is common with poor sealing between the window frame and the wall. Therefor as a standard, due to flanking sound transmission a correction of – 3 dB was added to the SRI of the windows.

To get an idea of how great the loss of sound insulation was, due to the passive ventilation slot, it was modelled and calculated for. From the field study the cross-sectional area of the slot was assessed to be 30 cm^2. For the draft ventilation and the active ventilation – 2 dB respectively 0 dB were assumed.

From the City Administration Archives, data of important parameters such as the average window area and the average dimension of a bedroom *(l x d x h)* could be extracted. The areas of the exterior walls could then be derived.

Below the assumptions that have been made are summed up:

- The window area varies between 1.7 – 2.7 m^2 depending on the year of construction and architectural design.
- The insulation of windows was corrected – 3 dB in order to adjust for flanking sound transmission.
- Ventilation was modelled by adding a penalty to the window sound reduction:
    - Draft ventilation penalty: -2 dB
    - Passive ventilation slots: -4 dB
    - Active ventilation cassettes: 0 dB
- The method is only valid for apartment buildings in Stockholm, Sweden.

Estimation by calculation of the compound SRI of the exterior wall, i.e. logarithmically adding the SRI of the three partial surfaces was then performed according to standard equation 1. This is a standard equation used when deriving the compound sound insulation of a wall regarding traffic noise. The results are compiled in Appendix 1.

$$R'_w + C_{tr} = 10 \cdot log_{10} \frac{\sum_n S_n}{\sum_n \left(S_n \cdot 10^{-R_{A,tr,n}/_{10}} \right)} \qquad (1)$$

S = surface area

$R_{A,tr}$ = sound insulation regarding traffic noise

Depending on the possibility to manually open and close the passive ventilation slot, SRI for both options was calculated. In order to visualise the connection between the year of construction and the SRI of an exterior wall, a curve for each option were produced.

5 RESULTS

5.1 Sound Reduction Index

In Appendix 1, the calculated results, the SRI of each partial surface for walls and windows, are compiled. Due to flanking sound transmission the window insulation has been adjusted with - 3 dB as well as a correction, due to type of ventilation.

It could be observed that it was the SRI of the window and the ventilation decrease that determined the total SRI of the exterior wall. The wall constructions did not have the same impact.

5.2 Number of Inhabitants Annoyed by Traffic Noise Indoors

From the Stockholm Administration Archives, the width of the buildings in the selected area could not be connected to the construction year and neither could the distribution of one- or two-sided flats. Further, it was not possible to derive the width of the buildings from the provided 3D-model used within noise map analysis software.

This is due to:

- That it is not possible to within the noise map analysis software, find a convenient way to sort out walls that are not significant, i.e. walls that are not exterior walls.
- The separation of the buildings within the noise map analysis software does not correspond to the construction year of the buildings

In general, provided 3D-models used within noise map analysis software are inconsequently modelled and it is therefore not possible to derive the number of inhabitants.

From the literature survey and the field study no results on how many inhabitants that experienced being annoyed by traffic noise, could be derived. However from the Swedish Tax office it is possible to derive information regarding the number of inhabitants in a building.

5.3 Estimated SRI as a Function of Construction Year

In order to visualise the resulting estimated SRI for both open and closed passive ventilation slots, as a function of construction year two curves were produced. The results are displayed in figure 1 below.

To be able to simplify the implementation of the results in noise map analysis software e.g. CadnaA from Datakustik GmbH, trend lines were added to the resulting curves, see figure 1 below.

