A Research for Technologies of Sound Reductions on Windows

- focused on the Active Noise Control System

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A Research for Technologies of Sound Reductions on Windows

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A thesis presented

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M. Eng. Daniel Arztmann

Declaration

I hereby declare that the Master Thesis with the title

"A Research for Technologies of Sound Reductions on Windows"

has been written only by the undersigned and without any assistance from third parties. Furthermore, I confirm that no sources have been used in the preparation of this paper other than those indicated in the Thesis itself.

Detmold, 15. 06. 2017. _____

Signature

Abstract

Multi million people in Germany feel uncomfortable during their night time sleeping. Naturally human being's physical, psychological diseases caused by this phenomenon. One major role of the windows, fenestrations is solving those problems meanwhile when the windows are opened. This study chased long-time researches from the basic theories of acoustics to imply those know-hows and also technologies, which are already adopted as status of arts. Fortunately, the author could gather some seed researches of the active noise controlling technology that were developed by music industry.

Those researches found out effective method for noise of lower frequency band that meant available technology for reduction of traffic noises. The paper mostly suggested the steps of new product development to challenge the overcome the present uncertainties. The proposed product could contribute to solve to people's basic rights of avoiding noises. As one part of window technologies, it could join the huge main streams of 'smart building'.

Key words: Acoustic window, Active noise control, Traffic noise reduction, Smart Window

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Terminologies (General terms) [1]

Acoustic: [adjective] relating to sound and the way people hear things

Acoustics: [noun, uncountable] the scientific study of sound

Cancellation: [noun] a decision that an event that was planned will not happen

Control: [noun] he ability or power to make someone or something do what you want or make something happen in the way you want

Façade: [noun] the front of a building, especially a large and important one

Music: [noun, uncountable] a series of sounds made by instruments or voices in a way that is pleasant or exciting

Noise: [noun] a sound, especially one that is loud, unpleasant, or frightening

Reduction: [noun] a decrease in the size, price, or amount of something, or the act of decreasing something

Sound: [noun]

1) something that you hear, or what can be heard
2, a) he sound produced by a television or radio programme, a film etc.
2, b) the loudness of a television, radio, film etc.

Soundproof: [adjective] a soundproof wall, room etc is one that sound cannot

pass through or into

Wall: [noun] an upright flat structure made of stone or brick that divides one area from another or surrounds an area

Window: [noun] a space or an area of glass in the wall of a building or vehicle that lets in light

1. Introduction

1.1. Background of the study

According to World Health Organization (WHO) Europe guideline the night noise should be recommended less than 40dB(A) of annual average for sleeping and the health. [2] Unfortunately the case of Germany, in accordance with German Federal Environment Agency: [1]

“More than 4.7 million people were exposed to night-time noise levels above 55 decibels dB(A) in agglomerations, along main roads and around major airports at the middle of 2015. In addition, more than 3.4 million people were also affected by noise levels above 65 dB(A) in these areas throughout the day.” [3]

There is no surprising that such amounts of people are suffering by noise. Unluckily those noises mainly specified by traffic noises. On the other hand, probably those kinds of vicious circle will continue for a while not only in Germany but also worldwide, due to the increase of world populations. Especially the complexity of urban area of course brings more noise pollution than before. The overcrowded cities need more transportation networks apparently; those means of method would be motorized vehicles. Recent researches and developments of window systems at the same time widely focus on natural ventilation even outside’s airs are polluted due to laws and regulations.

Meanwhile if one building faces roadside or is close to noise sources the users of building get noise pollution together. As overall estimation if we provide the ventilation with opened windows, the noise problem would be one of the critical point of barrier to overcome. Even we close the windows and make them be air tightened noise will anyway bother the interior environment through the windows.

As a common sense, human beings cannot ignore the effects of windows. Everybody knows massive walls are effective to prevent from noise than windows however, for people, by the aspects of emotions; humans definitely make openings for sun-lights, sun-heat, visibility, cooling and ventilations. Sometimes although they are in the middle of dense-urban area, people want to open the windows to feel the outside’s environments when it rains or winds when they make little noise.

[1] Umweltbundesamt

This research will cover the most advanced technologies of sound-proof of windows which had been proved by the tests when the windows closed and sometimes opened. Furthermore, it will trace the sound barrier technologies. The opened one probably not for the people who are very sensitive, however the window manufacturers or researchers should challenge the hurdles to reach the goals as much as they are able to. This paper looks over them.

1.2. Problem Definition: What is the noise control on windows?

This study mainly defines the objective of the noise control or sound-proof would be “window”. The concept of façade includes walls and etc. Occasionally windows also need to contain additional panels however, this paper describes about windows that have visionary parts. If it should be necessary to explain about neighbour parts such as roller den, spandrel etc. those should be mentioned with main windows.

To prevent from the confusions of concepts in this paper, some initial definitions should be determined here. About sound and noise, naturally people can recognise what those are different. Noise is one part of sound, however if you hear the tweeting of birds outside of the room, that is a definitely sound but can you also name it as a noise? Probably for some listener, it would be noise for some others not. What about children sounds from playgrounds outside, music such as classic or heavy metal? All those depend on the audiences’ private status. Basically this research starts from overall “Sounds”, nevertheless it would be considered if some specific sounds of frequencies or objectively some sounds which bother psychologically, those would be mentioned as “Noise”. Of course, when the author from time to time quotes other writers’ results here, those would be converted here with contextual meaning. Technologically if we proof sound or noise major methods would be similar or same, in this step of study, both terminologies would be used without serious borders. In case of “Control”, the goal of the study is absolutely “Reduction”, therefore controlling noise, cancellation of noise/sound should be 100% reduction or proof.

Again, “Noise control on window”, this agenda definitely focuses on noise and sound reductions by window systems as a main material of building elements. When it comes to sound’s movement that surrounded building, we can clarify those five ways of sounds activities.

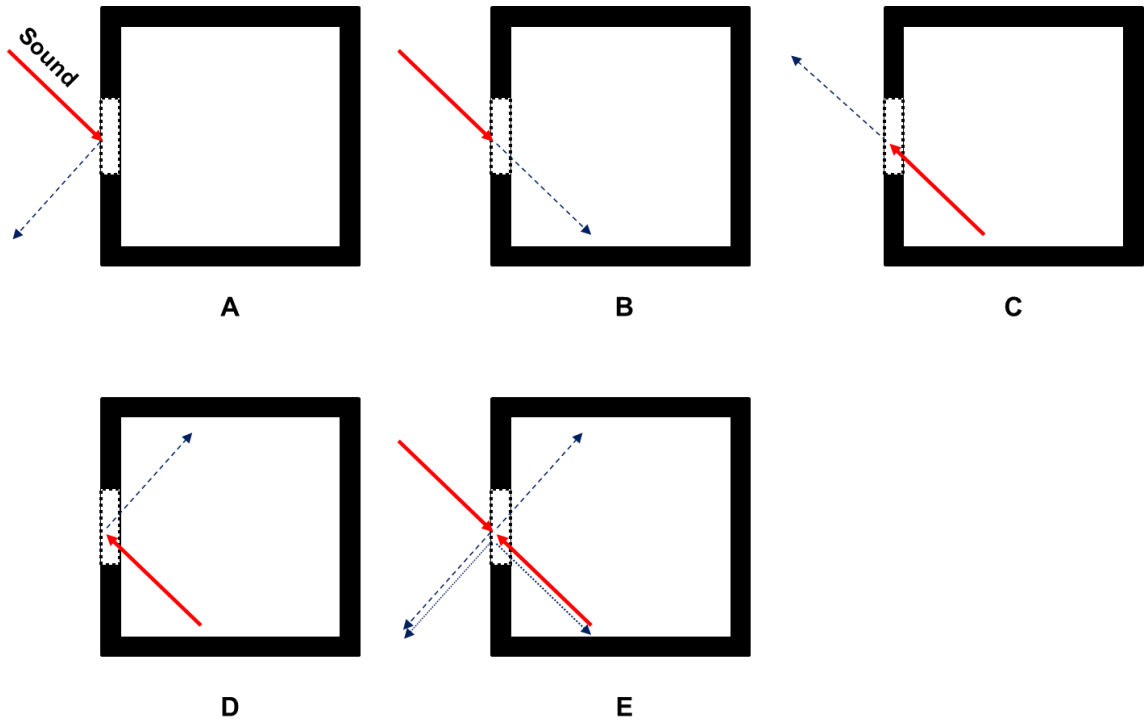


Fig1. Five cases of sound movement through the window systems

A. Noise from outside to outside
ex) The district of high-rise building
The created noises reflect and move to other spaces

B. Noise from outside to inside which passes through the windows
ex) Sound effect that the residents feel usually

C. Noise from inside to outside which passes through the windows
ex) Speeches, musical sounds, TV sounds

D. Noise from inside to inside
ex) Music hall, cinemas, studios

E. Noise effects to each other

This study mostly will cover case B. The large numbers of architectural, acoustical studies are orienting case D, due to the projects that related musical theatre, hall, and studios should critically check the realities for acoustical qualities or related engineering works for their commercial success and related approvals. The case C, for example the project that can affect noise pollution to the sensitive neighbours should take care of their

outputs. Recently studies of the sound effects such as case A is vividly undertaking because the traffic noises reflect very well on building façades and remain for seconds or move to specific areas. According to Krimm et. al, they found the façade shape could control the noise effect in the urban area. Their research considered how the building wall elements react against the sound from outside and how to reflect to the outside. [4]

Now, why include this study, numerous scholars, scientists, engineers and industrial experts are focusing on noise controlling? This chapter will start from some part of the author's personal experiences. The company that the author had worked defined five main functions of windows as followings: [5]

1) Thermal insulation

2) Wind-load resistance and structural issue

3) Air tightness

4) Water tightness

5) Sound-proof

When it comes to the main functions of glass panes: the functions of 1), 2), 5) are critically carried by glasses along with the area of glass out of the total are. Of course in case of glasses they have additionally other aspects such as optical function. Among windows and façade industries, the fundamental technologies of the thermal insulations, wind-load resistance that includes structural supports, airtightness, and water-tightness have been properly developed and are continuously improving. Simultaneously the energy issue is one of the hot topics of global climate changes and so on. About wind load agenda or structural issues of windows, the certified engineers often critically debate due to the building codes for basic safety. At the same time, these weather proof and anti-gravity challenges have brought such as huge competitiveness and innovations.

To compare with those aspects, the acoustical parts were not actively touched by related technologies or even attempted enthusiastically nevertheless; the results were not ground-breakings. Fig2 shows the empiric graph of technological hardness for achieving the goals versus investments on window development in accordance with the author's experiences at work.

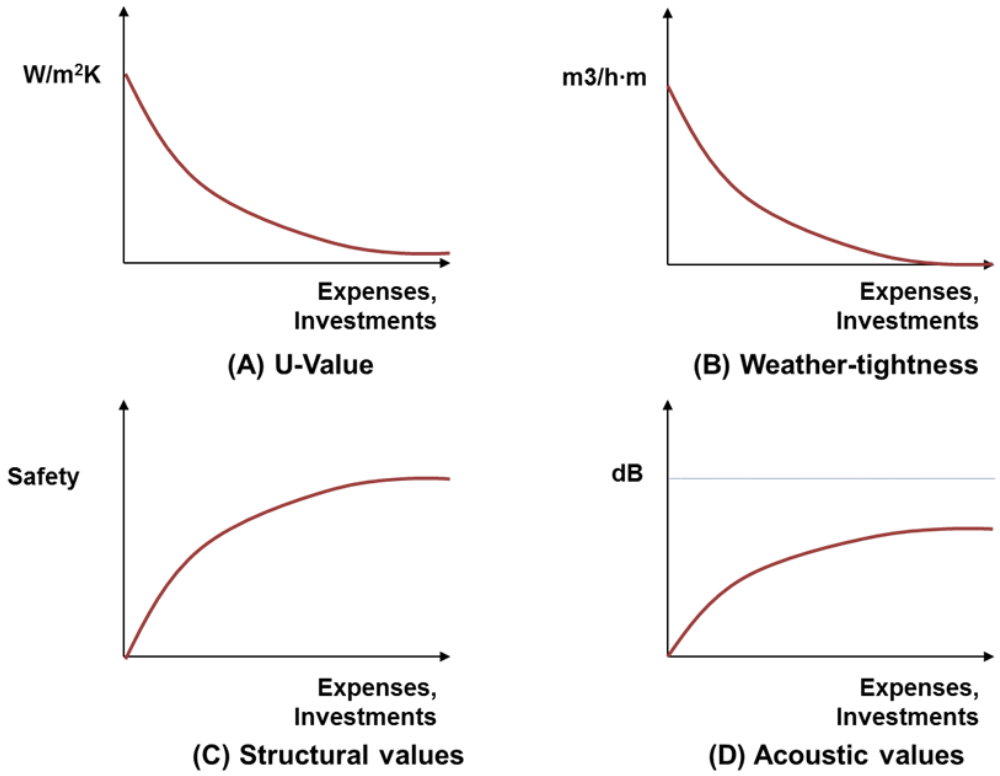


Fig2. Conceptual graphs of hardness of achieving the purpose of window's performances

Representative values of windows normally show the thermal performances such as U-value, or relative thermal insulation values. Theoretically and practically it could be realised approximately under 1.0 W/m^{2}K or less. A couple of standard product series of Schüco which contain triple glazing on 75mm or 90mm window profile set show 0.71W/m^{2}K through 0.92 W/m^{2}K. These values involve when the window sets adopt more functional, insulated glass panes. [6] Technically vacuum glazing is possible in the market whether we calculate the value-price ratio or not, we can achieve at the state of art in the meaning of the thermal performance. Vacuum glazing itself widely known as its performance as 1.1W/m^{2}K, if it combined with Low-E glass whose emissivity is 0.03, the vacuum insulated glasses can achieve 0.4 W/m^{2}K. [7] Decisively, occupants cannot feel the differences of 0.1 W/m^{2}K improvement when they dwell in the building, only energy consumption bill will tell the truth.

In case of weather tightness, under the regular test standards, the windows resist water and air by various sealing technologies, preciseness of designs and moulds, and the development of window fabrications.

Remained two natural invasions are quite hard to overcome the structural

issues and acoustical problems. However, the structural problems normally solved with the safety factors therefore those cover with twice or three times safer solutions unfortunately the matters come from budgets. The structural engineers and governmental administrates should not take the adventures which over their knowledge limitations, technological critical points. Anyway, the completed proven reports of structural calculations always include approvals and by this analysis, the manufacturers or construction contractors are able to guarantee the life cycles. On the other hand, the engineers normally cannot guarantee the sound problems. Occupants simultaneously cannot ask the warranties from builders and this phenomenon of natural system, sound is very emotional elements to person-by-person. Generally people can recognise 10 dB differences even they do not feel 0.1 W/㎡K energy loss of windows.

As many people acknowledged after 1970's oil crises, developed countries started to regulate the energy fenestrations by their building codes. The countries that prefer high-rise buildings, located in windy or stormy areas strict the structural values for public's safety. Meanwhile the window industries avoid the full-scale agendas of acoustic factors. More and more regulations are stating about natural ventilations on windows or mechanical ventilations even though those would occur acoustic problems, ironically.

In summary, about thermal issue, governments, industries, end-users are concentrating and putting their continuous efforts. In case of high rises, the projects that face structural problems, without the guarantee of the safety, those would be never realised by regulations. However unfortunately sound-proof levels are only assignments for project owners or occupants, they mostly have responsibilities furthermore ventilation issues are always on the top of the project issues. As a result, who are mostly suffered victims from the noises? Who are still living next to the noisy roadside, near airports? Who cannot adopt the sound-proof windows for the securing their basic silence rights and prevent from the noise for their residents which located near the serious traffic occur day and night? This study could not get over all those humps widely, but will expose some possible methods of improvements. Then what is this study's focus? In large meaning, there are two systems of noise control on windows, one is the active noise control and the other one is passive noise control. This paper will chase one by one however many window manufacturers, mainly dig into the passive noise control, because the system of active one has a lot of additional parts rather than the manufacturer's work boundary. The system at this moment should be relatively easy to purchase, sell, maintain and develop. To compare with the active noise control system, the passive noise control system is close to achieve the goal, the reduction of the noise with economic values. However

someday it will be sure that the active systems, which have the effective solution, user-friendly mechanism, could be the majority of the market. Even there are not many experiences on the active noise control that is the reason people have to challenge to the system. It probably has limited amount of introduction, which is valuable task to take into account. As a result, it will search both, however as a topic, the paper will cover the possibilities of the active noise control. Simultaneously it will challenge at opened status of the windows.

NOTE

- **To compare with other basic functions of windows, acoustic values were underestimated therefore this study wants to improve this part.**
- **This paper will verify the acoustic aspects when the window was opened.**

2. Literature Survey

2.1. Basic knowledge of acoustics

2.1.1. Physical characteristics of sound [8, 9, 10]

This chapter provides basic knowledge of sound for understanding this thesis. The sound theories or so-called “Acoustics” have huge boundaries in the physics’ sections therefore this study only touches brief introduction that are related especially for window sound-proof. This thesis only focuses neither the acoustics nor the author is a professional acoustic engineer, therefore the level would be not high and the main target readers are architectural backgrounded people. Furthermore, the theme of thesis is not digging into deep area of acoustics normally readers are able to get the related facts and hypothesis. In this paper, the research mainly looks for the solutions of window’s sound insulation values that give better solution therefore the paper only describes some basic related terminologies.

- Sound wave

Sound is known as “Wave”, this wave is conveyed by proper medium and the sound wave makes vibration.

- Sound pressure

The medium (normally we are saying air) has the random densities, when the sound wave is moving then the wave should proceed through these variable densities of medium. Therefore, those make the movement between this medium, and this make also the pressures high and low. This variation of wave is sound pressure.

- Wavelength

The length from the highest point of pick and the lowest point of valley is wavelength. The symbol is λ and the unit is m (meter).

- Frequency

The numbers of vibration for one second, the symbol is f, unit is Hz (cycle/second). However the velocity of the sound is very constant, therefore when the frequency is high, the wavelength is short, on the other hand, the frequency is low the wavelength is long. Generally, the longer wavelength has larger energy naturally this sound reach farther than shorter wavelength.

$$f = \frac{c}{\lambda}$$

c : the velocity of sound (≒340m/s), f : frequency (Hz)

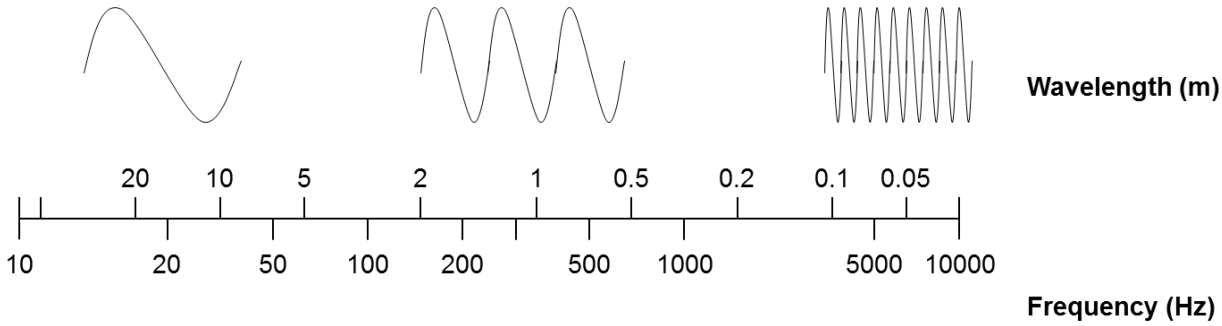


Fig3. The relationship of frequency and wavelength (Kim 2010, p.15) [8]

When we are standing wide and opened area if there is a musical band's playing, we usually can hear the sound of drums or percussions first than later other instruments which have high frequencies could be heard. The reason is the lower frequency has long wavelength and lager energy.

▪ Sound power and sound intensity

Sound power means the total energy from the sound source, unit is W(watt). This sound power is indicated the surrounded area of sound source multiply the sound intensity.

W = I x S

I : surface sound intensity (W/㎡)

S : sound source's surface area of emissivity (㎡)

The sound's energy volume which get through the perpendicular unit are of one ㎡ per one second is sound intensity

$I = v \times P$ (W/㎡)

P : sound pressure

v : velocity of particle

▪ Sound intensity level (SIL)

The level of the sound's size is sound intensity level, the unit is dB. The

initial of the sound intensity level is I, Io is the normal hearer's minimum intensity, indicated 10^{-12} W/㎡, therefore usually presented (decibel, dB)

$$\mathrm{SIL} = 10 \log \frac{I}{I_o}$$

I is the intensity that we are comparing.

$$\mathrm{SIL} = 10\log(\frac{P^2 \div \rho c}{I_o})$$

$\rho c \fallingdotseq 400$, $I_o = 10^{-12} W/m^2$, therefore

$\mathrm{SIL} = 10\log(\frac{P^2}{4 \times 10^{-10}}) = 10\log(\frac{P}{2\times10^{-5}})^2 = 20\log(\frac{P}{2\times10^{-5}})$ = Sound pressure level (SPL)

- Sound Pressure level (SPL)

Sound pressure level also indicated as decibel. The symbol is P and the unit is Pa.

$$\mathrm{SPL} = 20\log(\frac{P}{P_o})$$

The P is the pressure that we are targeting P_o is the standard pressure, 2×10^{-5}Pa. This standard sound pressure at 1,000Hz is the minimum sound pressure that human can hear. The table below shows the proper examples.

Table1. Sound pressure and level of acoustic pressure (AGC INTERPANE 2014, p.54) [11]

Effect	Example	Sound Pressure p(Pa)	Acoustic Pressure Lp(dB)
Blackout		**200,000**	**200**
			190
		20,000	180
			170
		2,000	160
			150
Pain Threshold		**200**	**140**
	Aircraft Engine		130
Danger	**Klaxon**	**20**	**120**
	Lawnmower		110
	Metro Train Arriving	2	100
	Large Ochestra		90
	Heavy Traffic	0.2	80
	Busy Street		70
	Loud Voices	0.02	60
	Quite Apartment		50
	Normal Voices	0.002	40
	Quite in the Mountains		30
	Whispers	0.0002	20
	Slience in the Desert		10
Hearing Threshlod	**Total Silence**	**0.00002**	**0**

- White noise, pink noise

If an experimental environment or equipment mixes all the sounds that human can hear, the frequency wavelength, phase continuously change. A noise that has the random spectra called ‘white noise’. The white noise now constant sound volume however, human ears feel the higher frequency more; therefore architectural noise assessments normally use this white noise for measurements. On the other hand, on high frequency, ‘pink noise’ sound volume decreases then normally on low and medium frequencies human ear feel higher sound volumes. Then pink noise hears constant noise to listener even it has same amount of sounds. In conclusion, when technicians measure the status of music hall, they generally use the pink noise to check meanwhile for the overall architectural tests, they measure with the white noise. [9] The reason to differentiate these noises is supporting the one test which used the pink noise at chapter 2.3.

- Sound insulation / Sound Proof

The terms of the reduction of sound energy transmitted into adjoining air space. Later both are going to be used on the field of acoustics and practical building industries however these terminologies definitely different.

- Sound absorption

It is a reduction in the sound energy reflected by the surfaces of a room.

- Airborne sound

This term is one way of the noise transfer. Airborne sound is the sound that travels through the air before reaching a partition however additionally if the vibrations in the partition that also started by this sound then it should combine as same meaning.

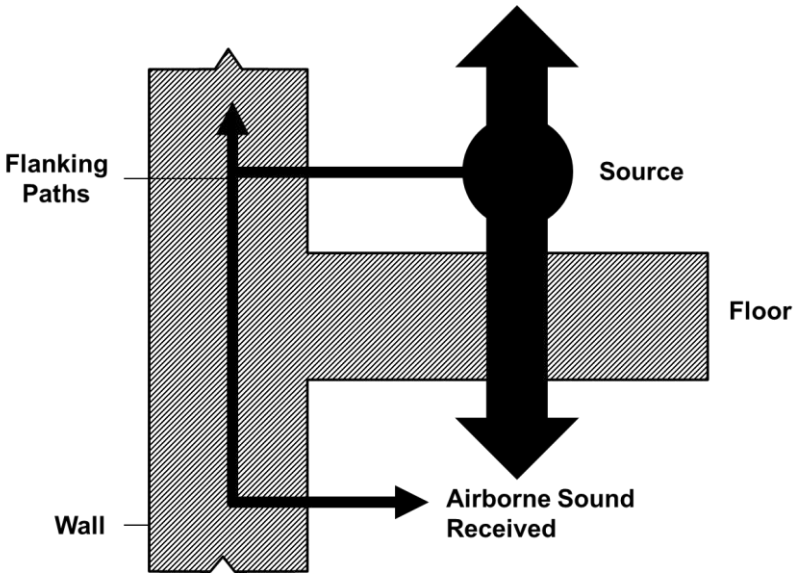


Fig4. Airborne sound transmission (McMullan 2007, p.191) [10]

- Impact sound

This is the sound that is generated on partition. The typical sources of this sound are footsteps, sound of door-slams, windows, noisy pipes and so on.

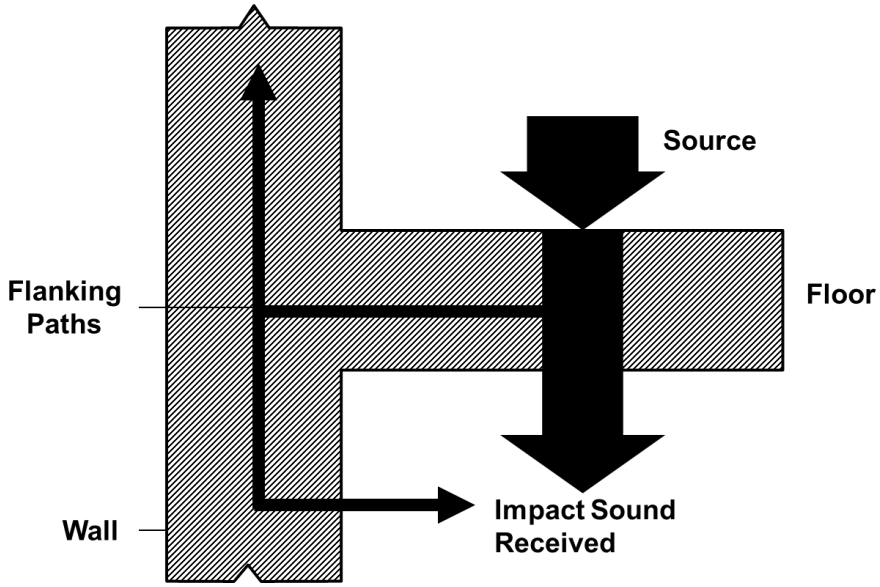


Fig5. Impact sound transmission (McMullan 2007, p.191) [10]

- Weighting scale

When deal with frequency content of sound, sound level meter which measures the sound pressure level can emphasise or give 'weight' to the frequency. These weighted scales are adjusted, for example 'A' is for human hearing sense, that indicated as dB(A). Weighted value C is for analysing frequency itself. D is using for airplane's noise, Z means plain content. This study and many of architectural measurements are using A scale when they notify the measured values by sound level meters and laboratorial experiments.

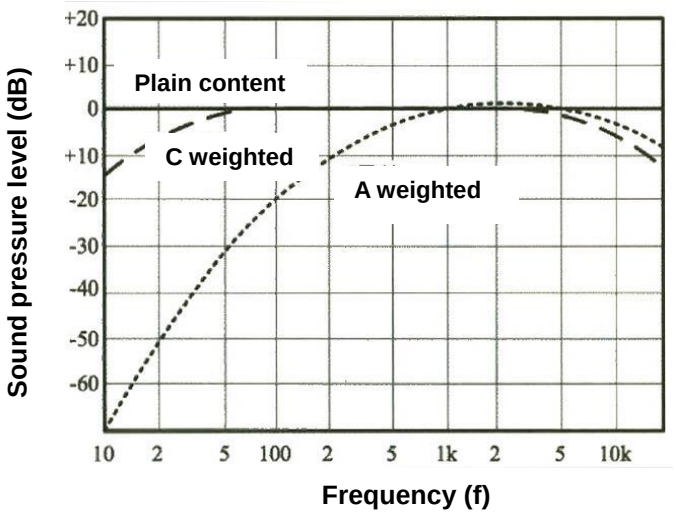


Fig6. Sound lever meter's weighting filter (Kang, S. 2012, p.21) [9]

2.1.2. Sound proof theories

This means the prevention from the sound transmission that submitted the reflected sound and absorbed sound. The way of sound proof indicated the transmission loss on every frequency.

Sound Transmission Rate (STR) (τ) = $\frac{I_t}{I_i}$

I_i is the sound intensity of the incidence. I_t is transmitted intensity.

The transmission loss is

TL = $10\log(\frac{1}{\tau})$ (dB)

For example if we compare with same thickness of concrete and veneer,

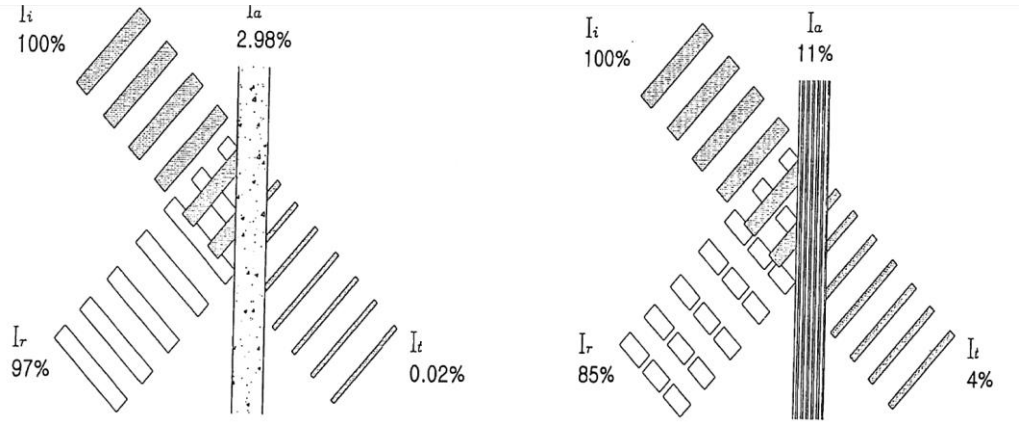


Fig7. Concrete and veneer's transmission loss (Kim 2010, p.310) [8]

① in case of concrete wall

$\tau = \frac{I_t}{I_o} = \frac{0.02}{100} = 0.0002$ therefore $\mathrm{TL} = 10\log\left(\frac{1}{0.0002}\right) \fallingdotseq 37\ \mathrm{dB}$

② in case of veneer

$\tau = \frac{I_t}{I_o} = \frac{4}{100} = 0.04$ therefore $\mathrm{TL} = 10\log\left(\frac{1}{0.04}\right) \fallingdotseq 14\ \mathrm{dB}$

If we have to calculate a composite wall, we need to imply total transmission loss.

$\mathrm{Total\ loss} = 10\log_{10}\frac{1}{total\ \tau}$ (dB)

$$\text{Total } \tau = \frac{\sum S_i \tau_i}{\sum S_i} = \frac{S_1\tau_1 + S_2\tau_2 + \cdots + S_n\tau_n}{S_1 + S_2 + \cdots + S_n}$$

S_i : the area of the wall (㎡), τ_i : the transmission loss of the wall

Therefore the total transmission loss would be

$$10\log_{10}\left(\frac{\sum S_i}{\sum S_i \tau_i}\right)$$

2.2 Transmission Loss of Windows [12]

These paragraphs borrowed the ideas of main descriptions from a book that originally focused on acoustic science, “Schallschutz und Raumakustik in der Praxis” (Sound Insulation and Indoor Acoustic in the Practice, Fasold & Veres, 1998) particularly this paper translates and re-explains those window parts for thesis elements.

Window is one of the most complexed elements among the construction materials. To compare with other construction materials, it should provide multi-functions such as visibility, light transmission, heat insulation, weather proof, structural role and sound proofs and so on. Nevertheless, window is the one of the weakest part of the building components. However generally the performances of sound proof of windows have been shown like below:

Table2. Standard window’s sound proof performances (Schüco, 2013, p.73) [13]

Windows	Glass Composite	Winodw Rw	Glass Rw
75mm Series	6 / 12 gas / 6mm	37	35
90mm Series	4 / 12 gas /4 /12 gas/ 4mm	33	32

According to Interpane’s technical manual standard double glazing starts their value from 29 dB up to 40 dB, with the laminated special acoustic glazing shows 52 dB, similar result was shown by Guardian 51 dB. [11, 14]

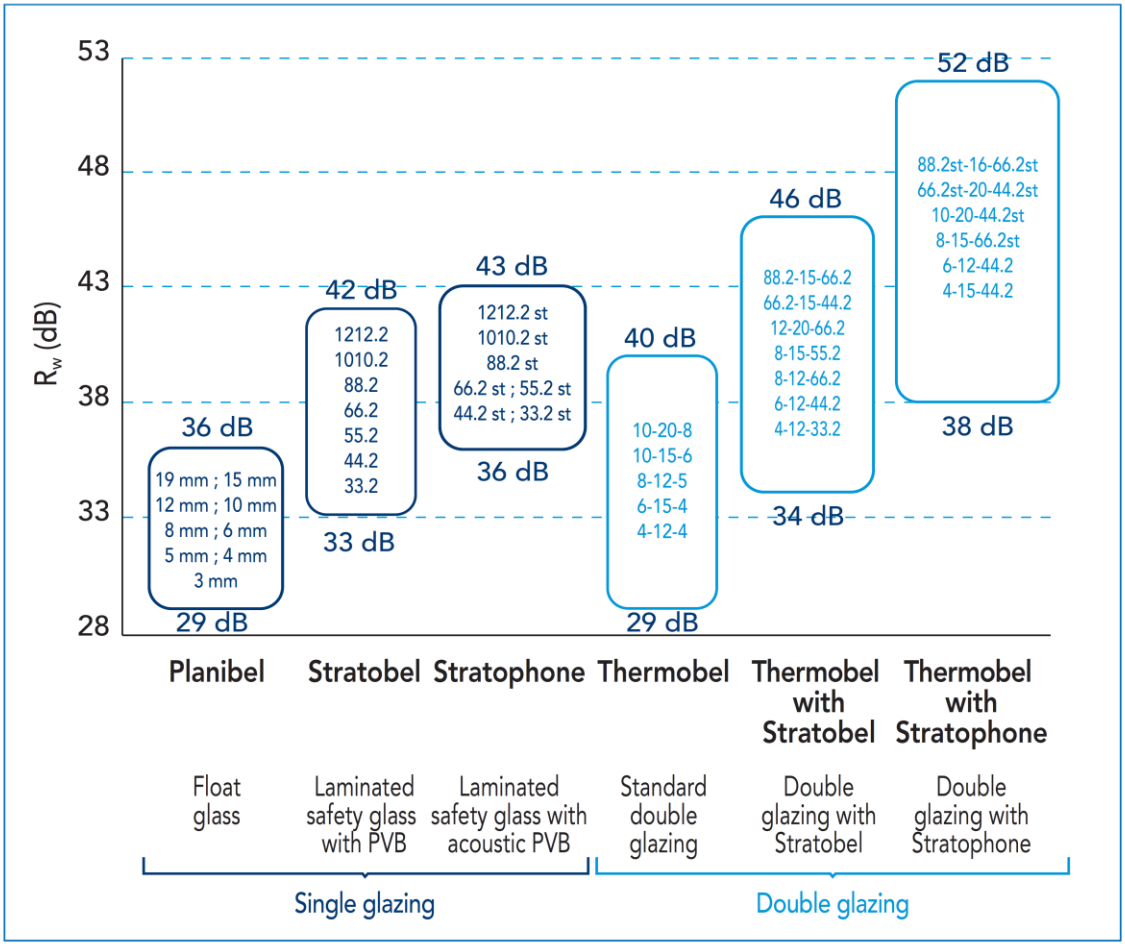


Fig8. Acoustic performances of glass performances (AGC INTERPANE 2014, p.142) [11]

Then what are the methods of improve their performances especially for this sound proof? Here the paper describes several ideas that many former scholars already had proven.

2.2.1. Laminated glass and raising the weight of glasses

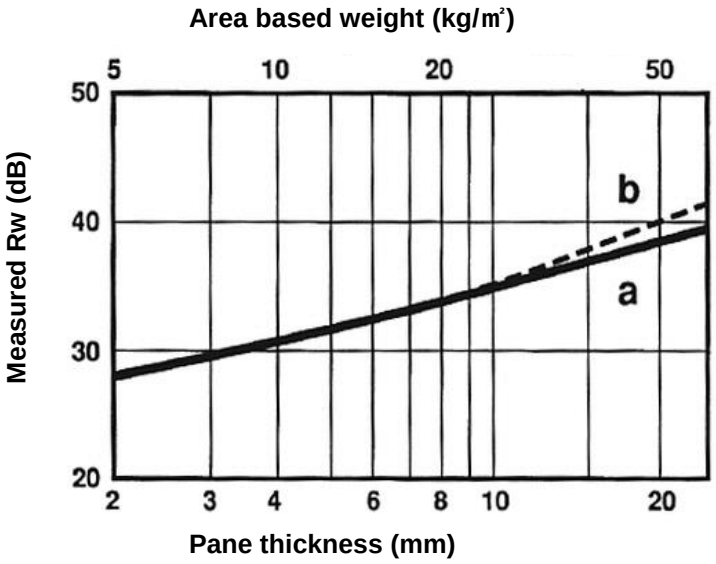


Fig9. Sound attenuation measure (FASOLD & VERES 1998, p.283) [12]

It is known that normally if the weight of glass is increasing, the sound proof, sound transmission loss is simultaneously increasing. At the same time if the glass was composited with laminated glass for safety or sometimes for sound proofing, from the thickness of 6mm, the performance would more increase. As shown, it is basically mentioned about single glazing. However depend on the climate conditions, firstly the glasses would be coupled or tripled for the performance of heat insulations. These fabrications also help the sound insulation of glazing and windows, but it should be realized under certain conditions.

2.2.2. Relationship between the layers

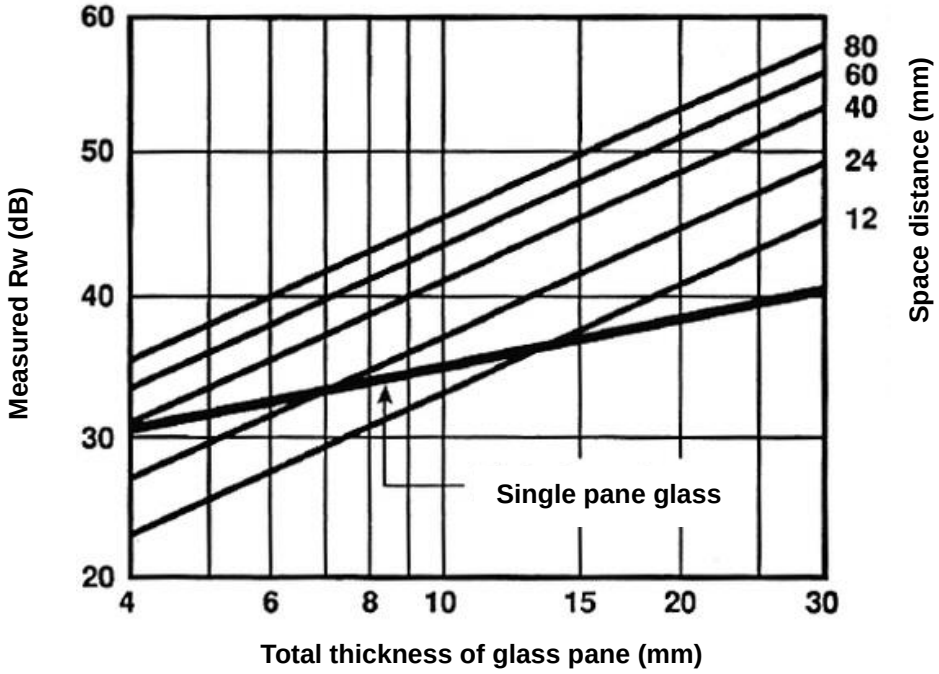


Fig10. Sound attenuation measure Rw of double glazing with single glazing (FASOLD & VERES 1998, p.284) [12]

To differentiate the sound transmission loss, in case of double glazing, the distance of the two panes should be 16mm. Shown as above figure, until the same thickness of 8mm, the single pane and the doubled total 8mm glazing are same, even the space gap is up to 12mm, the performance is not significantly different from the single, therefore the double glazing should at least to maximize the sound proof, the space gap needed to be 16mm.

2.2.3. Gas variation

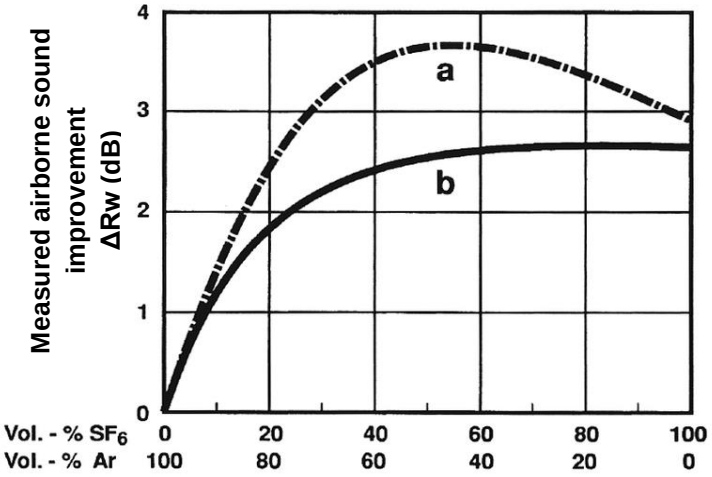
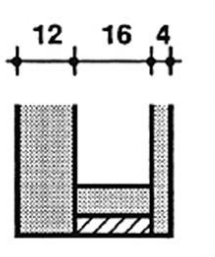
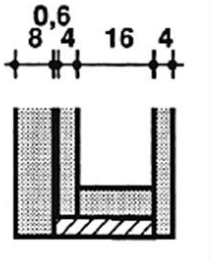
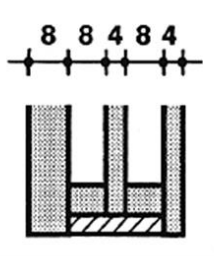


Fig11. Measured airborne noise improvement ΔRw, caused by a mixed gas mixture as Ar / SF6 mixing ratio using the example of two typical insulating glass systems (FASOLD & VERES 1998, p.285) [12]

Above results only assumed the gaps that filled with air when the fabricators made. Commercially in the glass fabrication industry for improving the heat insulations the project owners or contractors order the argon gas, and the results usually improved up to 0.3~0.4W/㎡. Ironically on this combinations of gas, in case of the mixture SF_6 (Surfide Hexafluoride) and argon gas, the assemble of glass panes, the 6mm pane, 12mm gas, 4mm pane would be recommended. According to the book, when the gas gap is 12mm, the heat insulation performance would be the best to catch the sound insulation together. However maximised sound proof of the assembling recorded at 50%, 50% ratio of SF_6 and argon gas. Meanwhile the assembly of 8mm pane, 16mm gas, 4mm pane, argon gas should be filled less than 40%. Even these results are unique, at the commercial fields, SF_6 gas is not widely using. Additionally the comparison between the air filling, argon filling and SF_6 filling with various panes are showing such as Table3.

Table3. The relationship between types of gas and glass distances (FASOLD & VERES 1998, p.287) [12]

Glass assembly			
Air-filling	Rw=40dB Ug=2.9W/m²K	Rw=41dB Ug=2.9W/m²K	Rw=38dB Ug=2.1W/m²K
Argon-filling	Rw=40dB Ug=1.5W/m²K	Rw=41dB Ug=1.5W/m²K	Rw=38dB Ug=0.7W/m²K
SF_6-filling	Rw=43dB Ug=2.9W/m²K	Rw=44dB Ug=2.9W/m²K	Rw=41dB Ug=2.1W/m²K

2.2.4. Tight sealing

As we have seen above the finding out with the improvement of sound insulations of gas filling windows only have minor effects. Sounds should be prevented at windows move with air therefore the air tightness should be taken into account. No leakage space should be allowed to improve the performances naturally the following ways are the examples

- folded locking
- staggered sealing layers
- maximised distance between seals
- fittings adapted to the weight of the window
- soundproof installation of the glazing in the window frame
- professional wall connection

The second possibilities to improvement are the fittings and gaskets. As known as 20~30% of the area is the window frame from total window set. However exclude the frame, fittings and gaskets are essential to seal the main leaking points. Especially during the process of installation, these elements have to be handled very carefully to prevent from any kind of disconnections. Third, some experiences show that the values of the sound insulation of the windows of the buildings, which are measured in the laboratory often significantly, make huge differences about 10dB, normally these critical differences are from leakage of joints. Various types of suitable elastic sealing products are available for this purpose, especially

elastic or porous materials have those functions.

2.2.5. Material of frames

Sometimes the materials of the frames help the improvements. In case of studio, normally it requires high levels of sound proof, sound attenuation, such as over 60dB. In order to be satisfied with this requirement, multi layered windows or large spacing is using. As a common sense and occasional selection of the materials are metal series, however if it choose the wooden frame, it indicates up to 66dB. Fig12 shows the one example of the experiment that performed at wooden framed window.

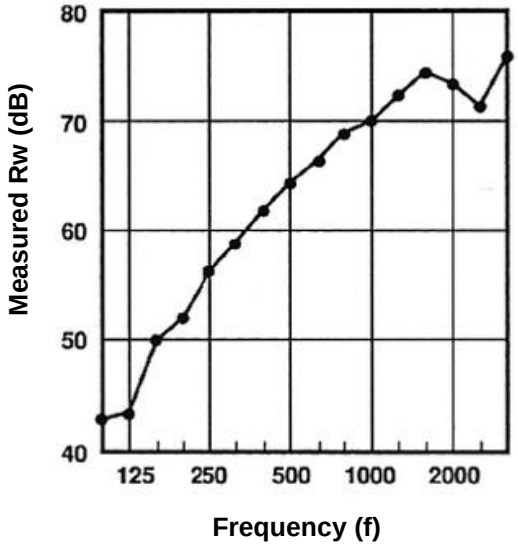
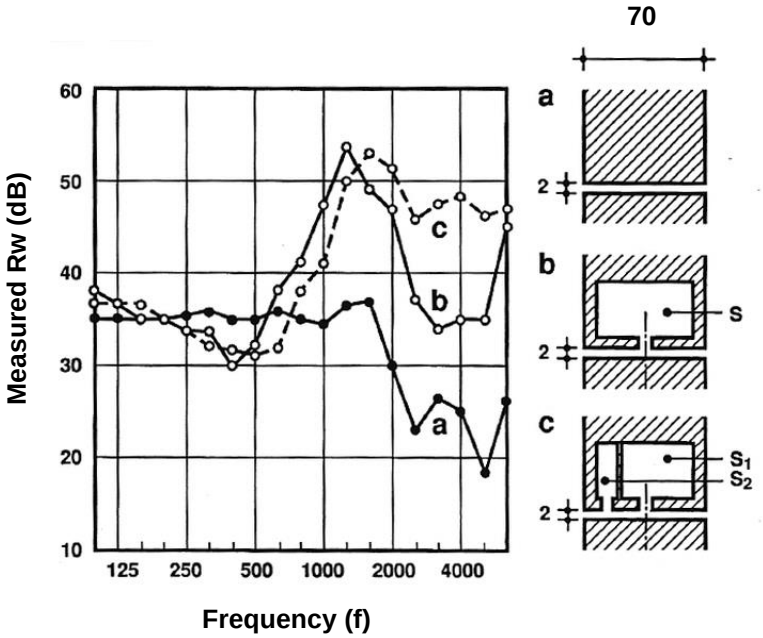


Fig12. Sound insulation result of a studio window with wooden frame that measured in the laboratory. Panel consisted of 8mm float glass, 130mm space gap, and 11mm laminated glass and recorded 66dB (FASOLD & VERES 1998, p.289) [12]

2.2.6. Resonators

In some special cases of construction, single or multiple kinked joint sequences or coupled cavities could act as helical resonators. If the window that has large frame can adopt this kind of structure. This theory comes from Helmholtz resonator that maximise sound absorptions. This matches to the frequency range of resonance like amplified sound transmission through the joints.