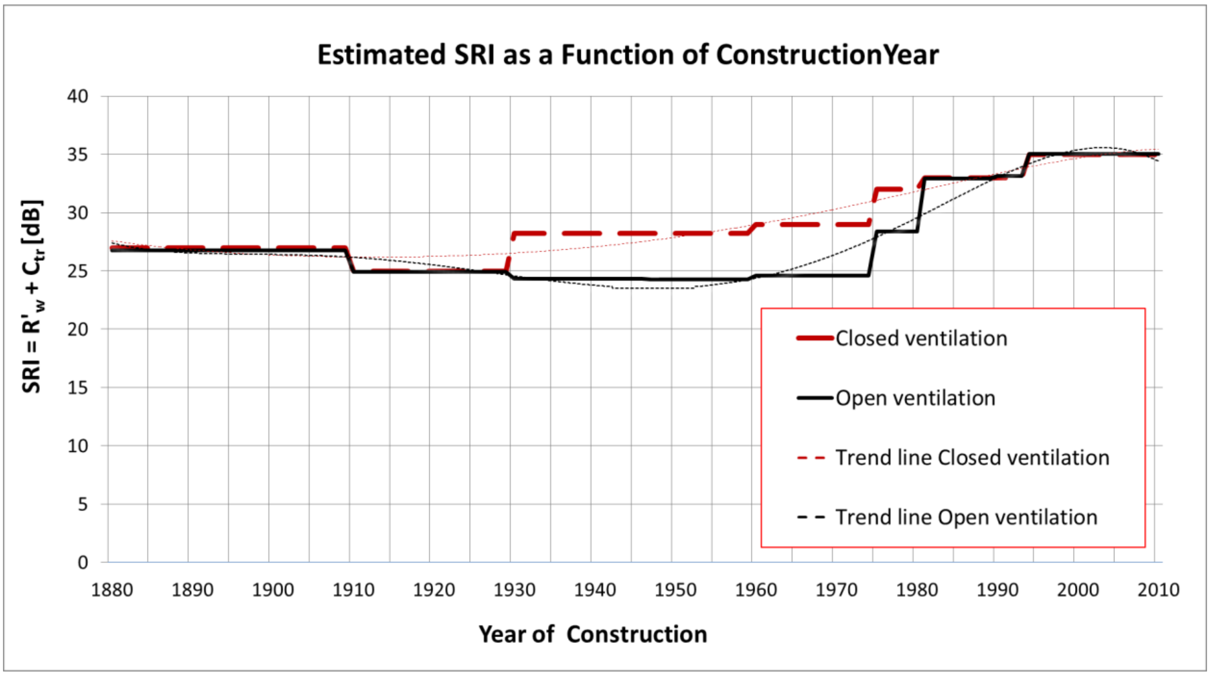

Figure 1 Exterior wall insulation regarding traffic noise as a function of construction year. Also note the trend lines of open and closed passive ventilation slots.

The equations of the polynomial trend lines are as follows:

SRI (open ventilation) $= -10^{-9}y^5 + 4*10^{-7}y^4 - 3*10^{-5}\,y^3 + 0{,}0025y^2 - 0{,}1045y + 27{,}683$ (2)

SRI (closed ventilation) $= -10^{-8}y^5 + 4*10^{-6}y^4 - 0.0003y^3 + 0.0122y^2 - 0.1912y + 27.561$ (3)

where *y* denotes the year of construction.

As can be observed from figure 1, the SRI varies depending on construction year. This variation is due to the different types of construction of the windows and type of ventilation systems.

It is also notable that the curves, depending on construction year, differ from the standard sound insulation of 25 dB. From 1880 to 1920 the SRI is above or equal to the standard value 25 dB. Then the SRI decreases from 1930 until approximately 1959 with open ventilation. For closed ventilation the SRI increases for the same period. From then on the SRI improves. This improvement is due to better windows and ventilation systems.

Since the trend lines are only approximations of the estimated SRI in order to simplify the implementation in noise map analysis software, the numerical values for each period are also presented for both closed and open passive ventilation slots, see table 1. These values may then be implemented in noise map analysis software in order to obtain more accurate results.

Table 1 Numerical values of the SRI for open and closed ventilation

Start	**End**	***$R'_w + C_{tr,}$*** ***open ventilation***	***$R'_w + C_{tr,}$*** ***closed ventilation***
1880	1909	27	31
1910	1929	25	29
1930	1946	24	28
1947	1959	24	28
1960	1974	25	29
1975	1980	28	32
1981	1989	33	-
1990	1993	33	-
1994	2010	35	-

6 SOURCES OF ERROR, CONCLUSIONS, VALIDATION AND FUTURE WORK

6.1 SOURCES OF ERROR

The SRI produced by the method described in this deliverable are all estimates and sources of error may have impact on the result.