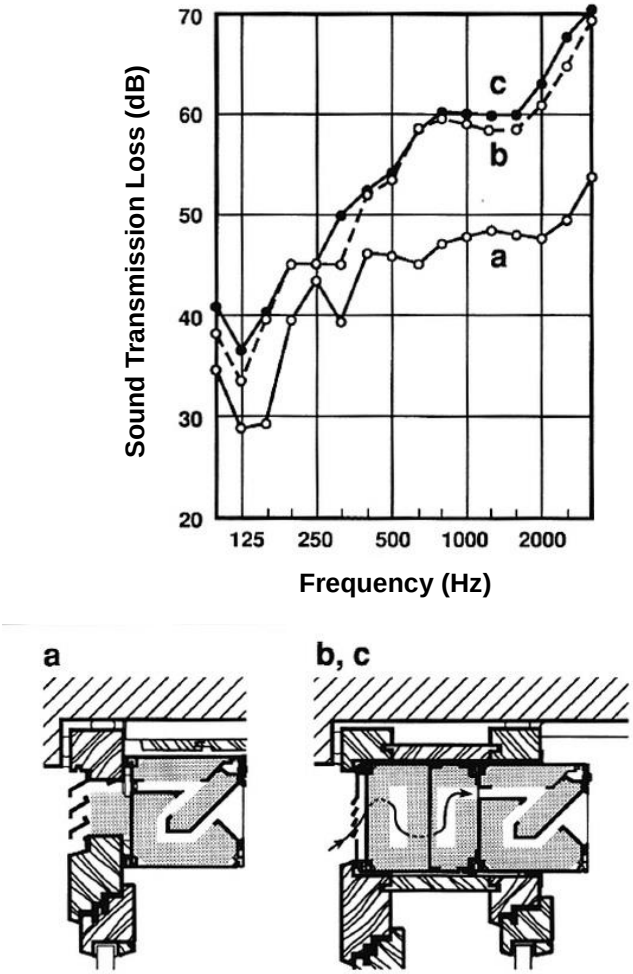


A without resonator: 32dB
B with a cavity as a resonator S=1600mm: 38dB
C with two cavities S1=1200mm, S2=400mm: 39dB

Fig13. Joint without resonator and with resonator (FASOLD & VERES 1998, p.289) [12]

2.2.7. Ventilation systems

In the opened status of window, sound insulation capacity naturally decreased. The performance comparison will be described later with commercial products however the ventilation function is one of the essential parts of windows. Ironically, significant time of the ventilation is night therefore; windows often have the function of so called “night ventilation”. During this time the occurred noise bothers the residents therefore the noise level should be acceptable. Generally, the noise problem and the ventilation assignment in the window industry make conflict and those need compatibility. As a result, the ventilation kit equips labyrinth structure to absolve more energies of sound during the traveling way of noise; the absorbing materials effectively work to reduce the sound. Fig14 shows the examples of the experiments and later the commercial products example will cover more details.



A built-in depth 158 mm, without ventilation blowing = 47dB
B Built-in depth 308 mm, without ventilation blowing = 55dB
C as B, with blowing = 57dB

Fig14. Sound level differences of sound insulation ventilations (FASOLD & VERES 1998, p.294) [12]

NOTE

- **Traditional studies showed the acoustic performances by tight sealing, resonators, and mostly depended on glass variations such as thickness, air spacers.**
- **For ventilation purpose, they limitedly found out the opened status noise reductions.**

2.3. Contemporary researches of noise control on windows

2.3.1. Active noise control

As mentioned the main purpose of these kinds of researches had started from the compatibility of ventilation and noise control. Contemporary window sets have developed, kept those pace with the other related industries' evolutions. As results, normally when the occupants close the windows the sets perform promptly by those original functions. In case of sound-proof, depends on the performances of glasses, thickness, materials and the tightness of their sealing. The users could be satisfied with designed outputs about acoustic aspects. Now, the problem occurs by ventilation. As widely known as in architectural fields, mechanical ventilation itself has the fundamental drawback, the mechanical sounds. However here as the basic review of the sound-proof method as the way of prevent from the noise outside, and to search more economical way the controlling the motorized ventilation system would be not stated. That means this paper more specifies rather natural ventilation with sound-proof the mechanical ventilation combinations. The one of the original concepts of the active noise control is like below:

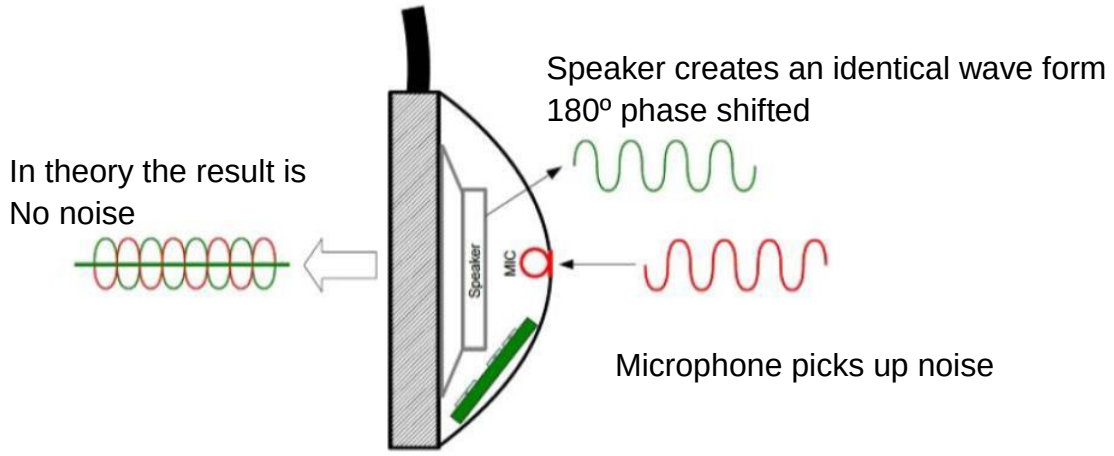


Fig15. Active noise control feed forward block diagram in the headphone (GETHER 2013) [15]

The active noise cancellation technologies are widely using all over acoustic engineering such as electronic devices, automobiles and so on. To help the understanding here is the simple concept of the headphones that we are using mostly in the daily lives. This technology helps to listener to hear the sound that the listener only wants. However for example when a music

listener stands on a street, in a vehicle or other locates on a noisy place that provides the un-wanted sounds the listener by him/herself cannot filter the sounds out. The active noise control normally senses by itself by the microphone and recognised these un-wanted sounds and makes reversed purse then it could neutralised the waves through the speaker. Historically this technology has been studied from 1950s, however in 1984 Sennheiser developed the first commercial product that had ordered by Lufthansa airline's inquiry for pilots. The main reason of the invention was intention that to prevent from pilots' hearing loss after their retirements. From 1987, the companies such as Sennheiser and Bose authentically have developed and popularized their series of the commercial products in headset markets. [16] European Standard also defines this technology and the theory what the active noise cancellation technology is. [17]

Fig16. A commercialized product of active noise cancelling headphone, it has smaller ear cap than passive noise cancelling headphones [18]

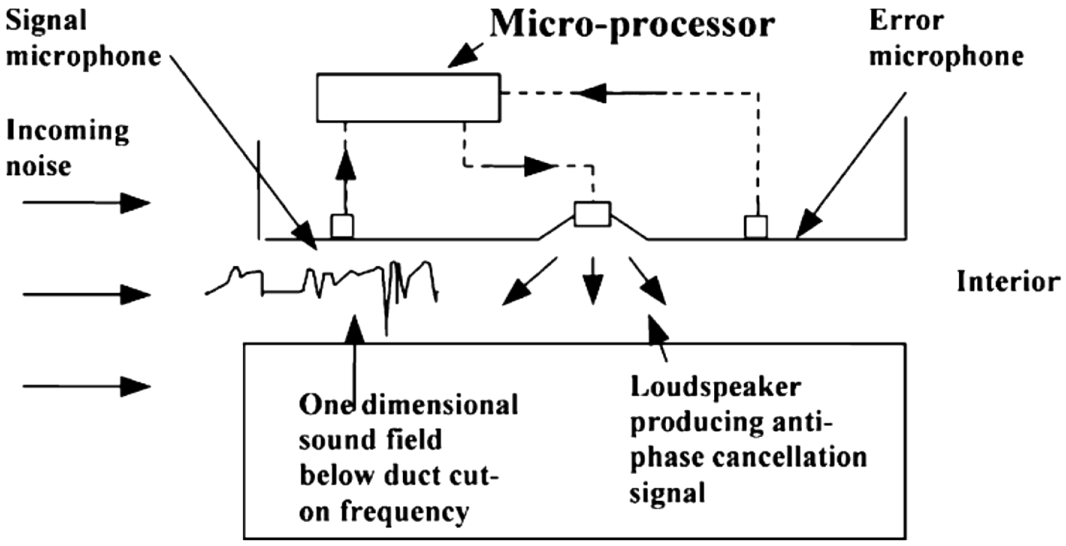


Fig17. Schematic active noise control on window (OLDHAM et al. 2004, p.122) [19]

Oldham et al. used and indicated the active noise control as the Fig17, due to the window system need the ventilation slots or ducts. The active noise control systems mostly adopt duct system, which means the window frame should install the attached or hidden active noise control somewhere. There are two microphones, one is the signal or reference microphone, another one is error microphone. When the outside noise comes in the signal microphone understands and conveyed to processor or controller, then the processor orders to let the sound to be as “reversed purse” and presented by the loudspeaker. Along with the error microphone system gives the result of the mixing then the controller works again. In accordance with Carme et al. they suggested the labyrinth structure to reflect the sound directions and to expose the area through the labyrinth path to absorb on this active noise control. [20] Their further study with Fraunhofer Institute for Building Physics (IBP), basically IBP designed as an active noise control system module which has the function of the active noise control function for the window system.

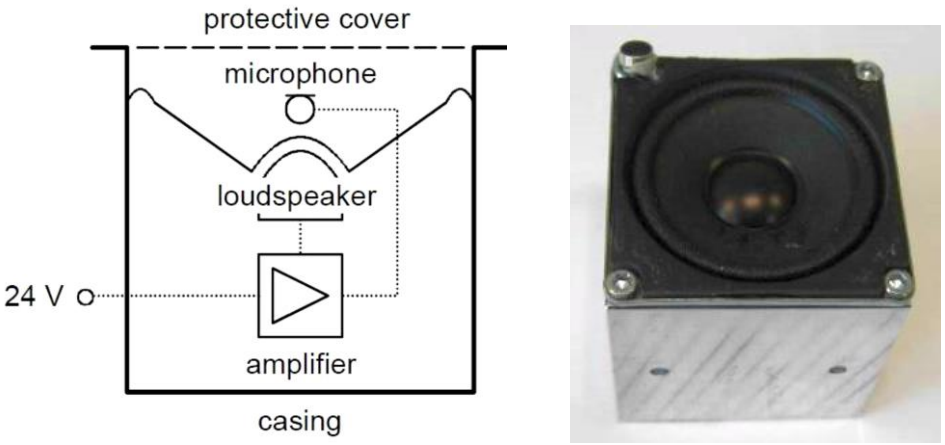


Fig18. Active noise control module designed by IBP (CARMER et al. 2016, p.4) [20]

Additionally TechnoFirst had experiment that based on the module. They created the box-typed testbed that has one window set and five active noise control modules. Specifically the test set consisted of one controller, one reference microphone, and five loudspeakers. On the process of the test-sets can measure and express those criteria:

(1) Active window set that has normal duct-shaped active noise control system that also includes absorber

(2) Active labyrinth feedforward set which has refracted duct structure

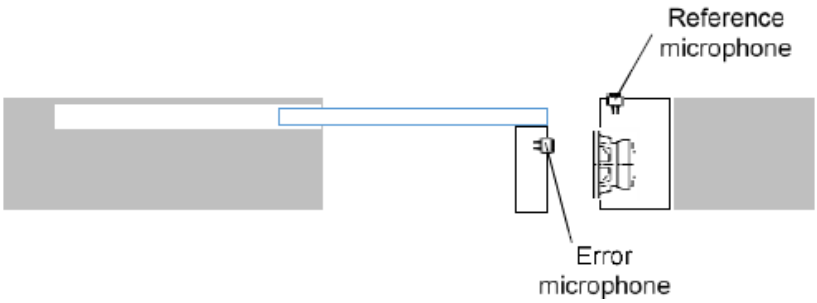


Fig19. An active window (CARMER et al. 2016, p.3) [20]

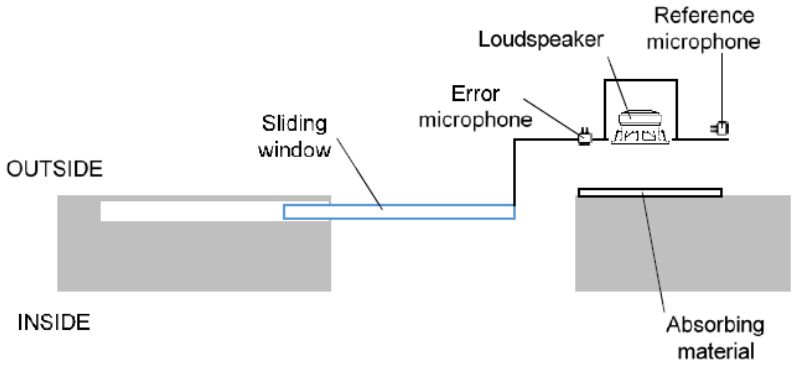


Fig20. Active labyrinth feedforward set (CARMER et al. 2016, p.3) [20]

The results show as Fig21 and Fig22. According to their summaries, the model (1) had the maximum result as 15.5dB, during only the passive model showed 3.6dB. Meanwhile the model (2) reached 16dB and the passive model had 3.5dB. Literarily the numeric results are almost same however, the labyrinth model (2) has meaningful reductions on the higher band. The next figures show the differences:

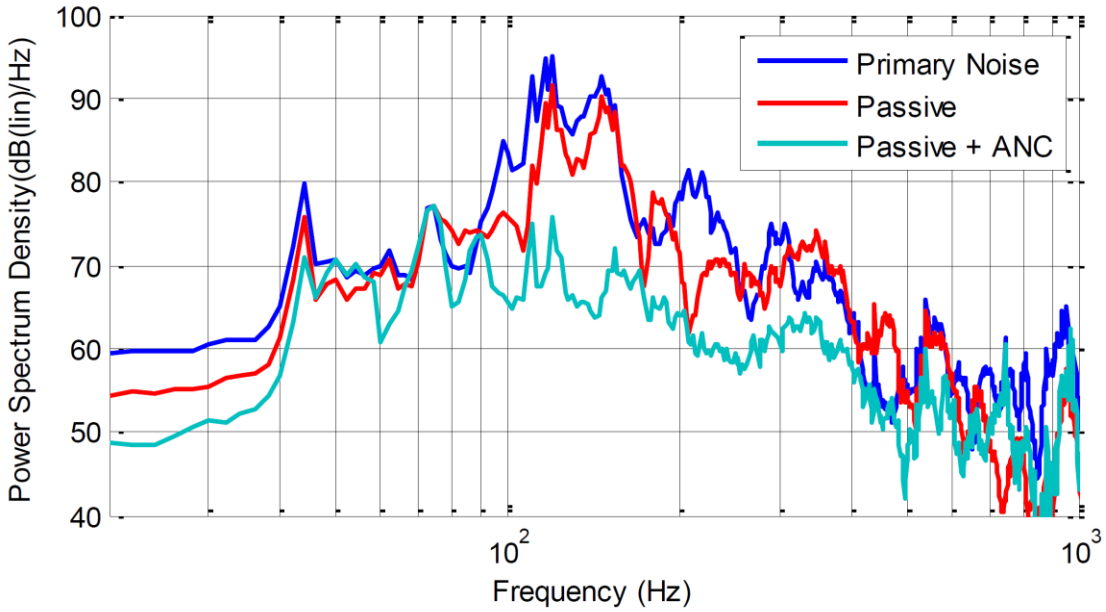


Fig21. Performances of the active window configurations (CARMER et al. 2016, p.6) [20]

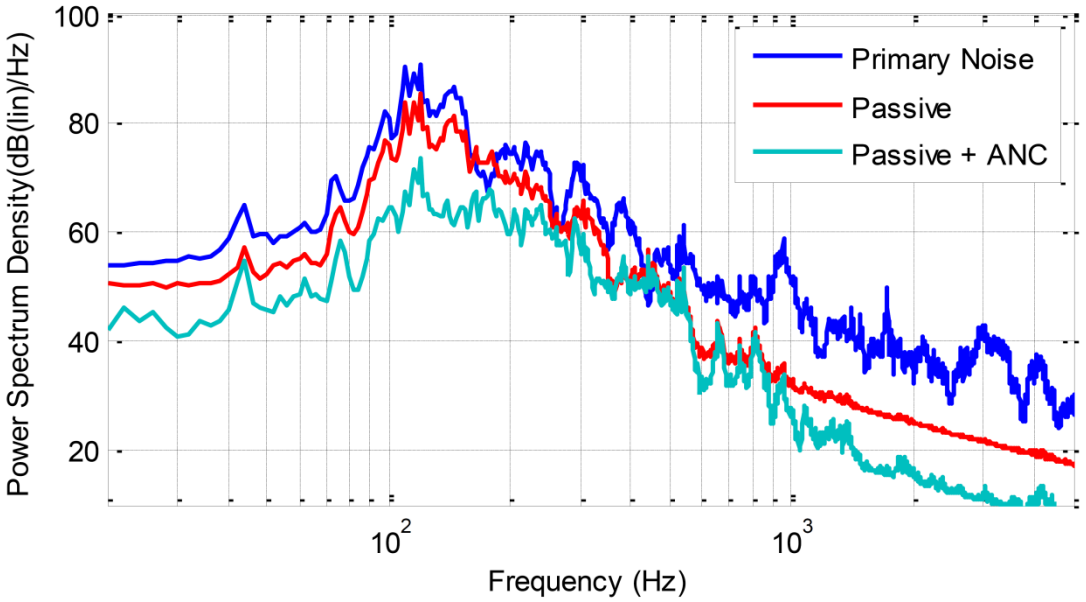


Fig22. Performances of the active labyrinth configurations (CARMER et al. 2016, p.6) [20]

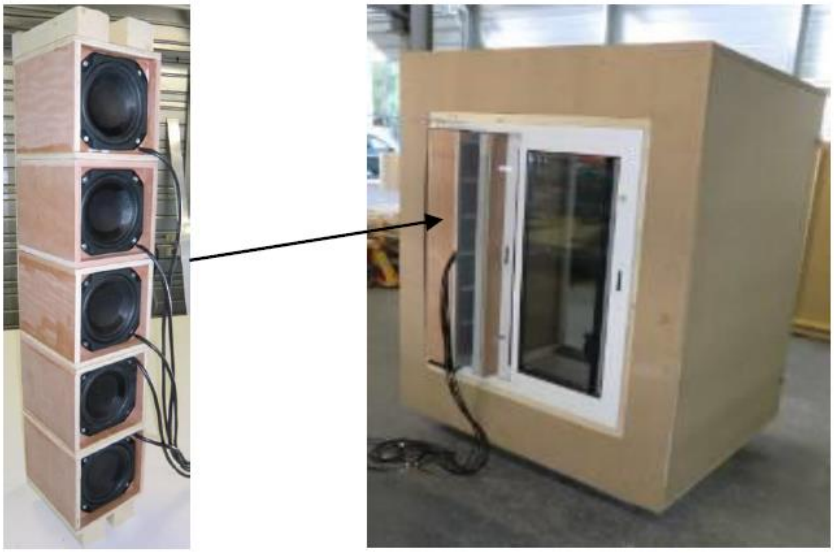


Fig23. Test model of active noise control window (Carmer et al. 2016, p.5) [20]

During the literature survey, the author found two other similar however particular researches. Oh presented the 2rd International Conference on Innovative Engineering Technologies (ICIET 2016) in Bangkok Thailand, especially about pink noise and music. [21] His experimental setup consisted of a box with small path as a window. The window size was 0.12m x 0.19m during the length was 0.52m. The window itself was a duct type active noise control window. The results show the pink noise and music 6.4dB(A) and

9.4dB(A) each, those were interested because normally as well known the active noise control has benefit against low frequency noise sources. However, at these experiments the system also has the advantage on pink noise and music on the medium and low band as well.

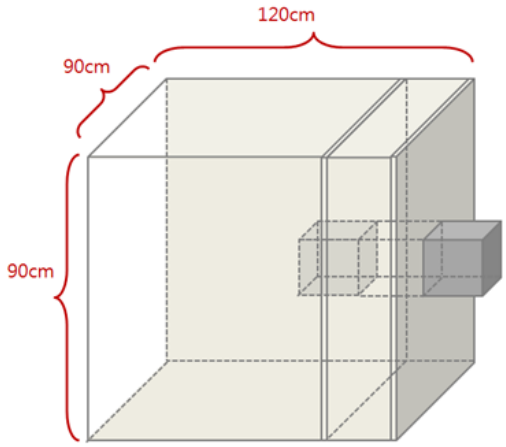


Fig24. Experimental setup of duct type window (OH 2016, p.2) [21]

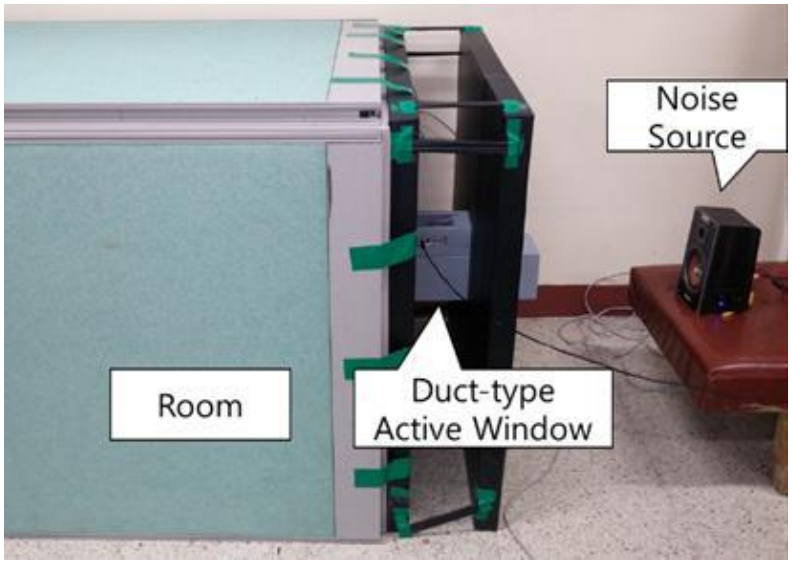


Fig25. Picture of the setup (OH 2016, p.2) [21]

Table4. The average sound pressure level in the room (OH 2016, p.3) [21]

	ANC off	ANC on	Differences
Pink noise	68.2dB(A)	61.8dB(A)	6.4dB(A)
Music	69.9dB(A)	60.5dB(A)	9.4dB(A)

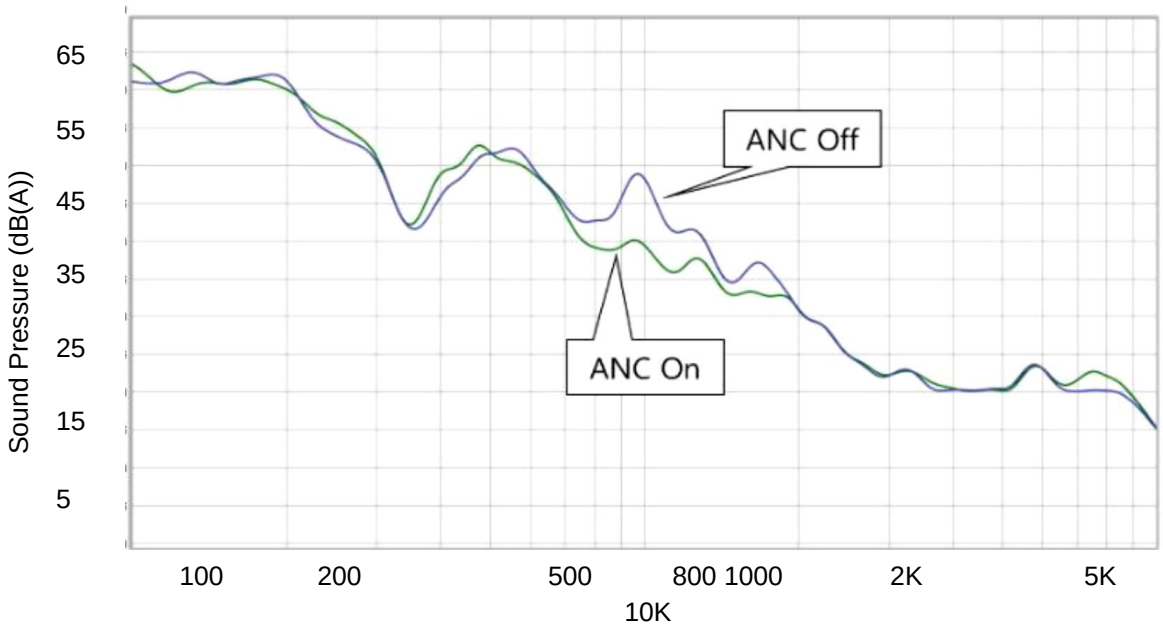


Fig26. Averaged spectrum at the error microphone with and without active noise control (Oh 2016, p.3) [21]

It is known that the low-frequency noises were caught effectively by active noise control, but what is the reason? Kwon and Park also had experiments with similar models. [22] Their main directions were two the first one was how to design the active noise control system inside the window system because the microphones, controllers and speakers themselves occupy the specific spaces of systems. The second one was to focus on low frequent noise that already known effectively cancelled by the system however; they tried to verify their test models were like below images:

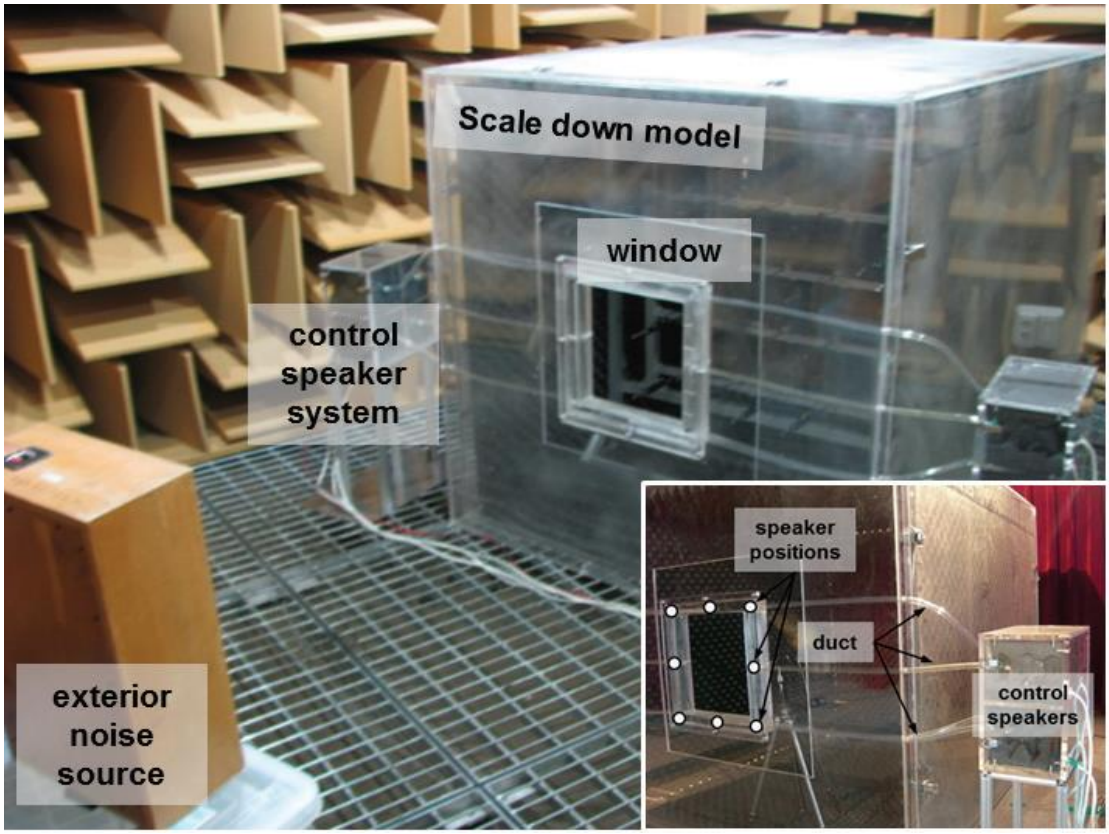


Fig27. Experimental setup and control speaker system (KWON & PARK 2011, p.825) [22]

The test box's size was 1.2m x 1.5m x 1.2m and the window area was 0.3m x 0.3m. Their results showed the Fig28 and expressed under 700Hz the control index was approximately 10dB. About their second focus, the high frequency, they mentioned it depends on the size of the openings of windows however the high frequent noise has short wave lengths therefore those usually have complexed directions. Additionally it has spatial aliasing therefore the active noise control system hardly controls from the location of edge of the wall. That means on the other hand that is the reason the porous passive systems effectively control the high frequent sounds. As the Fig28 indicates the active noise control effects to the low-frequency noises, meanwhile the curves of the conventional windows perform normally better at the reverse ways, such as the high waves in the high-frequency bands.

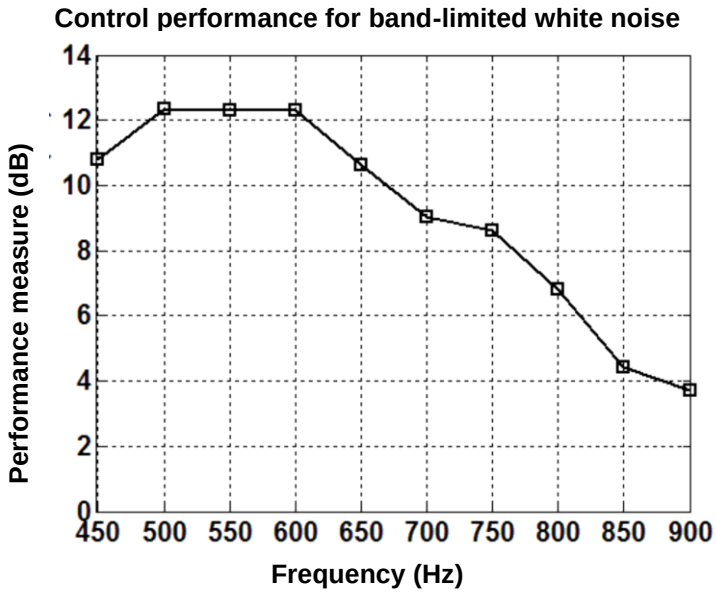


Fig28. Performance measure as the frequency (KWON & PARK 2011, p.826) [22]

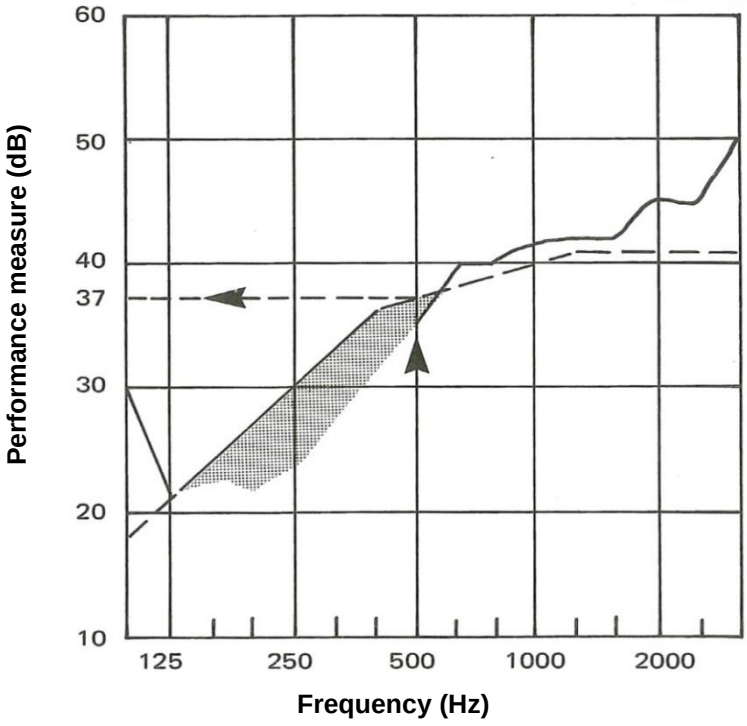


Fig29. General measurements of the sound proof of windows (GLÄSER et al. 1992, p.47) [23]

De Salis et al. they steadfastly identified various noise control systems with literature and other studies. [24] They summed up one of the powerful advantages of active noise control is the highly efficient at attenuating low frequency noise. Especially the traffic noises are mostly located these low

frequency band, therefore the prevention from traffic noise and the buildings such as located roadsides and near the airport this option would be essential to avoid. According to their search, Leventhall and Wise found 10-19dB between 63 and 400Hz. [25] Bai and Lin recorded up to 20 dB under their certain test circumstances. [26] De Salis et al. without hesitation, pointed out the drawback of active noise control is the consumption of energy however the total use of electricity is not critically high particularly the microphone, speaker and controller system. In common sense, those devices unlikely consume away such as heating devices, therefore the problem itself is minor thing. Separately recent trend of electric gadgets, reduce the total energy use in the future this hurdle would be removed. Nevertheless these active noise control system sufficiently modules of electric devices therefore the system size should be carefully considered.

Until now the automated system on windows are not popular on window or façade markets. In the author's experiences at the industry there are largely three reasons, however these opinions from the analogy of the specific market situations and end-users customs especially in South Korea and few other countries. Therefore it is not the trial to make it generalization of worldwide phenomenon definitely at this moment the electric supporters for the window sets are not so popular thus this would be purely hypothesis from the personal experiences.

First, the special experts should maintain the electric devices, in particular the ventilation systems or noise control system unavoidably located outside or exposed. Even it located other place it, water drops, moistures, winds and dusts often affect to the functions of ventilation. If the devices have much complexity to handle them, the maintenance issue would be more serious than avoid of the noise. The maintenance should be quite easier than other Do-It-Yourself items however; it is not apt to apply. For instance in the automobile industries end-users are able to change such as air conditioner filters by their own, on the other hand to change the muffler system is the specialists work boundary.

Second, this window industry has to consider installation works. The devices should be designed as a kit for plug-in item however the kit also should be tightly co-worked with window manufacturers. The device makers must provide them to window makers to let them do not complicated things. At the end of the most problematic supply chain is normally installation. Many of window installers do not directly belong to window fabricators, therefore the installation companies also should temporarily bring the people by human-resources markets or their familiar networks of suppliers. As a result, the installation training of the systems themselves would be the remained issue. Therefore, a kind of active noise control system or similar kits usually

need the special work forces that were highly trained.

Third, the end-users should overcome the psychological barrier to use some electric devices on building. Already in window industry and consumers' market, numerus electric systems that help better solutions for window performances. Nevertheless, this long-term habits neglect those breakthrough features frequently. For example in Germany, most of the people still use the key sets rather than adoption of the number locks or card key systems. There are many reasons to resistant to that however; people feel difficulties to change their old habits. When it comes to active noise control how will normal users see or feel the active noise controller? They could just open and close the windows for their biorhythmic needs during their normal days, how many times would be those activities? How many people seriously care the opened window and want to eliminate stress over the noise? Of course, inventions always run in front of the peoples' needs, and we are able to expect the new devices that do not let us feel the inconveniences. By the way, in the sense window manufacturers should act like pioneer, however it naturally brings the adventures and the following budgets.

NOTE

- **The active noise control basically started for protection of ears of pilots. It is using the reversed phase of the noise that makes the original noise as "Zero" phase.**
- **These technologies performed by many researchers however there is no commercialized product.**
- **This technology is especially effective to low-frequency noises such as traffic noises and even we open the windows, it could work for cancelling the noises.**

2.3.2 Passive noise control

To compare with the active noise control, here the present technologies of the passive nose control would be described as much as minimum. This paper intended to search mainly active noise control; therefore this technology is the one of the comparison examples. It seemed to be developed as one of the method to prevention from the noise when the window manufacturers improved the ventilation systems. Those were more 'passive' than the opening the windows, rather we can call them for the way of the ventilation. That means the window developers wanted to create the

slots for the ventilation use, however the incoming noises were the threat elements. To fulfil the natural ventilation for the human being's health, slots were invented; however they needed to overcome the noise problems from outside. As results, naturally the developers located the porous materials inside the ventilation kits. If the travel ways of the noise and the airs are longer, afterwards the results of the acoustic effects were increasing. Fig30 shows the one of the kits, a Belgian company, Renson developed and would be one good example to see the detail. As we see the brand name of the product 'Sonovent', it targeted 'Sono' as absorption of the sounds and the 'Vent' as ventilation. Furthermore, their performance table says about the relationship between the capacity of the ventilation and the sound reductions. As expected, if one product guarantee relatively large amount of the ventilation, the performances of the sound reduction will decrease.

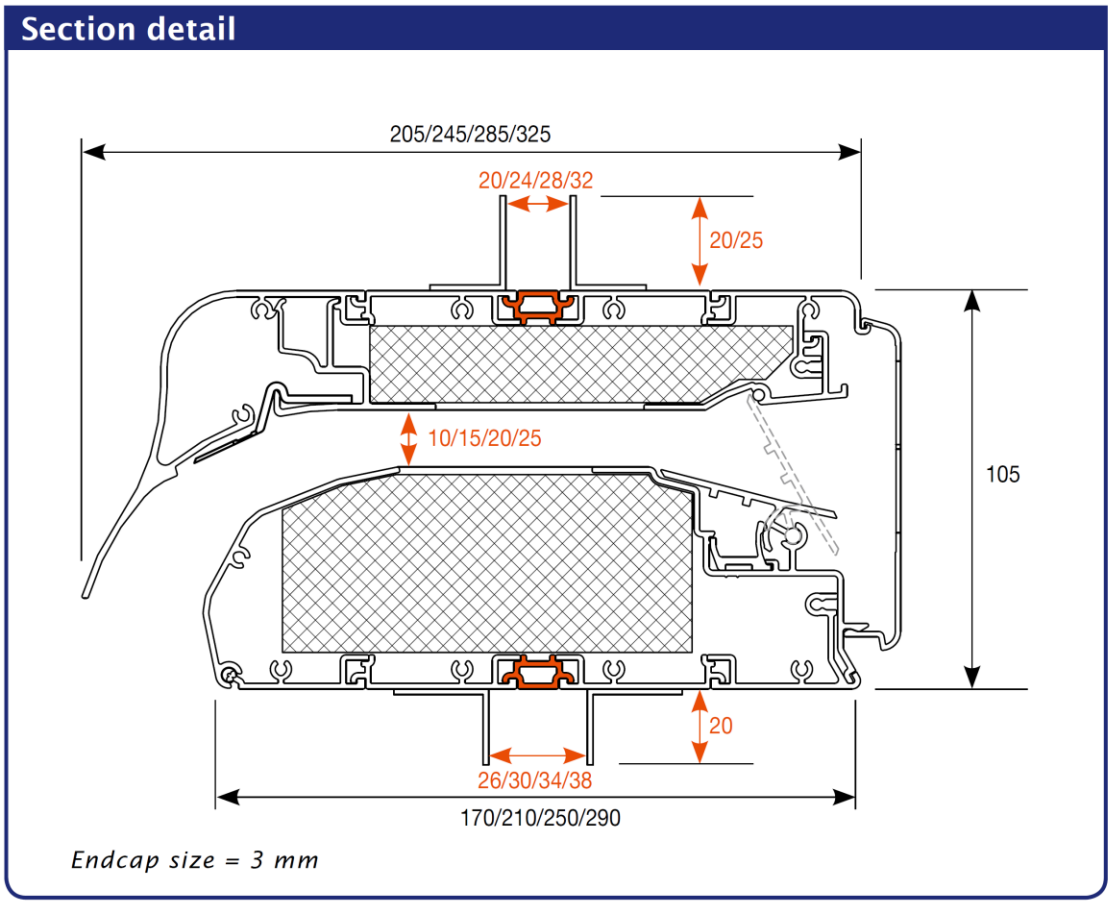


Fig30. A product 'Sonovent' from Renson [27]

Technical characteristics	Sonovent®			
	Small	Medium	Large	Xlarge
Airflow				
Equivalent area				
Air slot 10 mm	17756 mm²/m	17509 mm²/m	16153 mm²/m	14427 mm²/m
Air slot 15 mm	29593 mm²/m	26511 mm²/m	25524 mm²/m	21578 mm²/m
Air slot 20 mm	31813 mm²/m	33292 mm²/m	32059 mm²/m	31073 mm²/m
Air slot 25 mm	33786 mm²/m	34032 mm²/m	33416 mm²/m	32676 mm²/m
Q at 1 Pa				
Air slot 10 mm	14,0 l/s/m	13,8 l/s/m	12,7 l/s/m	11,3 l/s/m
Air slot 15 mm	23,3 l/s/m	20,8 l/s/m	20,1 l/s/m	17,0 l/s/m
Air slot 20 mm	25,0 l/s/m	26,2 l/s/m	25,2 l/s/m	24,4 l/s/m
Air slot 25 mm	26,6 l/s/m	26,7 l/s/m	26,3 l/s/m	25,7 l/s/m
Q at 1 Pa				
Air slot 10 mm	50,2 m³/h/m	49,5 m³/h/m	45,7 m³/h/m	40,8 m³/h/m
Air slot 15 mm	83,7 m³/h/m	75,0 m³/h/m	72,2 m³/h/m	61,0 m³/h/m
Air slot 20 mm	90,0 m³/h/m	94,2 m³/h/m	90,7 m³/h/m	87,9 m³/h/m
Air slot 25 mm	95,6 m³/h/m	96,3 m³/h/m	94,5 m³/h/m	92,4 m³/h/m
Q at 2 Pa				
Air slot 10 mm	14,0 l/s/m	13,8 l/s/m	12,7 l/s/m	11,3 l/s/m
Air slot 15 mm	23,3 l/s/m	20,8 l/s/m	20,1 l/s/m	17,0 l/s/m
Air slot 20 mm	25,0 l/s/m	26,2 l/s/m	25,2 l/s/m	24,4 l/s/m
Air slot 25 mm	26,6 l/s/m	26,7 l/s/m	26,3 l/s/m	25,7 l/s/m
Q at 10 Pa				
Air slot 10 mm	15,3 l/s/m	15,1 l/s/m	14,0 l/s/m	12,5 l/s/m
Air slot 15 mm	25,6 l/s/m	22,9 l/s/m	22,1 l/s/m	18,7 l/s/m
Air slot 20 mm	27,5 l/s/m	28,8 l/s/m	27,7 l/s/m	26,9 l/s/m
Air slot 25 mm	29,2 l/s/m	29,4 l/s/m	28,9 l/s/m	28,2 l/s/m
Q at 20 Pa				
Air slot 10 mm	22,9 l/s/m	n.p.d.	n.p.d.	n.p.d.
Air slot 15 mm	28,5 l/s/m	n.p.d.	n.p.d.	n.p.d.
Air slot 20 mm	29,2 l/s/m	n.p.d.	n.p.d.	n.p.d.
Air slot 25 mm	27,1 l/s/m	27,5 l/s/m	25,0 l/s/m	n.p.d.
Comfort				
Sound reduction $D_{s,A,w}$ (C_i;C_{tr}) in open position				
Air slot 10 mm	46 (-1;-5) dB	48 (-2;-6) dB	50 (-2;-6) dB	56 (-2;-6) dB
Air slot 15 mm	41 (-1;-2) dB	45 (-2;-6) dB	49 (-2;-7) dB	53 (-2;-6) dB
Air slot 20 mm	40 (-1;-3) dB	43 (0;-3) dB	44 (-2;-6) dB	46 (-2;-6) dB
Air slot 25 mm	37 (-1;-3) dB	39 (-1;-4) dB	41 (-2;-6) dB	45 (-2;-6) dB
Sound reduction $D_{s,A,w}$ (C_i;C_{tr}) in closed position				

Fig31. The company Renson provides the comparisons of the ventilation capacity and the sound reductions [27]

Like the ventilation oriented company the representative German façade manufacturer Schüco also launched as ventilation-kit windows. The product series “VarioAir” showed the similar performances and the purpose-driven design below. The Fig32 indicates those designs, however as we pointed out at 2.2.7 the ventilation kit adopted a labyrinth structure for the interrupt the traveling of the sounds.

However about more advanced porous-passive noise cancellation, the paper will describe verse 3.6. Those recent product series’ development was driven by regulations of the local government and was going to more crucial experiment to prevent from the outer noises.