For instance, information regarding how the passive ventilation slots are actually constructed is hard to find. And since there is no adequate information concerning the number of buildings that have been refurbished, it is also difficult to estimate how many dwellings that are likely to have exchanged the passive ventilation slot to active ventilation.

There is also the aspect of exchanged fresh-air intakes with improved sound reduction that will have an impact on the SRI. In this study it could not be derived during which period this was performed.

Further, old windows have poor sealing and therefore the SRI may be overestimated.

From 1980 and onwards, traffic noise was considered in the planning process, why the values derived for this period, might be overestimated.

6.2 CONCLUSIONS

The method described here; the estimated SRI of typical constructional designs as a function of construction year, gives a good view of how the SRI has changed and been improved over the years in Stockholm, Sweden.

In the study it was shown, as could be expected, that the contribution through the wall could be neglected. It is the dimensions and the construction of the windows and ventilation that determines the SRI of the exterior walls, unless the wall construction is very poor.

By using the estimated resultant curves, a more accurate prognosis of the number of inhabitants annoyed by traffic noise in apartment buildings can be made, compared to using the standard value $R'_w + C_{tr} = 25$ dB. The curve shows that the sound insulation of facades have been much improved over the years, especially since the 1970s until today, as an effect of the energy crisis and the ever increasing cost of heating.

From the literature survey and the field study no results concerning the number of inhabitants that lives in apartment buildings or how many inhabitants that experiences being annoyed by traffic noise, could be derived. However from the Swedish Tax office it is possible to derive information regarding the number of inhabitants in buildings.

6.3 VALIDATION AND FUTURE WORK

In order to validate the method described here; the estimated SRI as a function of construction year, façade measurements performed by Stockholm City on apartment buildings before and after the exchange to improved windows, will be provided. The data will then be analysed and compared with the estimated SRI and presented in WP 5.2 within the CityHush project.

7 ACKNOWLEDGEMENT AND REFERENCES

This project could not have been accomplished without the help of Martin Lagergren, heritage expert at Tyréns AB.

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Apendix 1 Table of Construction