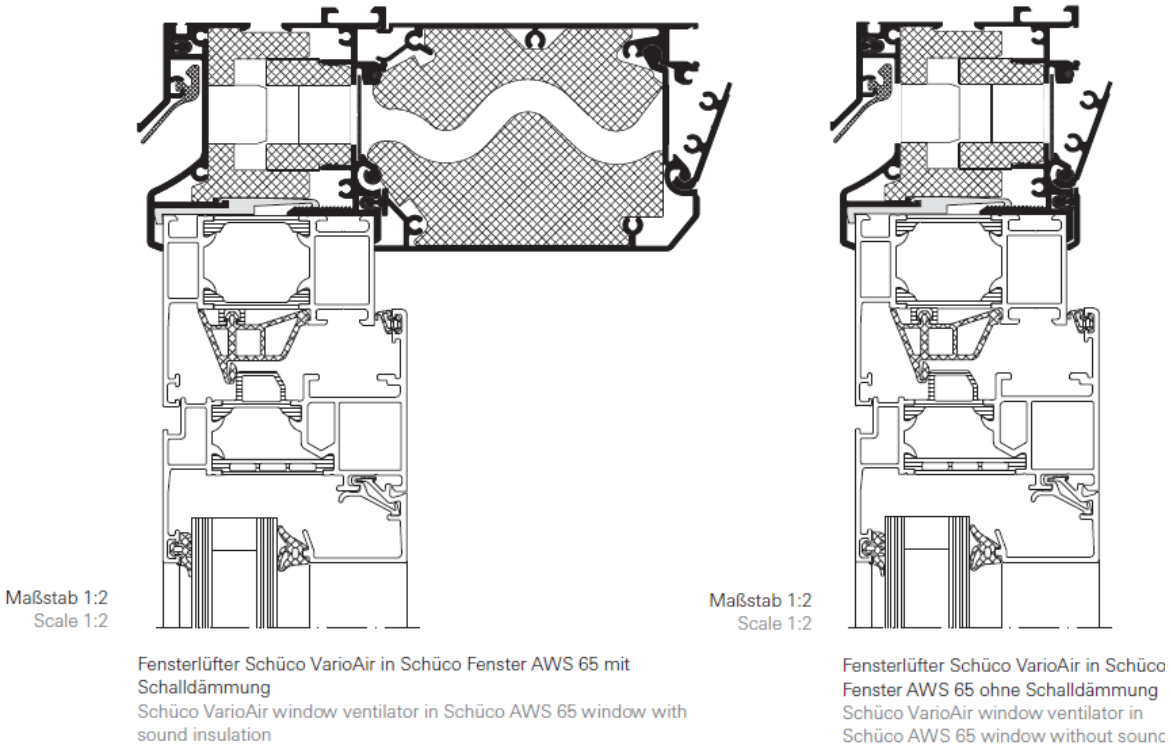


Fig32. Schüco's ventilation window system [28]

3. Methodology – a process of new product development

With the gathered information, this study is able to set up the direction to suggest as complete cases of idea. During the time of literature work, the author searched basic aspects of sound proof by window sets. In terms of product level, in this field of sound proofing window has to prove the innovation by new technologies or advanced products. That means these series of innovation, improvement, invention and development must be realised by realistic product line. According to this context, the thesis work's direction needs to adopt one of the methods of 'product development processes. Even this work is still under an academic process beside a literature background, to finalise a practical and feasible result, hiring a proven methodology can lead it to better conclusion.

Here the author brings one world widely spread, popular process from Dr. Robert G. Cooper, a professor Emeritus at McMaster University in Canada and the president of the Product Development Institute. On his organisational outputs, we could find mainly from a book "Winning at New Products". Originally, his processes, theories mostly focus on the businesses that are going to prepare the launchings of new products as the meanings of surviving from recent super competitive world of business that is following the law of jungle. [29]

This innovation tool originally started to minimise the failure of new businesses or brand new products, at the same time it intended to maximise the probabilities of their new items' successes to their markets. Naturally, that contains the reductions of the expenses or sunken costs that normally follow the business failures. His idea began from the concept to check the mismatches between customers' needs and product developers. The fig33 shows the system named 'Stage-Gate®." The critical concepts of the tool could regard as a reviewing system of every business organisation that develops now products as their daily operations. Every gate has its own mission of checking, reviewing or filtering and the criteria support these gates for launching the products. However the series of steps in fact have overall internal, external processes that begin from the tiny initial idea to the launching the item. This thesis work is close to the second half of the stage 2 and the first half of stage3. Nevertheless, during the describing, this acoustic idea will also mind the next stage to maintain the practicality.

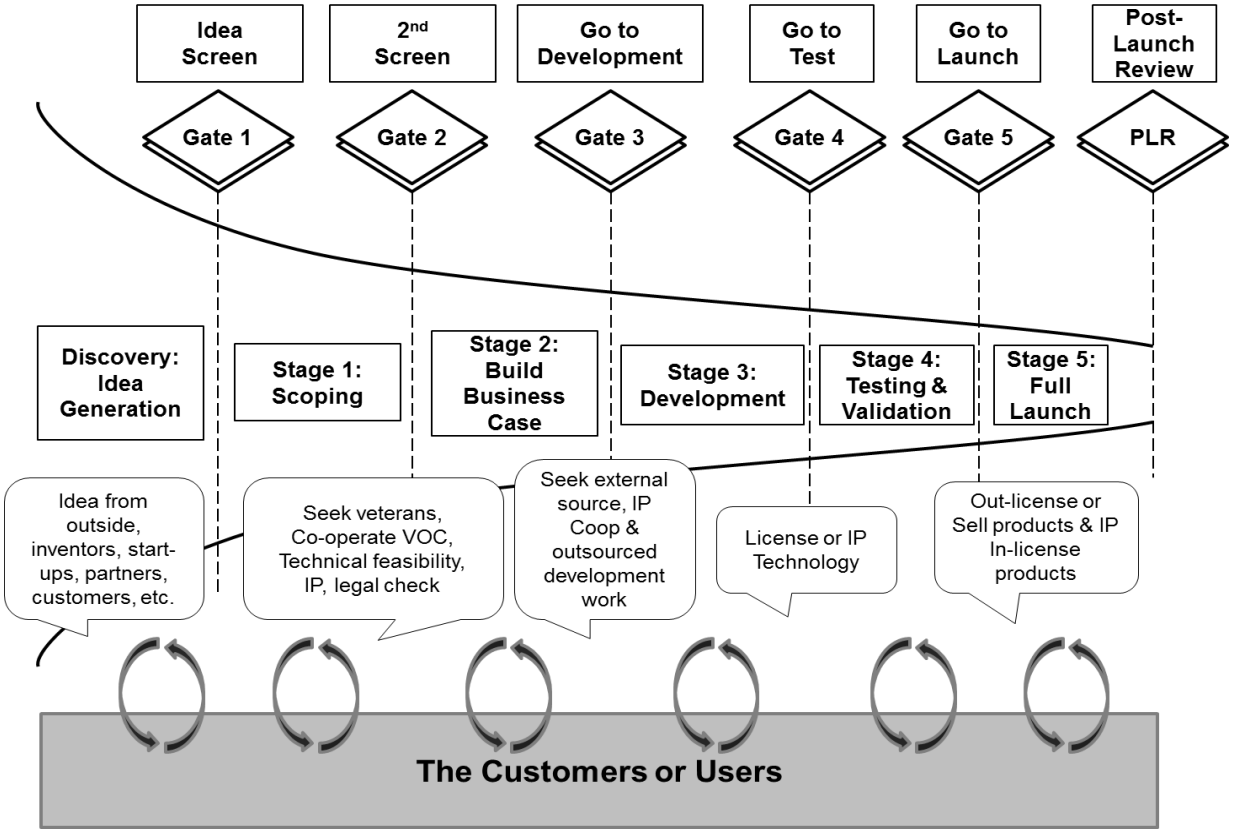


Fig33. The idea to launch Stage-Gate® system for product development project (COOPER 2011, p.143) [29]

If we make this tool simple and chase their step, firstly, discovery: Idea creation. The second one is stage 1: Scoping. Those stages are general work stages of businesses. The product designers, developers and managers are seriously performing the activities such as scanning ideas, hearing voices of customers, searching new technologies, gathering information of patents and checking their internal knowledge. At the stage 2, the business people are setting as a business model, how to make, how to sell. However, until this stage, this still belongs to the planning phase. The stage 3 is the main developing that we can imagine as the industrial work process for inventing some specific items. One example of stage 4 is the mock-up testing especially building materials industry. Stage 5 is as literarily launching. When this paper performs the stage 2 and 3, will mainly adopt following process selectively because this work is focusing a student's idea level and is not able to involve in a specific business territory.

Cooper's writings mostly focused on market driven, customer centred methodologies. About technologies and product designing part, he suggested searching, referring small related businesses and start-ups. Meanwhile this paper assumes the customer' needs through the basic study such as noise

damages by literature works. In this chapter the author mainly will search the functions, values, technological completeness, and possibilities. Overall the main direction is the suggestion of the new product.

In the same context, P. Trott suggested similar theory. [30] In his book the process summarized as follows:

1. Assembling knowledge
2. The generation of business opportunities
3. Developing product concepts
4. The screening of business opportunities
5. Developing of product prototypes
6. Technical testing and consumer research
7. Market introduction

Additionally he added a diagram that indicates the suitability about the developing process industry by industry.

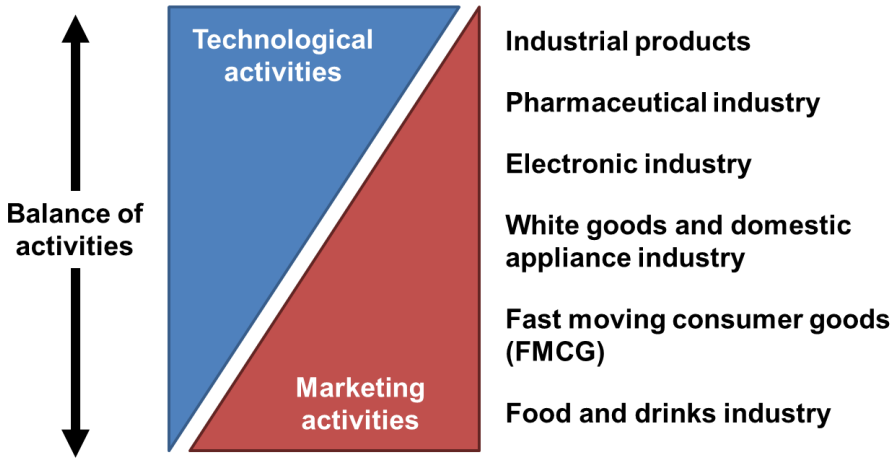


Fig34. Classification of new product development activities across different industries (TROTT 2017, p.603) [30]

The main ideas of process are near and both writings originally from business administration and management tools, therefore, both researched market and customers deeply. Additionally both concentrate on the customer's feedback when the entrepreneur involves the product

development process. Especially from Trott's writing, this paper will adopt the step 3 and 5 mostly. Thus, with the following statements of process, this thesis will find and suggest the academic results, the product concepts. That means the paper is arranging the detail processes for the purpose of the study, and research of technology mainly. Finally the described steps of methodology are:

1. Product defining: What is the item for market or industry?
   (1) What is the target output?
   (2) Who are the users?
   (3) What is the specific product idea?
   (4) What are the main benefit values?
   (5) Where is the position of the product series?
   (6) Who are the potential, current competitors?
   Which are the alternative products?

2. Estimated outputs of the thesis
   (1) What are the attributes, how they or it will look like?
   (2) What are the specifications?

3.1. What is the target output of this paper?

Through the literature surveys and searches of the sound proof technologies, the paper could set up the direction of the composition of the work. Overall, that searched the active noise control, the passive noise control and their related masterpieces at this time. However, the study mainly focuses on the active noise control here are some reasons.

(1) Advanced window industries, companies already developed the proper technologies and innovative actions are under their operations with conventional acoustic solutions. Relatively active noise control has many questions and potentials at the same time that are unexplored and undeveloped

(2) The passive noise control can effectively work forward high frequency noise band meanwhile the active noise control does low frequency noises. This reason is one of the significant facts for the make it broader the related studies. The noises that mainly make serious damages to occupants are generally low frequency sounds. The building materials that perform for high absorption or insulation of sounds are normally effective to high frequencies. In normal surrounding, the continuous high frequency noise types are not

critical sounds that people usually hear. Some unspecific fricative sound would be those kinds of unexpected high frequency noises. On the other hand when we close the windows, human ears and bodies can feel these low frequent sounds, in fact, among our daily lives, the most avoidable noises belong to low frequent sounds such as the sounds from automobile, airplane, other means of traffics and etc. Therefore, the active noise control technology that particularly opened status of windows can trigger fundamentally large amount of assignments.

As a result, the digging into this active noise control is quite critical path to solve the noise problems certainly against traffic noises. Furthermore if the developers want to provide satisfactory to customers, this technology is relatively attractive because it makes to find the problems that occasionally people are ignoring and suffering without any eliminations of noises. Therefore, the thesis will figure it out the possibilities and supply with basic ideas to stimulate public's desires.

NOTE

- **This paper mainly suggests the 'New Product Idea' and follows the methodology of 'New Product Development' process.**

3.2. Who are the users?

In cases of German cities, many residential units are facing vehicle roads that emit much noise. Generally, the cities have been developed hundreds years ago. At the time of urban planning or the process of natural growing of the cities, they could not estimate the 20th or 21st centuries' traffic noises absolutely. Probably horse coaches, carts were the main vehicle of traffic before modern times however, before the development of electricity, obviously night time traffics would be rare cases of the urban society. Later human civilisation gradually increased the time of daily life until dark night along with the development of electric light systems. In the meantime, motorised vehicle had been developed and become popular especially last 100 years. In this modern times with this technological innovation, the world population dramatically increased especially the increasing of the urban population occur many problems and assignment to governments. Furthermore, the urban population is increasing steadfastly.

Fig35. The residences that located in a typical German small-medium city suffered from traffic noises (Neu Stadt, in Detmold) [2]

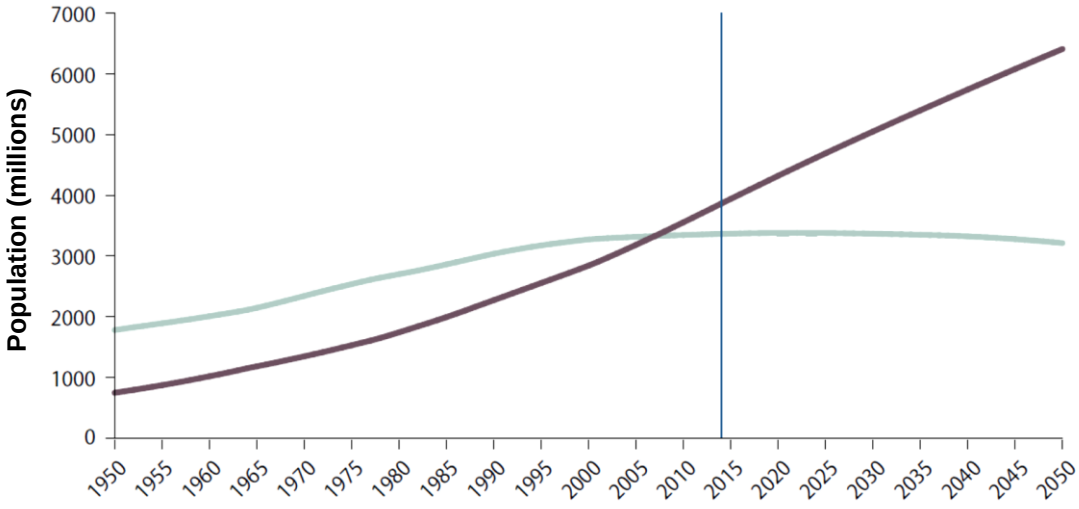


Fig36. UN report of urban population of the world, 1950-2050 (UNITED NATIONS 2014, p.7) [31]

Due to the many reasons, people are moving out of the serious traffic

[2] This measurement does not represent overall value near road side; especially the smartphone application could not provide the frequency band. Only it is able to show approximate values.

areas that make noises however to these empty spaces other residents are coming because economical or other conditional reasons. As mentioned, in Europe 4.7 million people under the suffering from the noises, world widely same kind of problems happen to the residents.

On the other hand, the occupants who are working at office buildings also need the acoustic solution on the windows. To compare with residential building s, offices are mostly operating their usage at day times. In terms of energy consumption, the consuming patterns are naturally different from residential. These hypotheses specifically assume the climate of temperate countries and subarctic regions.

Table5. Heating and cooling condition comparisons between residential building and office buildings

		Residents	Offices
Heating winter season	Day	Need	Strongly Need
	Night	Strongly Need	Switch off or maintain with low temperatures
Cooling summer season	Day	Selectable	Strongly Need
	Night	Selectable	No need

When it comes to summer seasons and parts of moderated seasons, the occupants of office buildings strongly need to open or control the windows or heating, ventilating, and air conditioning (HVAC) systems. Especially office buildings keep lightings, computers, servers, and even human bodies provide unexpected heats toward inside however the buildings which only control the heat by HVAC, naturally obtain much energy loads. This paper will not analyse the heating, cooling loads however, these climate area, offices that have openable windows have relatively superior conditions to control and additional economic values.

Not only for this cooling issue but also for a ventilation reason, offices must operate the conditionings by mechanical or manual ways. Under these conditions of the environments of offices, the occupants naturally have the problems of noise when they open the windows. Here are the German major cities' cooling-degree-days (CDD) data. The CDD means to recognise the numbers that how much of cooling energy needed to specific place, city. 1 degree-day means a place need to cool down 1℃ for the entire day's (24 hours) cooling demand. Absolutely that originally requires the standard

degree to start the figuring out of the cooling. If a user set 30℃ and the building's temperature inside is 33℃, then cooling devices such as HVAC or window have to work for the cooling the interior and the work amount would be 3℃.

It did not appoint specific standard degree which start the cooling of course the cooling conditions depend on many other considerable elements such as numbers of people, capacity of HVAC, thermal insulations of wall, window panes' Solar Heat Gain Co-efficiency (SHGC) and etc. Therefore here the paper's example, appointed just 25℃, however major German cities originally do not require many cooling energies to compare with desert area, tropical area. If we only consider about the cooling or air conditioning aspects, these cities do not need much chance to close the window and operate cooling equipment. That means conditioning by window is enough but now the noises become problems. In these senses, Northern hemisphere's large cities such as New York or many European large cities could have large amounts of needs that have to open windows for reduce the warmed airs. However, as all know, these cities have serious noise problems.

Table6. Cooling-Degree-Days comparisons between German major cities and other world major cities [32]

(Unit: degree days)

Continents	Central Europe				South Europe	North America	Middle East	Southeast Asia
Cities	Berlin	Hamburg	Munich	Colognue	Rome	New York	Jeddah	Bangkok
CDD	36.8	15.5	23.2	35.3	111.3	155.2	1,819.6	1,649.7

1) Criterial temperature: 25℃
2) Periods: 1 year (April 1st 2016 to March 31st 2017)

As the table indicates the cities in Germany which have high density can provide beneficial cooling conditions nevertheless they might experience the noise problems. The beneficial cooling condition means to compare with other cities or other countries, these data shows those cities do not have to spend much energies to cool. Even in the same continent, Rome also can reduce the cooling energies to compare with other cities above because they only need approximately 111 days to operate the systemic cooling. Back again, to in cases of central European cities, they are able to control such cooling just with open and close interactions during the summer days. Here we can imply one result: The potential needs of using acoustic windows are clear. Can the occupants put up with these noises?

Table7. A smartphone application, 'Decibel 10' can simply measure the noises. Numbers show approximate quantities that occupants feel near two-lane vehicle road

Street	Allee, Detmold	Bielefeldstrasse, Detmold		
Building types	Residences	University		
Measured position	Outside	Outside	Inside, Window tilted	Inside, Window closed
Maximum dB	85	93.6	71	55
Average dB	73.1	78.7	65	45

According to VDI 2058 (The Association of German Engineers), an Assessment of Noise in the Working Area with Regard to Specific Operations, each work place has to maintain their sound pressure level under certain levels. [17] Similarly German Working Place Ordinance as March 20, 1975. (Federal Law Gazette I. p729)[3] in work room must be kept under certain level. Those noises from outside also should be considered. For instance, intellectual work must keep it 55 dB(A). In same context, simple or mainly mechanised office works keep 70 dB(A). The other work places should not exceed 85 dB(A). [4] [5] If the noise level exceed over the value, the entrepreneurs have to provide personal protection equipment. Generally, at the workplace that the noise make the harms to employees, people are arming with ear protection caps, headphones or other specialized helmets. Even we assume the extreme case that the occupants have to wear those protection gazettes. Occasionally, the equipment adopt the passive noise cancellation theory, unfortunately the passive noise controlling has better reaction against high frequency noises then what can we solve for the low frequency noises? In normal situations, for the economic reasons and convenient habits when they open the windows, the noise level could exceed

[3] § 15 der Arbeitsstättenverordnung vom 20. März 1975 (BGBI. 1 S. 729)

[4] DIN 2058 does not consider so called extraneous noise such as talking for work between work place members, and other communicational signals inside. On the other hand, outer noise that caused by traffic or other outer noise, some noises inside by machines, equipment should be measured

[5] The exceeded value over 85dB(A) occur various problems to human ears and psychological symptoms as well. VDI 2058 explains them with detail.

such values easily. Overall, these aspects the occupants of residences and offices largely could be potential users of this target item.

Fig37. Noise protection helmet with ear capsule (BERNHARDT & JEITER 1975, p.59) [33]

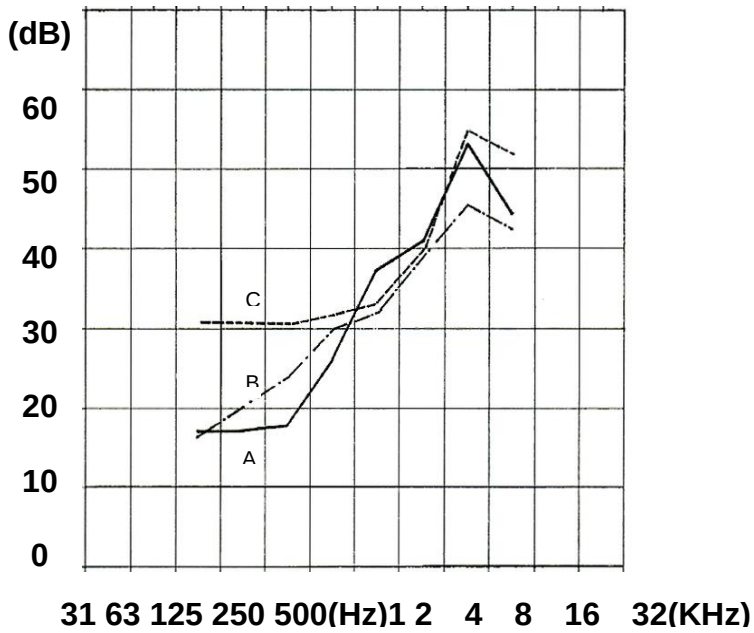


Fig38. The ear protection devices that adopt the passive noise control has effectiveness to high frequency noises (BERNHARDT & JEITER 1975, p.60) [33]

A Hearing protection cap
B Hearing protection
C Hearing protection plug

3.3. What is the product idea?

This paper will overall suggest the window system that contains an active noise control module. This chapter particularly covers (1) present status of technology, (2) main functions and additional functions, (3) benchmarking of other windows.

3.3.1. Present status

As we reviewed at chapter2, the active noise control window is on the idea and experimental stages. The author contacted few researchers among the surveyed projects, however one of the article representative author (Park, the corresponding author of Active window to reduce the exterior noise flowed through the open window, 2011) said there is no commercial products at this moment. During related search of the active noise control technology, the author found out a company on Youtube, named “Whisper” from Whython, however, it seemed not available in the market yet. Furthermore, this company’s product mainly focused on close status, bothers the view of outside because they install it on the glass pane, but here the paper will challenge with the opened status and no device design on glass panes.

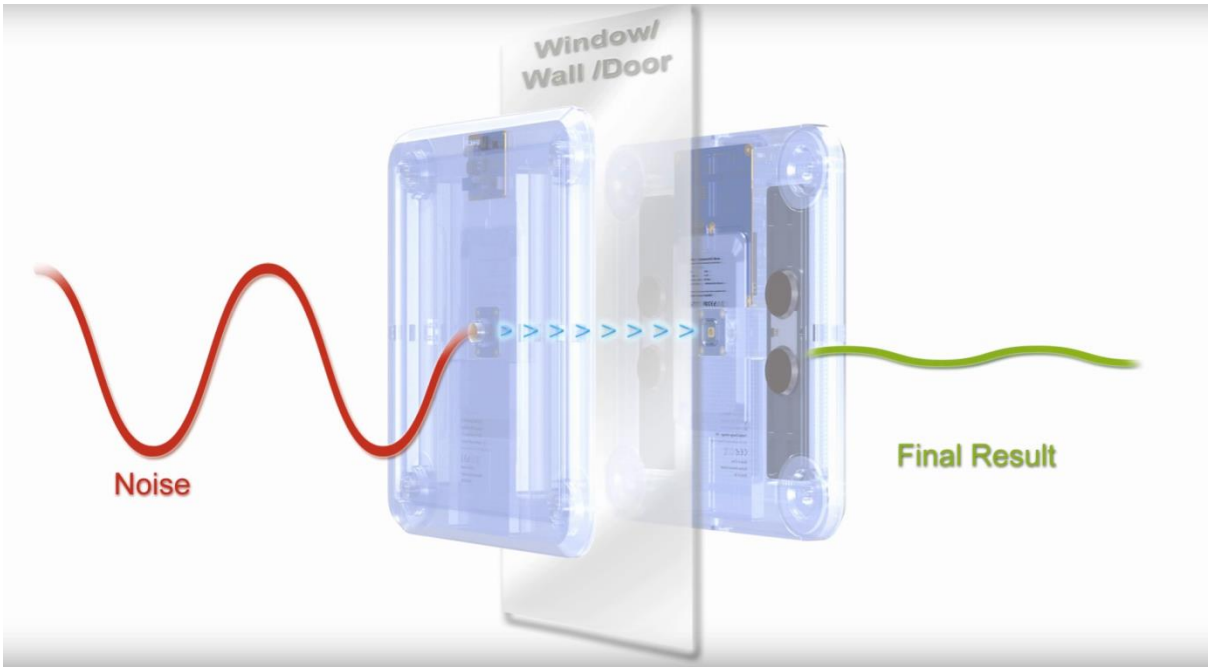


Fig39. Whyton active noise cancellation device (WHYTHON, Youtube) [34]

3.3.2. Main functions, additional functions

As a hypothesis, this paper names this virtual project as an Active Noise Control Window (ANCW). ANCW will contain certain functions therefore, the survey also must find those related technologies. Here are summaries of main functions and additional / optional functions of ANCW.

(1) Main functions
- Active noise control kit
- Automatic opening and closing
- Multi-direction noise cancelling

(2) Additional functions
- Noise source recognising
- Internet of things (IoT)
- Full automated set for CO_2 reduction and acoustic
- Advanced installation convenience

(1) Main functions

- Active noise control kit

It is the basic kit for controlling the noise when the window opened. It has to calculate specifically the sound power of the noises and the powers of the speaker located in the kits.

- Automatic opening and closing

When the noise level is higher than the set-up level of the kit, the ANCW must close its ventilation window. That means the reference microphone has to judge the outer noises' spectrums, characteristics and basic sound pressures.

- Multi-direction noise cancelling

The error microphones must locate multiple places for example, in residence, in the daytime; occupants' sound receiving area should be different from night time, their beds. Many studies and researches are finding occupants behaviour in residences or work places, therefore this ANCW can equip the functions of the recognising the behaviour or it can set at least two places such as desks and beds, or work tables and meeting rooms. If it is

necessary, it can locate spots that are more specific for example, listeners' ears or controller should calculate the value near around occupants' ears. Even the industrial norm suggests the specific place of measurements. Therefore if the ANCW can provide cancellation to the major points of receiving with error microphone, it approves proper solutions for the customers.

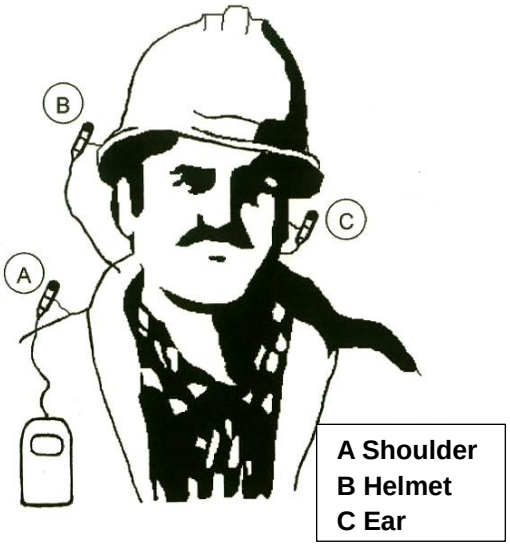


Fig40. DIN 45645 defines the measurement points (MAUE 2003, p.129) [17, 35]

Plenty of building and environmental researchers steadfastly have studied occupant behaviour parts. Mainstreams of the study group are concentrating building energy consumptions. For reducing the consumptions or optimising, these activities look into the occupant behaviour. Hong et al. defined the measurement methodologies.

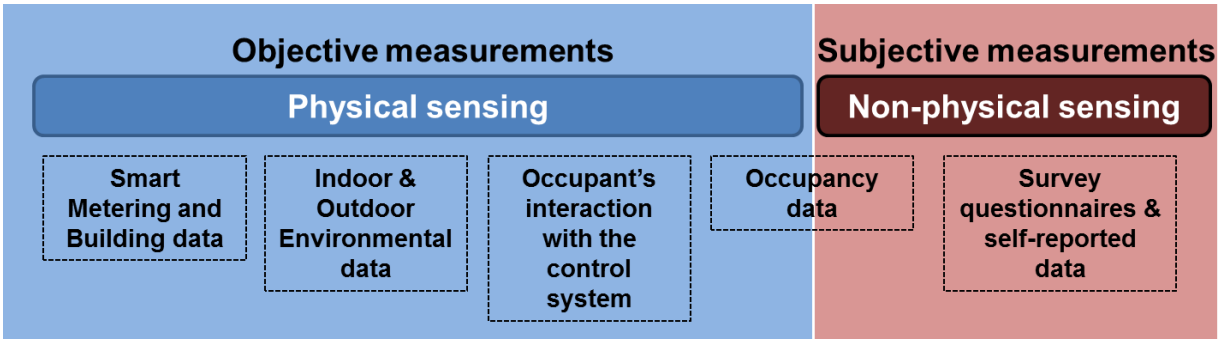


Fig41. Schematic and methodological approach on energy-related occupants behaviour in buildings (HONG et al. 2017, p.522) [36]

In case of the typical objective measurements contain plug-loads, electricity, building data (indoor, environmental quality, energy loads), outer environmental data (temperature, relative humidity, wind velocity, CO_2 concentration), the data that collected by occupancy sensors. Recently these use virtual reality, eye-tracing technology, advanced measuring by physical occupancy sensor. In fact, these technologies can enable to monitor individual behaviours and gather building related data. On the other hand, in terms of subjective measurements, the researchers contact individual occupants, identify the gathered data with using their own tools or types of interviewing such as mail or face-to-face methods. [36]

In the same context, Morrow et al. the atmospheric researchers and light researchers surveyed 58 private offices in Colorado. They used a ceiling-mounted infrared motion sensors each room. They wanted to see how much the occupants want to optimise the lighting environment. Finally, they found the directions to the outer window, their demands of lightings were changing absolutely. [37] This research also gives the implications; the acoustic researches can trace similar process. If the sensors or microphones are operating for the gathering the meaningful data, the noise cancellation will work properly.

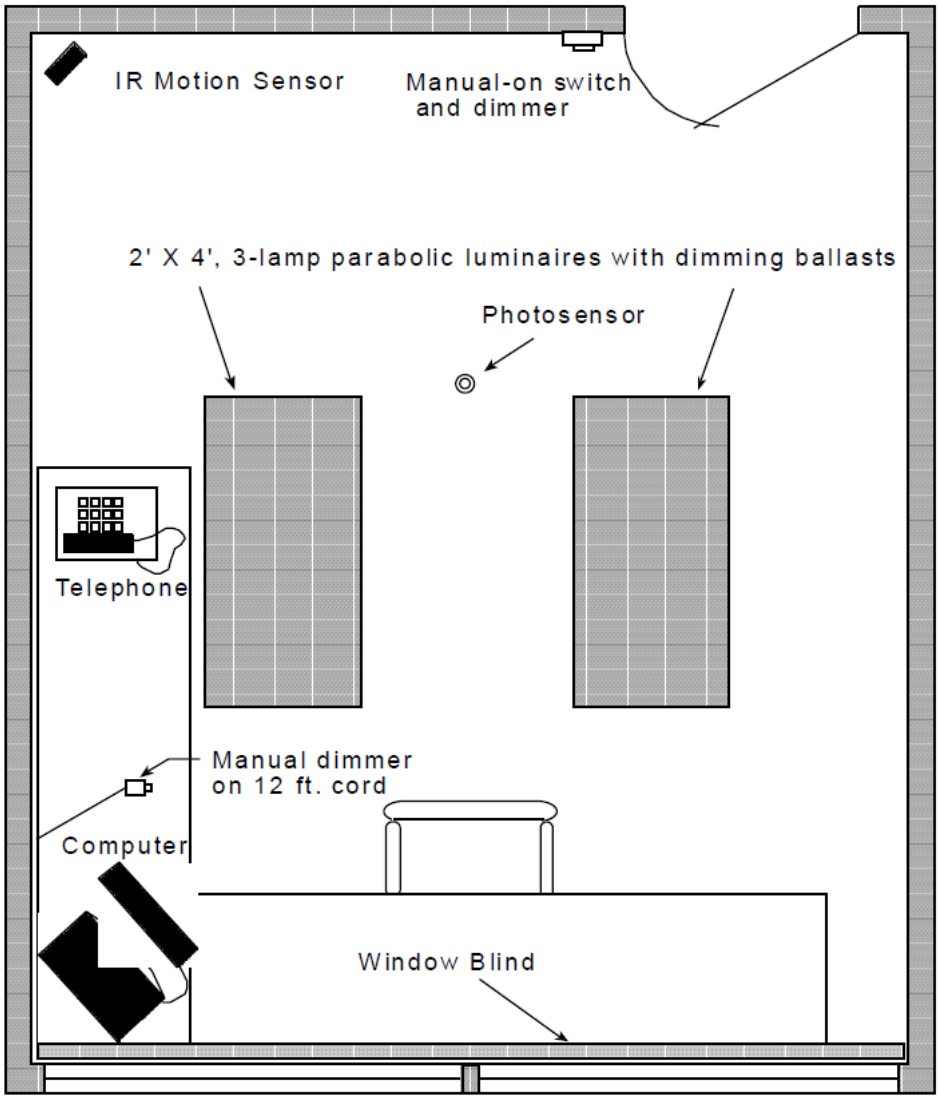


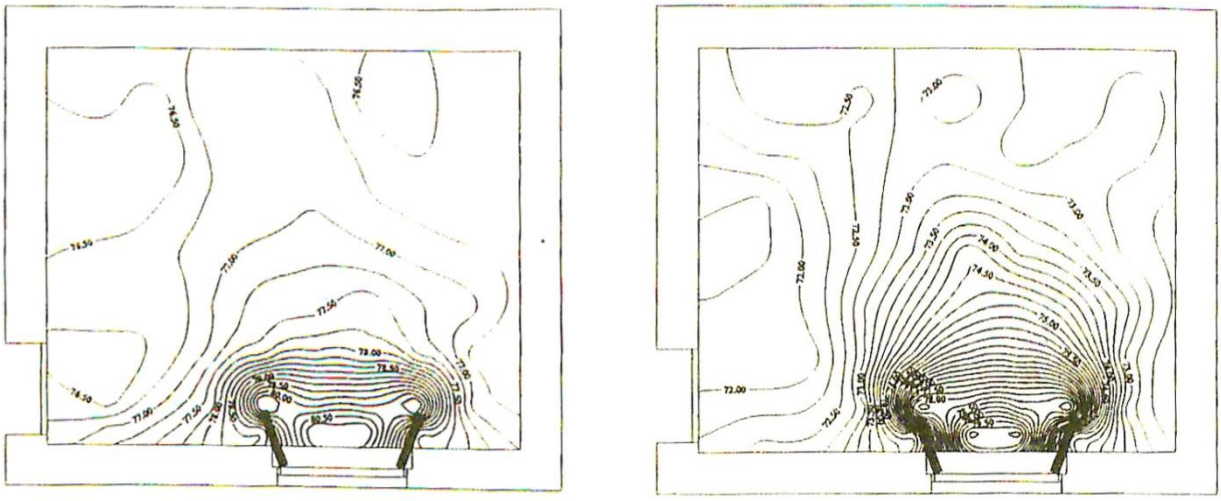
Fig42. Location of lighting controls in typical perimeter office (MORROW et al. 1998, p.5) [37]

One group of university student and faculties in Korea investigated the controlling habits when the occupants use the windows. [38] This research group surveyed 20 resident units and found out the behaviour of opening and closing windows deeply related the environment of the in and outside. At the same time, the reasons came from their behaviour patterns. The graphs show the relationship between the behaviour, time, and environmental conditions. Particularly, they noticed if the outer temperature is above 10℃, the hours of opening significantly increased. During their research, they simultaneously figured out the temperature of the in and outside, drops also affect to the closings.

(2) Additional functions

- Noise source recognising

This function means the kit also think, analyse the characteristics of noise sources. For example, it has to recognise what the noise sources are such as trains, airplanes, constructional machines or other means of noise producers. The noises that come into the indoor have different energies and directions. Buratti examined this when she researched ceiling absorber of rooms. [39] The figures show the noise spreading in the receiving room of the test facility. Fig43 (A) shows the noise trend inside without any ceiling absorber, meanwhile (B) shows when the ceiling has a certain type of absorber on that. The noise sources were the traffic noises. This indicates the ANCW should consider that the noise is difficult to handle and control.



(A) (B)

Fig43. Trend of noise receiving when window are open in receiving room with traffic (A) without the ceiling absorbers, (B) the ceiling with the absorber panels (BURATTI 2002, p.442) [39]

Not only the receiver's side, naturally near around the noise source also has the variations of the noise distribution, Fig44 shows the example.

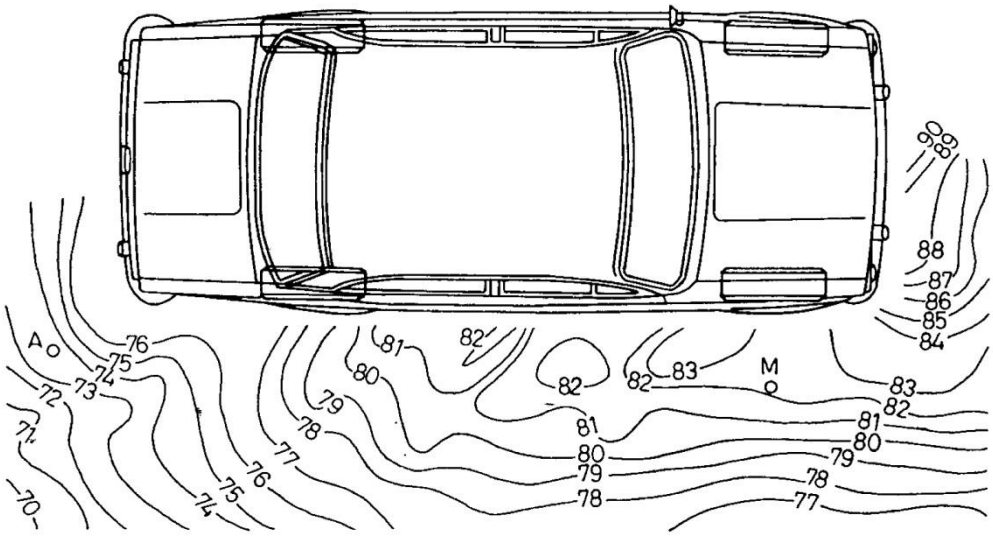


Fig44. Noise distribution of the automobile (BUNA & ULLRICH 1988, p.12) [40]

Additionally it is able to measure the distances of the source or the manufacturer's programmed noise sources' spectrums. As repeated, the active noise control system has excellent potentials to cancel the noise from outside especially the traffic noise. However, difference sources make the various characteristics of sounds. Ranjan et al. already recognise the basic effects of the active noise control, furthermore they challenged to diverse the noise sources and to try the cancellation of them. [42] They verified the vehicles of traffic such as motorbikes, car, truck, bus, subways and added constructional noises. First, they mapped the spectrogram of the noises, classified as the noise signals. Their idea was the system that is reacting selectively. With their selective active noise control, the system works against the noises of each means of traffic vehicles or machines. This trained active noise control system worked like below:

Table8. Noise reduction comparison for fixed filter active noise control and selective active noise control (RANJAN et al. 2016, p.8) [41]

Noise Type		Classification Accuracy
Traffic Noise	Bike1	67.96%
	Bike2	67.51%
	Car	72.13%
	Lorry	85.27%
Construction	Drilling	94.83%
	Jack Hammer	99.91%
Subway Noise		75.82%

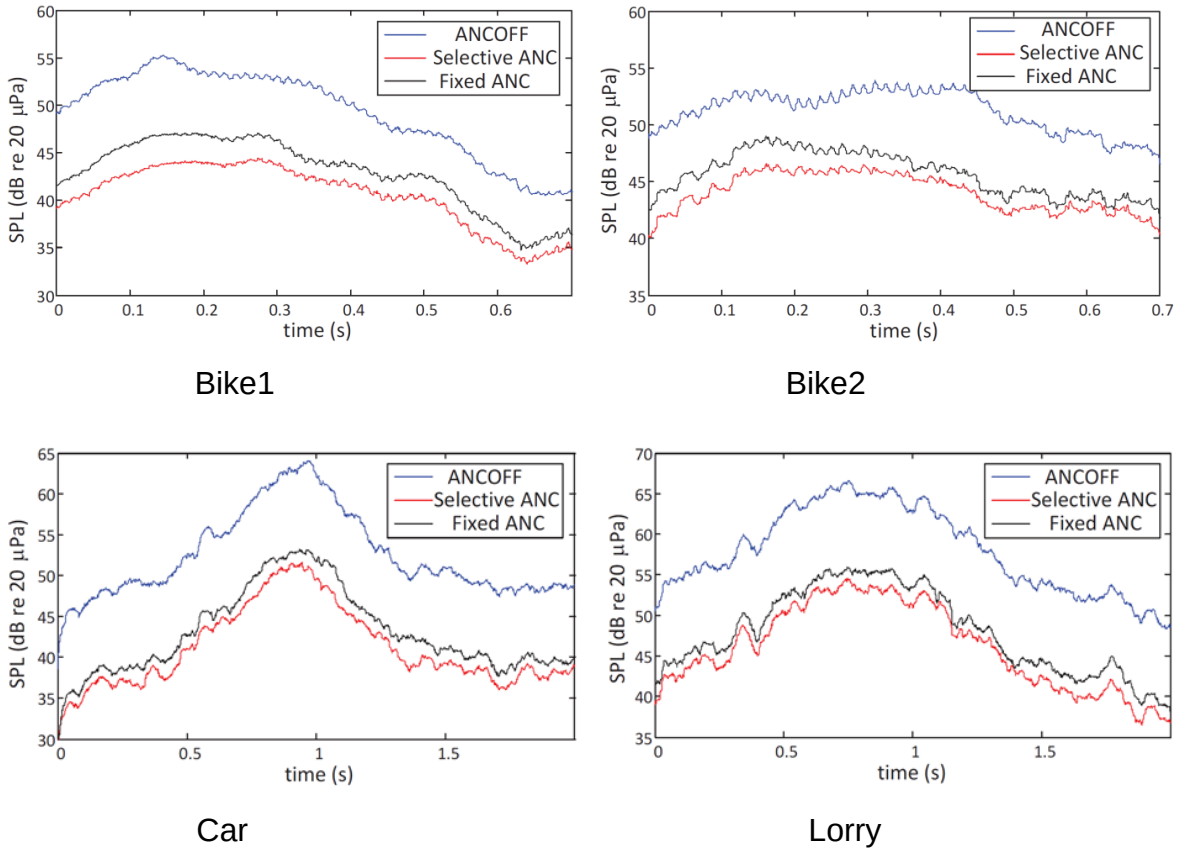


Fig45. Comparison between selective noise control system and the conventional active noise control system, example graphs of constructional machines and subway skipped (RANJAN et al. 2016, p.9) [41]

These experiments will the analysing functions of ANCW effectively. As a

result, for instance, if there are patterns such as regular train commuting, the controller should operate as reactions from programmes or memorised noise pattern analysis. Of course, the noise power is over the capacity of the ANCW, and then it must order the closing function immediately. To make it simple, when a train is far and coming to the object, the controller order to close and later after passing, it re-order to open it.

- Internet of things (IoT)

The IoT can combine this ANCW as a member of its subsidiary parts. The ANCW may think, convey the outer information to IoT central processor and react as following IoT's orders with ANCW's basic functions. However, if the users from time to time need to control it by their own will, they can control the IoT and subsidiary kit, ANCW freely when the user is able connected to internet anywhere. The recent IoT technology supports this requirement.

- Full automated set for CO_2 reduction and acoustic

As a full automated, a multi-functional window kit, it can control not only the noise, but also CO_2 levels and cooling conditions. The central processor or controller will normally operate to optimise above conditions. Meanwhile it can set up the priorities of adjusting and the occupants can involve the controlling or these settings. In this suggestion step, if we do not regard as the prices, the described functions, except an active noise control, are available technologies in the market.

- Advanced installation convenience

The ANCW at least has to use, obtain the electrical power sources. The system has to operate reference microphone, main controllers, multiple speakers which need specific sound powers of reversed soundwaves and the related circuits. Similar to other built-in devices in buildings the ANCW would rather to choose 'plug-in' electrical power inputs than a battery or charging system. Traditionally the adjoins of electricity to window sets by window manufacturers were a bit later to compare with the development steps of other electric devices. In the meantime, general window users do not expect much on building materials have the electrical functions. The author's experience in the field, one colleague who was a charge in the product development and the research, invented an exothermic glass that could heat up by itself with electricity. It must bring the powers from electricity from in-

house circuit. Internally his pre-launched product had powerful competitiveness than conventional products on markets. (This paper is not going to describe the detail because it has been one of the confidential and that story is not the essential of this study) The company even supported professional industrial designer for the outlooks. When the author went to the first mock-up test-bed, an apartment, on the installation process, the inventor and the related engineers had to re-consider about the installation. To make the story simple, at that moment the part of the people who related windows and glass had lack of the knowledge of electricity in the buildings. The electrical technicians did not well equip the knowledge of windows. Unfortunately, the developer did not spend his process on the laying down the circuits and cables inside the window profiles. At the site, no one had the idea to connect the excellent device through the framed window sets to the building structure. When they finally finished the circuit work, the complete product set, then people can quote it as the “exothermic glasses on windows”. They did not find a way to connect to plug-in to the house electricity. It was just simple example however this could happen at the installation sites occasionally.

This kind of “electrical” building components must equip a simple plug-in kit to link to the home grid systems. There are briefly two ways of solving the problems of these installations. One easy method for installation, it has to simple ‘plug-in’ lines to grids. The second method has to be from the planning step. The specification or drawings have to details of installations and especially the connecting to main grids must be discussed the project managers or general contractors at earlier stages. As a result, newly building projects have to concern these kinds of electric windows normally rather than renovate projects in this second case. Here are some Russian heating glasses on market.

NOTE

- **The active noise control will catch the noises; however the noses have the different directions pressures of each frequency. Nevertheless along with the technology, the ANCW has to work as cancellation of the noises with its analyzed reactions.**
- **Means such as behavior analysis, inside the ANCW, the processor has to receive the outer problems and then make the different outputs for the occupants.**

3.4. What are the customer's values?

The ANCW's functions will largely target three benefits. The priority function and this study's purpose is going to be the noise controlling. Beside this function, if window manufacturers invest minor efforts, the automated open-and-close systems can simultaneously perform CO_2 control and temperature control. These later two functions are already available in the market and the technologies are matured and not that complexed things. Of course, even if the targeted ANCW does not need to consider the rest two functions, anyway it has to consider the automated functions. The ANCW could only equip the controlling system and users can use them manually. However the function that the processor let the open-and-close is mandatorily matter. The developers, product designers are able to equip only the active noise controlling system, but why the manufacturer input only one option on the control set or control box when it serves the users for automated open-and-close actions. As for the cheapest product, the ANCW can adopt those microphones, controller and speakers, then users can open and close manually. Nevertheless, if the ANCW once choose the electrical supports, with this opportunity, the system rather is created as automated system than traditional manual opening system.