Period		Typical wall constructions	Typical window and ventilation	Bedroom height [m]	Bedroom window area [m^2]	Wall area (6) [m^2]	Wall R'_w+C_{tr} [dB]	Window R'_w+C_{tr} [dB]	Correction for ventilation slots [dB]	Total R'_w+C_{tr} [dB]	Comments
Start	End						for wall 1 if several				
1880	1909	20 mm plaster, 400 mm masonry ρ = 1600 kg/m3, 15 mm plaster.	Originally the window frames were hinged separately. Glass distance: 105 mm (1) Glass thickness: 2 mm Draft ventialtion	3,2	2	7,6	56	25	-2	**27**	During the 1980's windows were changed into connected frames, though the ventilation were still the same.
1910	1929	20 mm plaster, 400 mm masonry ρ = 1600 kg/m3, 15 mm plaster (2)	Connected frames, two-glazing Glass distance: 35 mm Glass thickness: 2-3 mm Draft ventilation	2,8	2,7	5,7	56	25	-2	**25**	Homogenous building technique during the period, diverse later. During the 1980's windows were changed into connected frames, though the ventilation were still the same.
1930	1946	1: 20 mm plaster, 250 mm masonry, 38 mm insulation material (3), 15 mm plaster. **2: 20 mm plaster, 250 mm aerated concrete ρ = 600 kg/m3, 15 mm plaster** 3: 20 mm plaster, 380 mm masonry, plaster	Connected frames, two-glazing Glass distance: 40 mm Glass thickness: 3 mm *Passive ventilation slots (4)*	2,6	1,8	6	51	25	-4	**24**	Brick walls are common during the period parallel with light concrete, normal sized bricks instead of larger bricks
1947	1959	1: 20 mm plaster, 250 mm masonry ρ = 1200 kg/m3, 50 mm insulation, 15 mm plaster **2: 20 mm plasters, 250 mm aerated concrete ρ = 600 kg/m3, 15 mm plaster** 3: 20 mm plaster, 125 mm aerated concrete ρ = 400 kg/m3, 150 mm concrete, 15 mm plaster	Connected frames, two-glazing Glass distance: 42 mm (5) Glass thickness: 3 mm *Passive ventilation slots*	2,6	1,82	5,98	50	25	-4	**24**	Swedish Building standards, BABS 1946 applies in 1947, the end of the war entails the end of lack of material
1960	1974	1: 20 mm plaster, 150 mm aerated concrete ρ = 400 kg/m3, 150 mm concrete **2: 70 mm concrete, 100 mm Styrofoam, 120 mm concrete** 3: 80 mm concrete, 95 mm bar with mineral wool, plastic foil,13 mm gypsum **4: 20 mm plaster, 300 mm aerated concrete ρ = 500 kg/m3, 15 mm plaster**	Connected frames, two-glazing Glass distance: - Glass thickness: 3 mm *Passive ventilation slots*	2,6	1,68	6,12	52	25	-4	**25**	Swedish Building Standards BABS 1960 applies, new regulation regarding the distance between the glazing.
1975	1980	1: 120 mm brick ρ = 1800 kg/m3, air gap, bar with 50 mm insulation material, bar with 95 mm mineral wool. **2: 60 mm concrete, 140 mm styrofoam, 80 mm concrete** 3: 10 mm plaster, 100 mm styrofoam, 150 mm concrete **4: 120 mm lime stone, air gap, 9 mm outdoor gypsum, 120 mm bar with insulation material, 50 mm bar with insulation material, plastic foil, 13 mm gypsum.**	Connected frames. Tripple-glazing 2+1 Glass distance: 48 mm Insolated glass unit with an air space of 15 mm Glass thickness: 3 mm *Active ventilation*	2,5	1,68	5,82	52	29	-4	**28**	Swedish Building Standards SBN 75 applies with new regulations regarding energy.
1981	1989	1: 120 mm brick ρ = 1800 kg/m3, air gap, bar with 50 mm insulation material, bar with 95 mm mineral wool. **2: 60 mm concrete, 140 mm styrofoam, 80 mm concrete** 3: 10 mm plaster, 100 mm cellular plastic, 150 mm concrete **4: 120 mm lime stone, air gap, 9 mm outdoor gypsum, 120 mm stud with insulation material, 50 mm stud with insulation material, plastic foil, 13 mm gypsum**	Tripple-glazing 2+1 Glass distance: 48 mm Insolated glass unit with an air space of 15 mm Glass thickness: 3 mm *Active ventilation*	2,4	1,4	5,8	53	29	0	**33**	In 1989 applies a new regulation concerning new buildings "Boverkets nybyggnadsregler", with greater freedom and less detailed governance.
1990	1993	1: 100 mm limestone, 10 mm air gap, 120 mm insulation material, 180 mm concrete **2: plaster on 50 mm hard insulation, outer gypsum, 120 mm load bearing studs with insulation, plywood, 70 mm transverse studs with insulation, gypsum**	Tripple-glazing 2+1 Glass distance: 42 mm Isolation casette with an air gap of 15 mm Glass thickness: 3 mm *Active ventilation*	2,5	1,4	6,1	55	29	0	**33**	In 1994 Swedish Building Standards BBR and BKR applies.
1994	2010	1: 20 mm plaster, 120 mm brick ρ = 1800 kg/m3, 34 mm air gap, 80 mm insulation material, bar with 120 mm insulation material , 0,2 mm plastic foil, 26 mm gypsum **2: plaster on 50 mm hard insulation, outer gypsum, 170 mm studs with insulation, platic foil and gypsum**	Triple-glazing 2+1 Insulated glass unit Glass thickness: 6 mm Glass distance: 50 mm Glass thickness: 4 mm Glass distance: 12mm Glass thickness: 4 mm *Active ventilation*	2,6	1,4	6,4	55	31	0	**35**	

(1) Average glass distance 90-120 mm
(2) The buildings from 1910 often lack plaster on the façade, hard burnt façade brick gives however other performance
(3) 38 mm average since 25 mm and 50 mm mineral wool occurs
(4) The passive ventilation slot has approximately a cross-sectional area of 30 cm^2
(5) 42 mm is an average, the glass distance varies between 36-47 mm
(6) The exterior wall area excluding the windows

Appendix 2a Map of Hammarbyhöjden, Stockholm. Construction Year of Building Apartments

Apendix 2b. Map of Hammarbyhöjden, Stockholm