Therefore as a full automated system that can controls noises, indoor-air-qualities and temperature, then what are the values for occupants?

The one of the essential values is the reducing the stresses from noises. As known, noises make many psychological diseases and physical symptoms. Those are necessary functions that occupants are expecting from the traditional meanings of windows. Nevertheless people must open their windows for basic desires of ventilating, cooling and sometimes feeling winds for their psychological, emotional needs. As a result, this ANCW will help their basic instinct. As we summarized the ANCW firstly give the value of reducing noise problems even when they opened the window.

Second, with the automated processors and devices, the ANCW also helps to control the CO_2 gas and indoor temperatures. Absolutely those additional functions increase the costs and more investments. However the customer who invest the automated windows these could upgrade the customer's value about securing sufficient indoor-air-quality and proper temperature status. Especially cooling down or keeping up the temperature for considering indoor air temperature could save the additional energy costs.

3.5. Product positioning: Where is the position of this product?

Why do we have to mention the positioning of the ANCW? So called "Positioning" theory was develop Al Ries and Jack Trout the United States' marketing gurus. They started this theory due to how the companies and advertisement have to efficiently announce and plant their products or services to people's unconsciousness. [42] Of course, the positioning here is neither marketing nor sales skill. However, this phrase only looks for the ANCW's position among other products' position. It means we have to check the technological location of this product, if this is going to be launched. If the real values of the product are less than other neighbour products which has electrical, automated products, the position should change.

It is easy to launch expensive product which has multi functions. However if one product want to be positioned high-end product, it has to equip proper weapons to make the customers' satisfactions. At this moment, we cannot insist this must locate the luxury position. On the other hand, this ANCW should provide proper levels of values.

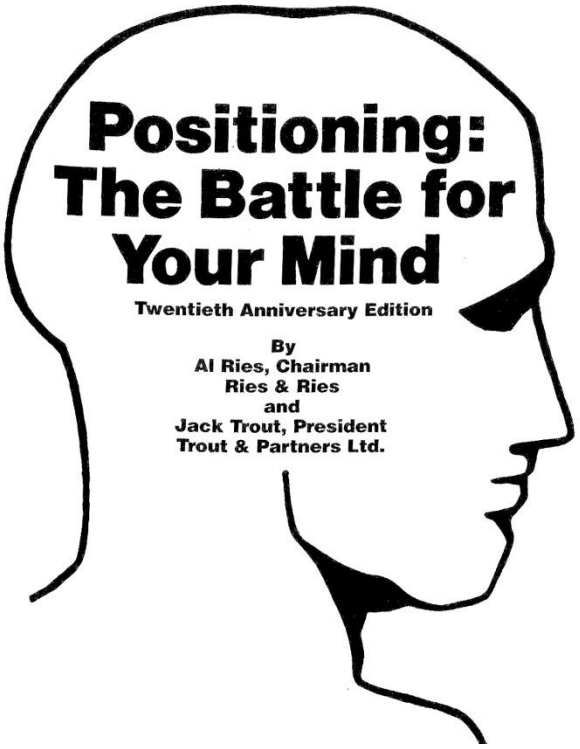


Fig46. The concept of "Positioning" (RIES & TROUT 2001, p.1) [42]

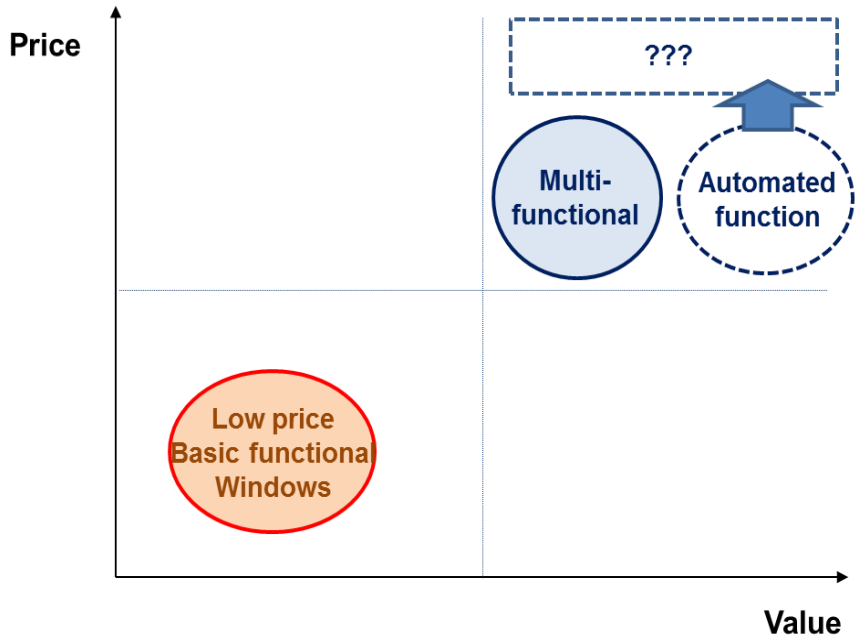


Fig47. Comparing with other similar products

NOTE

- **The final purpose of the product should contribute the human's psychological, physical health to prevent from the noises with the noise cancelling technology.**
- **Additionally it could equip the functions for reducing CO_2 and controlling the air temperatures.**

3.6. Who are the current competitors or alternatives?

As mentioned, the suggestion of this product, ANCW is under the idea level. However, new idea or new product has to mind about the existed things that already have launched in the world. Due to this paper is not a commercial driven project but mostly academic driven work, therefore will look around the neighbouring products. In chapter2, we checked out the systems that normally started from ventilation issues. However, recently the government of Hamburg push the regulations and the related industries to develop the acoustic window that can perform during the opened status. The city of Hamburg is the second largest city in Germany [43]. Naturally, it has high-density of its population.

Table9. Comparison of density of German cities [43]

City	Area	Population	Density
	(㎢)	(inh.)	(inh./㎢)
Hamburg	**755**	**1,787,408**	**2,366**
Berlin	**892**	**3,520,031**	**3,948**
Munich	**311**	**1,450,381**	**4,668**
Detmold	**123**	**74,817**	**606**
Bielefeld	**259**	**333,090**	**1,287**

1) Population: 2015-12-31 Estimated

2) Suburb omitted

They announced “Hamburg Guideline to Noise for Construction Management Plan 2010, Experience with indoor level”. [6] That described and explained: [44]

- Annually 6,000 new apartments increasing in Hamburg’s central locations especially one-person houses are increasing
- Noise sources also increasing
- Nevertheless residential area must secure 54 dB(A) daytime, 39 dB(A) at night time. That numbers are under the condition of opened and 0.5m from the inside of the window
- They oriented so called “Harbour City Solution” and aimed reduce 30 dB(A) because over 30 dB(A) at night would awaken sleeping occupants

The guideline suggested some models and their mechanism that is originally to fill up plenty of the absorbers near around openings and medium area. Of course, at the same time these windows keep the openings.

[6] Hamburger Leitfaden Lärm in der Bauleitplanung 2010

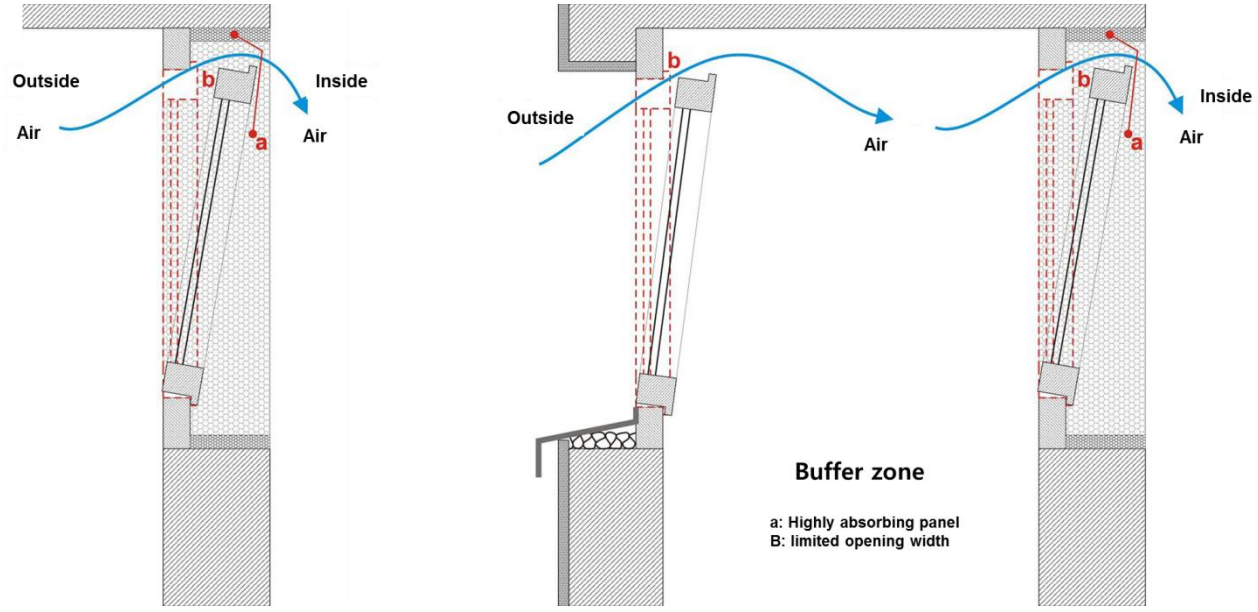


Fig48. Original concepts of Harbour City Solution or Hamburger Windows [45]

To minimise the damages of noise, the supported company Eilenburger Fenstertechnik developed “Eilenburger Hafencity-Fenster” (Eilenburger Harbour City Window) system. The table10 shows the representative performances of their product series. [46]

Table10. The performance comparison among Eilenburger’s product series

	Unit	A	B	C
Flips	**EA**	**4**	**2**	**2**
Ventilation amount 1)	**㎥/h**	**70**	**70~120**	**70**
Sound Transmission Loss 2)	**dB**	**46**	**35~39**	**35**

1) Based on 10 Pa

2) Tilted or partially opened

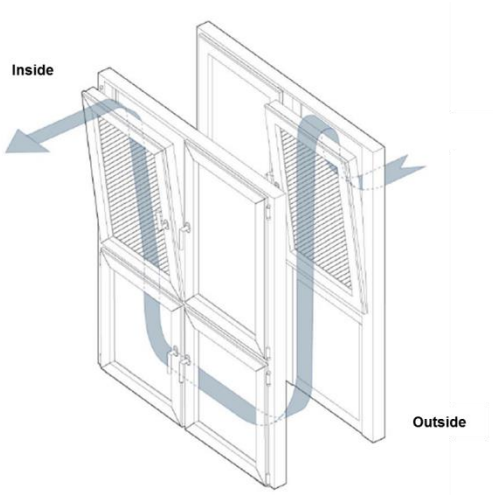


Fig49. Eilenburger's 4-Flip, A Type [46]

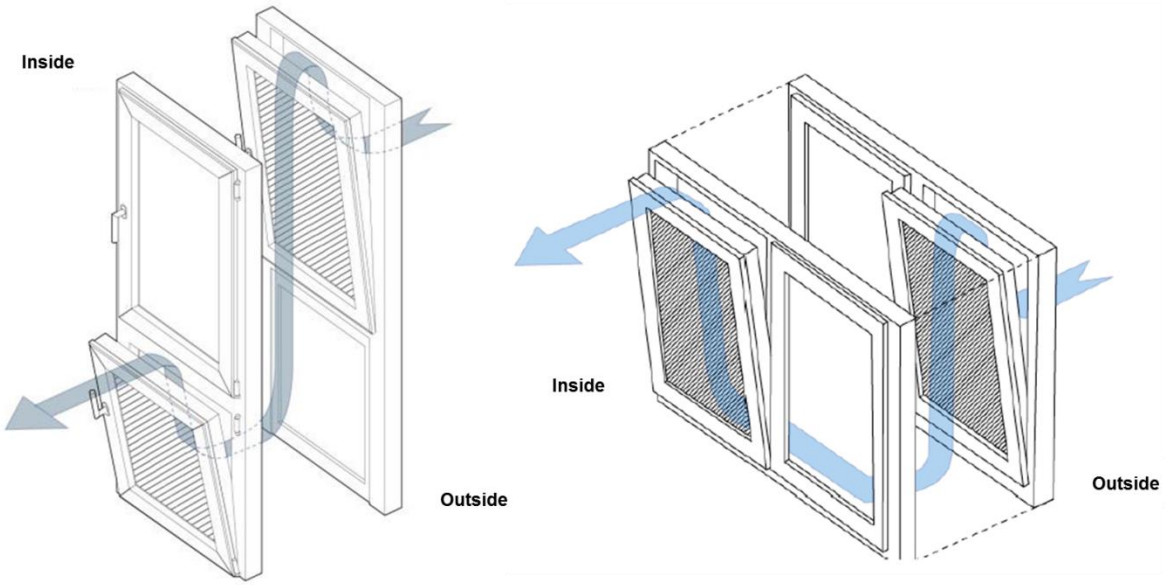


Fig50. Eilenburger's 2-Flip, B and C Type [46]

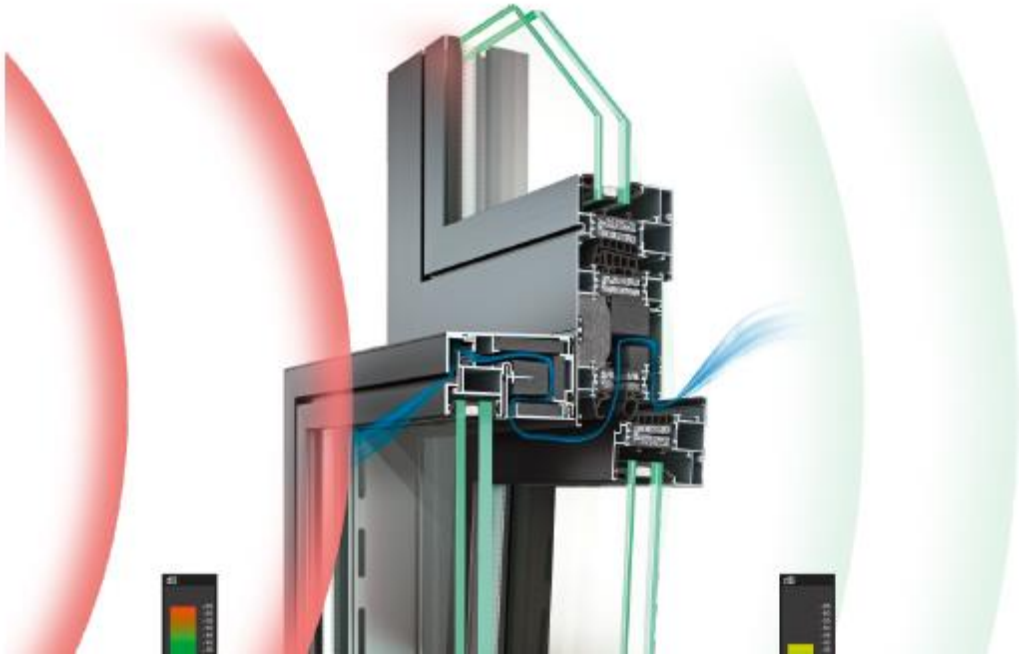


Fig51. Hueck's sound proofing and ventilation system [47]

In case of Hueck, they developed similar concept for targeting Hamburg Windows. However, the significant difference is the ventilation element. The company set the concept as the combination of the single and double layer at one vertical element. Especially the ventilation kit in the middle works efficiently for the mission while the entire system proofs the sounds. The company showed some other similar products in ranges, however, the theories are same. The essential element for the improvement of the system is the absorber. In the medium part, the system also equipped sound absorbers that work as a passive noise control system.

These product series are absolutely the products that adopt the passive noise control system and it means the systems are normally strong on high frequency noise band. Fig51 indicates those kinds of series to prove the traffic noises, the reference line should go above, it means the system should raise the thickness and reinforce with thick absorbers or improve total capacity of the sound transmission loss.

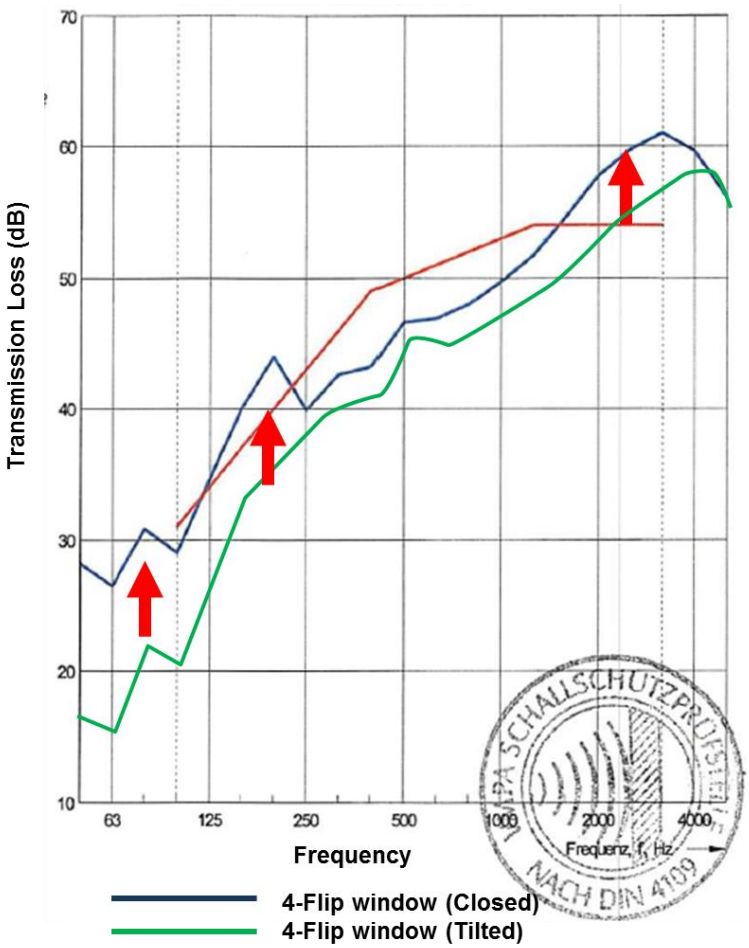


Fig52. Eilenburger Window's 4-Flip acoustic certification, the sound transmission loss improved 4 dB, however the lower frequency band is still hard to improve rather than higher band [46]

To compare with active noise control technology the conventional passive noise control type has lack of advantage to improve the sound transmission loss at the point. The main advantage of these passive noise control system is the economic value in terms of comparison to the active noise control. Probably the active noise control will equip the electrical devices to fulfil the main functions of the system. The passive noise control does not need any pug-in or battery systems. Thus this non-electric material means the occupants can use the system as semi-permanently. Traditionally the building materials have long life cycle and this passive noise control, when it comes to maintenance aspect, has the beneficial advantage. As a result, the light device, simple to maintain, easy to manufacture, and the user-friendly environment - the users do not need to learn its new operation methods-, have better competitiveness than the active noise control system.

What should the ANCW supplement the disadvantages of the passive noise control? The first priority of the active noise control is the effective capacity of the cancellation to the low frequency band. Overall, every kind of the traffic noise belongs to this low frequency band.

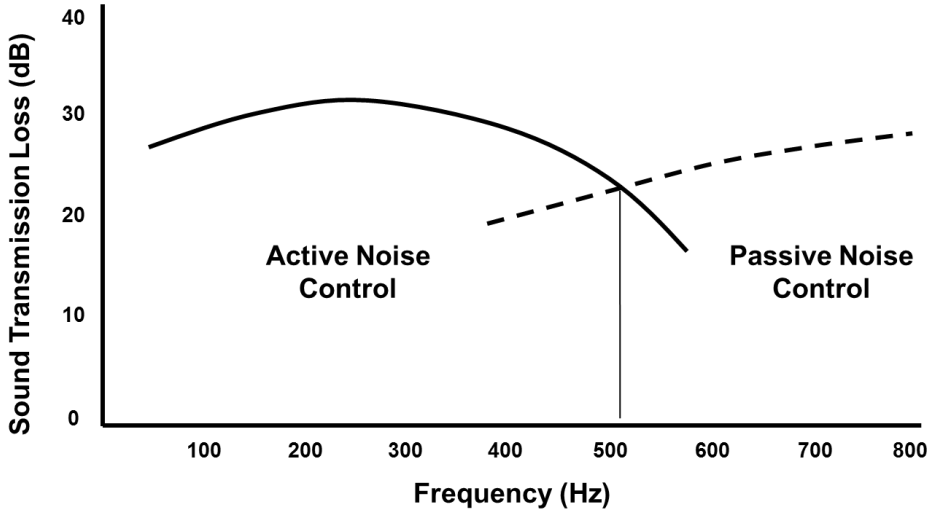


Fig53. Applications' effectiveness (EN ISO 11690-2: 1996) [17]

The passive noise control, of course, does not have any kind of thinking devices inside the window. However, this active noise control originally started the adoption of the electrical technology; therefore the system's main purpose of birth is the reacting against various kinds of noise spectrums. The active noise control's controller or processor become a low level of intellectual equipment, nevertheless it will sufficiently back up the entire system. From the author's point of view, if the active noise control is going out to the world from the development step, one of the biggest alternative points to the passive noise control would be the comfort on sense of use. As chapter 2 described, the active noise control began to protect human ears from continuous external noises. World widely the active noise control technologies have been provided to the headphone market, then naturally customers easily can experience the performances at their music industry. The comfort of listening is not compatible to any other aspects or values of the category of building materials.

Fig54. Consumers can compare with the performances of the active noise control and passive noise control in shops

NOTE

- **The present products released the passive noise controlled windows, however for traffic noise, the active noise controlling technology is effective and this technology already has proven and become popularization at music industry.**

4. Conclusions

4.1. Implications of the study

We have searched the possibilities of the ANCW. This chapter overall shows the outputs of the organised summaries. Here are four main results of the study, however as this study was not the exact designing assignment, mostly shows or suggests the directions and the stepping stones for the next further studies. The frames of conclusions are:

(1) Structure of the target product

(2) Flow chart for operational system

(3) Estimated location of the system and hybrid method

(4) Calculation method

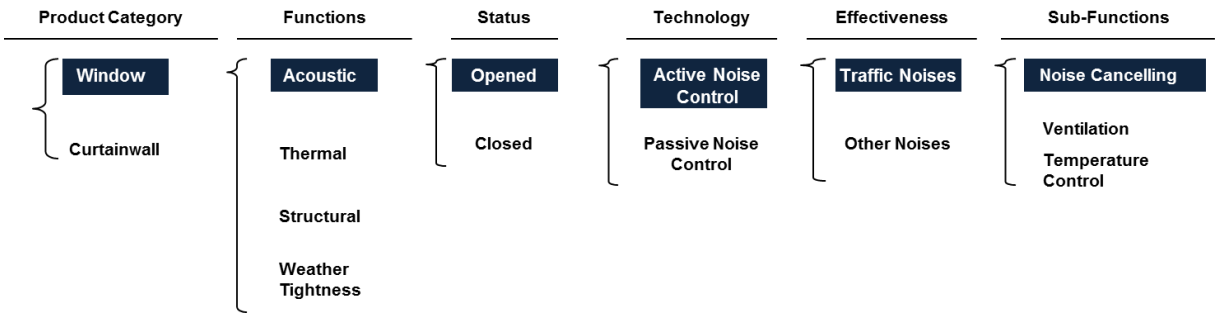


Fig55. Narrow-downed and 'key words' of the development

4.1.1 Structure of the development

Firstly the structure shows the narrow-downed summary of the study. It indicates how this study digs into the uncertain and untouched field of the challenges. Furthermore it also guides the next related researches if it is valuable to begin. Then why the paper narrowed down the structure? Overall, naturally within the time frame and the limitation, it could not cover all the categories. However here are the explanations of the each column.

(1) The first process of the product category, the study basically focused the openable windows which are mainly used in residences and small sized offices. In case of the curtainwall, if the technology of this ANCW completed,

it might be applicable.

(2) As the main theme of thesis, it should narrow downed to the acoustic.

(3) The status of the ‘opened’ is the same context of the product category. As we reviewed on 2.3.2, the study started to overcome the present technologies and exceed the debates of the performances that had measured with the ‘closed’ status. Former commercialized products must make a decision whether a ventilation or an acoustic performances during the occupation. However, after full development of the ANCW, the developers could catch both.

(4) The essential theme of the study was the bringing the idea of the active noise controlling from the music or mechanical engineering. The author recognised the issues were the planning of the output sound-powers of the speakers to react the original traffic noises. Even if it needs the further studies and development of the concepts, nevertheless the experiences from the active noise cancellation of musical industry was successful. It showed the huge possibilities of the applications for the architectural future challenges.

(5) The reason that we are considering the active noise control is the effective sound-proof against the traffic noises. Of course the passive noise control products such as which equipped the porous materials are generally economic rather than equipping these active control systems or electrical supported systems. Definitely those are effective to break noises that were created by vehicles because these noises are from high frequency noises. However most of the time, people are damaged and harmed by low frequency sounds such as constant traffic noises. Therefore the ANCW is very significant attempt to the next generation’s acoustic windows.

(6) With the main performances, the ANCW could serve the additional functions. However the reason that the ANCW includes the ventilation is a kind of reverse development. Because former times the ventilation kits or window sets that had the function with the ventilation considered the acoustic aspects. As repeated the sensors could locate inside of the processors, therefore those are fundamental reasons to bring those together. For example, in the automobile industries, the electronical, computational functions are increasing inside of cars; nevertheless the total volumes of the controllers or processing sets did not increase dramatically, because the accompanying technologies are developing with rapid speed. That means even the electronic sets are smaller than before these can combine further functions inside. Especially if versions or models of the cars are changing year by year, as a result, to the ANCW like as the automobile’s electronical

sets, the sub-functions of the ANCW could slightly come inside with noise controlling set.

4.1.2 The flow chart for the operational system

The second one would be the flow chart of “How it will work”. As mentioned the ANCW will work from the reactions of the thinking. By the occupants or the manufacturers’ initial settings of the program should order how it will operate. Sometimes the occupants are able to program it. For example when it opens, how long it will do, what it needs to control, in which parameters it should work. Especially most popular setting would be like follows:

(1) From which point of noise, the user wants to control or sometimes close the windows for user?

(2) What kinds of noises are mostly avoided, vehicles, airplanes, trains, especially motor cycles?

(3) What time does the user want to open the windows, sleeping time, night, working hours at the day time?

(4) Does the user want to ventilate the air regularly, or by their special needs?

(5) Which temperature is the most convenient for the user, and then the kit will control it during it cancels the noises?

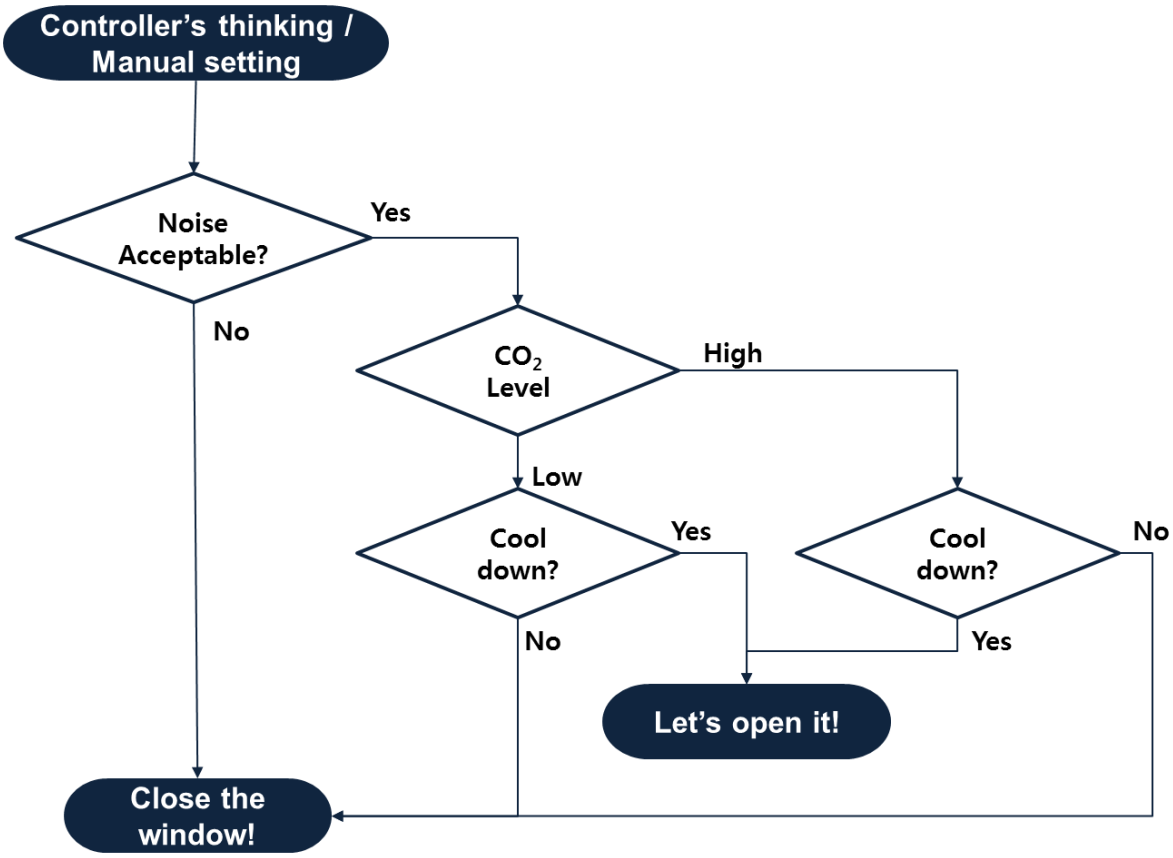


Fig56. The sequence flow chart of the ANCW

Therefore the ANCW will work like as this flow-chart. It is still in the estimated result, however it will guide the future development works.

4.1.3 The design advices for the system

Third, what would be the estimated design? Here the author is not the professional window or product designer, only can suggest the approximate overview upper side of the tilting part or near the outer frame of the window sets. Absolutely it should be tested by mock-ups however upper side can support the both ways to when the window has tilting and turning status, however also it will depend on the calculations of the out-put sound power.

If we go one step forward, the hybrid system could be a good alternative. As reviewed at chapter 2 and 3, the active noise control is effective to the lower frequency band and porous passive noise control is helpful to the high frequency and. As Bay of Fraunhofer indicated, if we combine an active noise control and porous structures especially which have labyrinth such as phrase

2.2.7, those can bring sufficient results. [48] Similar result was also found by Millard and Guigou-Carter. They found the knowledge by experiments both systems together. The fig 56 shows their results. [49]

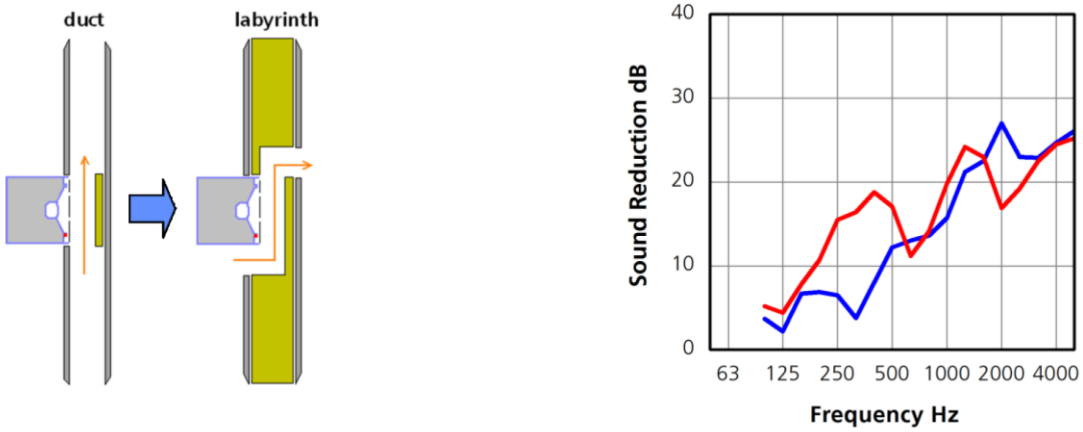


Fig57. Left: Installation of active noise control kit and passive ducts, Right: measured values of sound insulation with labyrinth, red-line shows the advanced result. (BAY & LEISTNER 2014, p.3) [48]

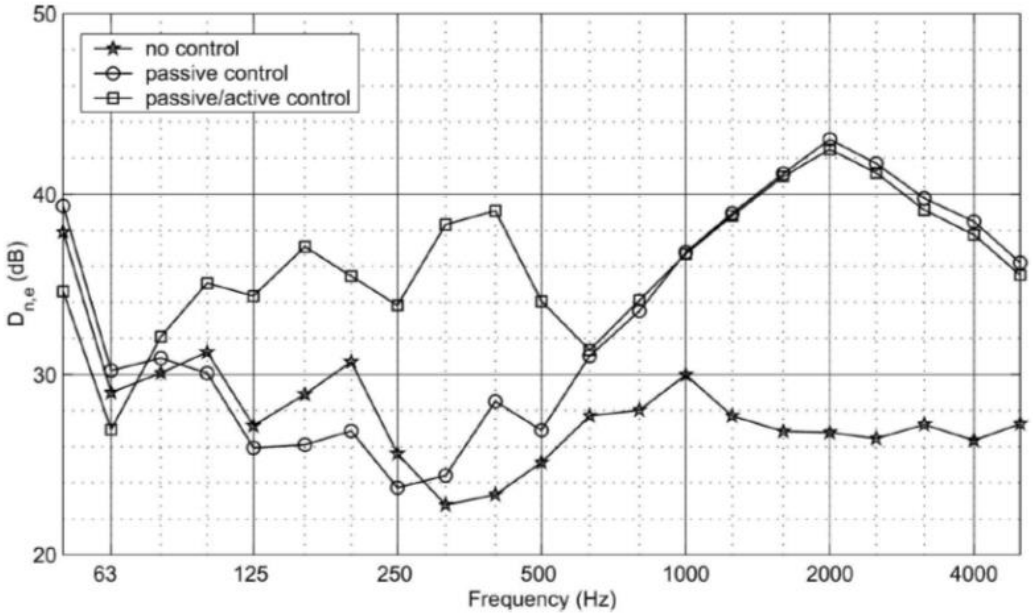


Fig58. Hybrid system's performances, no control, only the passive control and the both performances (MAILLARD & GUIGOU-CARTER 2000, p.4) [49]

4.1.4 Calculation method

About the calculation as we have searched from the literature survey, the attachment of the speakers and adjusting the sound power were the critical issues. However structurally and technologically the attachment of the electrical system was not the hurdle for the window manufacturers. In author's experiences, even product developer planned the concepts and the overall product schematic design, then the structural engineer, extruder engineer helped the main frame designs, and finally outer designs were prepared by industrial designers.

Here the author tried to find out the proper sound power of the speakers. Because the sound powers of the target noises and the reverse-phase noise determine the sizes of the active noise control sets include of the speakers. Then naturally it applies the result of the acoustic kit design and sizes of the total window sets.

If we look again back Kwon and Park's calculations, the author would like to remain this issue as a question, because it definitely requires professional knowledges of the acoustics and its engineering.

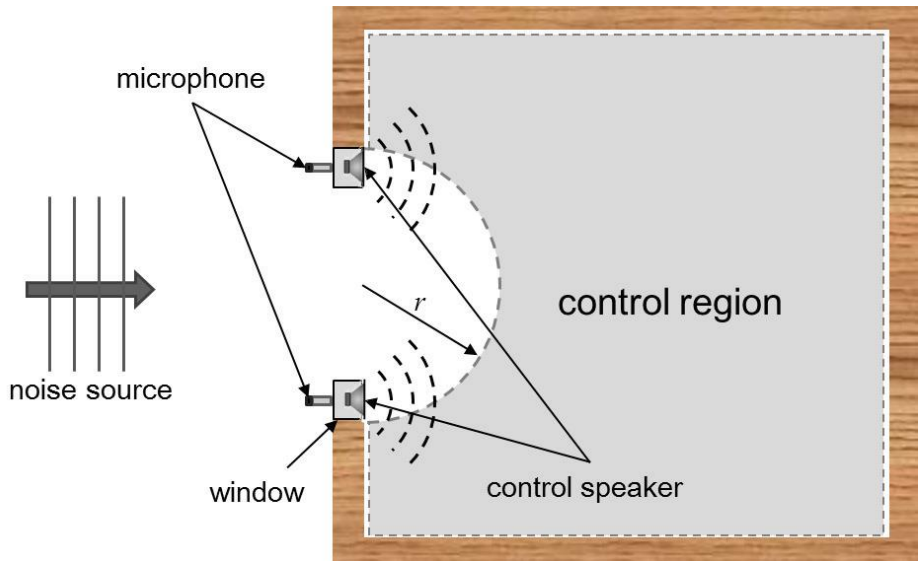


Fig59. Sounds travels into the window and emitted to the room (KWON & PARK 2011, p.822) [22]

Here the author will not comment the detail levels of this knowledge. However, the paper introduces the brief method of Kwon and Park's. The theory is to minimise the sound power which travelled the window, the specific numbers of the control speaker put the reverse noise out. When the noise comes into the room, it will move like circle such as Fig56. According to

them, they could imply the value of the control-gain of the sound power by the formulas.

$$J(\omega) = \frac{1}{2\rho_0 c}\int_S \left| p_n(\omega) - P_s(\omega)\cdot \boldsymbol{k}(\omega)\right|^2 dS$$

The abbreviations, Pn is the sound pressure of the inside the room. Ps is the sound pressure by the control speakers, ρ0 is the air's density; C is the velocity of the sounds. The N is the numbers of the speakers; S is the area of the window. These should be reviewed at the steps of next generation of the development.

NOTE

- **This study narrows down to acoustic window, which adopted active noise control technology. It could operate by controller's orders, analyzed answers of outer noises such as from traffic.**
- **It could also include the former technology, 'passive noise control', and supplement each other's weak points.**
- **The exact calculation has to be solved.**

4.2. Further study issues, discussions

Major several categories are the remained tasks and in the meantime, still those are valuable to discuss.

(1) Window design, which has the active noise cancellation technology as window frames and as completed window product.

(2) Calculations, simulations and mock-ups, later relative theoretical back-ups have to support the final products.

(3) Installation method is the one of the up-rising assignments.
As shortly discussed, the installations of electrical device-windows need special installations as follows the trainings and trials of those final of devices.

(4) Acoustical experts should prove the advantages of the product or find the improvement point for next developments.

(5) The developers should verify the additional functions that we have set at chapter 3.3.2 and that also mean expandability (scalability) and a connect ability.

4.2.1 General development issue

The industrial design for window is one of the tough issues to designers. If some stuff is attached on the window set, those are always on the agenda of the redundant. Because for long time, window design were optimised by numerous manufactures and crafts people. Additional design on the window set is therefore different. The calculation, if the sound power that the author already passed, to the specialist has to recalculate especially that is the reason why still this brilliant technology did not applied.

Later according to the calculation or relative simulation, the developers must perform the mock-up tests and the performance tests appropriately. As a common sense, if the occupants or the user invest the huge asset, nevertheless if it does not perform properly those would be the one of the new product failure. Like other new product development process, generally the new window set developing also requires lots of fields' technologies. However one thing different from other windows, the ANCW has to adopt the electrical devices and it should connect to the grids. However the window sets are typically faced to outside unlike the species of furniture or electrical devices, appliances, and naturally means the ANCW has to be ready to plug-in somewhere in the houses or offices. Therefore the further development if it is possible, the plug-and-play functions are very essential.

The sounds have directions, spectrums and each frequency's pressure levels. When the sounds are coming from outside to inside, the error microphones have to locate on optimised position. For example if we install the ANCW to one bed room, and one study room or office, according to the positions of the occupant when the error microphone locates as much as close to human's ears, those help the maximise the exact noise cancelling. All of these activities are requirements of the technicians or developers for the right directions of the new product development. Probably initially acoustic specialists should involve the installation on they have to compose the technical or user manual for the maximising the noise reductions.

Finally to combine with the ventilations and automatic open-and-close functions, those hybrid functions needs to be discussed. Here mostly at the

student level, the related idea was released however those attempts should bring the technical experts' advises.

4.2.2 Futuristic assumptions

If the options are getting increasing, the story would be more complexed, such as an IoT, smart home concepts, or new information technology are going to be involved. However normally the window industry is close to the traditional concept of the manufacturing, but for the information technologies and electronic device manufacturers, those are not the big tasks to composite these additional functions. Later those complexed functions bother the final design for the industrial designers.

Let us extend these issues from 3.3.2 and 4.1.2. For example, there is a house which is close to a railroad. Ironically the trains are only passing back and forth twice an hour. This kind of case is more extreme than one train per five minutes with regularity. The occupants have hearing inconvenience noises therefore they want to close their windows, but do not want to lose the fresh airs, anyway the train noises are not acceptable. However if the ANCW's sensors and controller recognise the trains' sound spectrum before the trains are passing by, the controller can order "to close" in advance. Afterwards, the sensor and controller find out the situations are released, the controller is able to re-order "to open". If we trace back to 3.3.2, the point of recognising, even the author suggested as the sensing points such as beds or desks if we go one step forward to more advanced technologies like "wearable", the story will change dramatically.

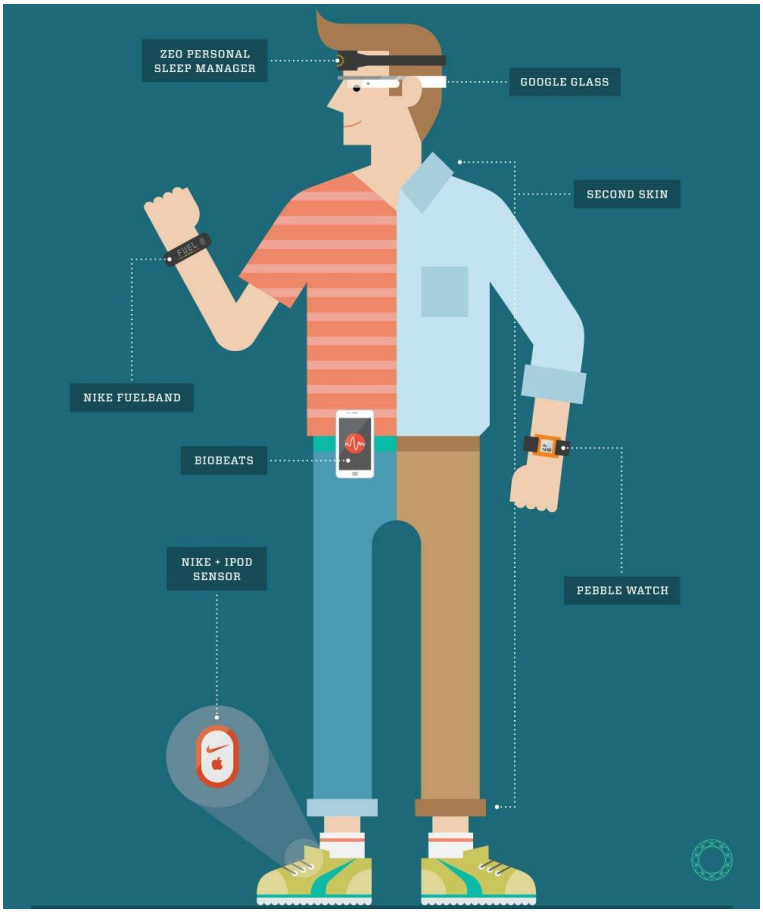


Fig60. As a recent new technology, wearable devices (PATEL 2014) [50]

Fig61. The movie, Iron Man perfectly showed the concepts of wearable by his 'suit' [51]

For a long time, many people are accustomed to wear the glasses. Probably the people could feel uncomfortable to do what they do. What about the hearing aids, the people who wear the aids, they perhaps want to take

them away if it is possible. However they are still wearing them without doubts. On the other hand, when it comes to ‘wearable’ devices, the people who want to take those technological things pleasantly dress up with those inconvenient devices. So to speak about the ANCW, the sensors, the error microphones could come into the wearable devices, however those are the next agenda of the second generation. Already one Finnish company released this technology to a market. Those kits seem to be hearing aids, however the usability or availability are variable. For example, users can take them at beds, work desks, outdoor works, constructional sites, in the planes and so on. When we come back to the inconvenience of wearing, then why do not we choose the place them on the windows?

Fig62. The wearable noise control device “QuiteOn” [52]

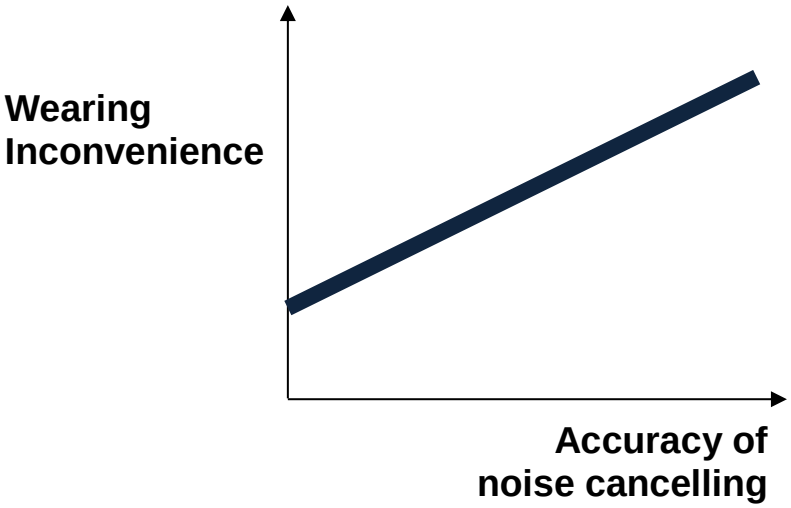


Fig63. It might be more accurate, when we wear the 'error microphone' closely to our ears. It naturally makes the body feel inconvenient.

Therefore the key issues are 'how we are reducing the inconveniences of the wearing', 'how we are increasing the accuracy of noise cancelling'.

Last phrases described about the occupants related sensing or assumptions for the attempts of the accuracy. If we come to the window sets' functions and their connections to buildings, then we can consider so called 'smart home' or 'smart building' concepts. The automation industries are not such far from our daily lives. Already automotive industries materialized many user-friendly 'smart' functions such as smart-key, navigation, automatic parking, electrochromic solar control, and those come close to the driving without human-beings. Building industries also are developing similar functions for occupants. In author's private experience, when author's family moved into an apartment that had a kind of automated system, even it was completely built in 2011. The apartment's automated supports were:

(1) Electricity, gas, water checking and recording

(2) Ventilation control, depends on the indoor air quality

(3) Security, door locking and opening

(4) Visitor alarm

(5) Courier system network

(6) Lighting and heating controls

(7) Network to the management office

(8) Elevator calling and etc.

The occupants can control them only with a couple of displays. Overall the smart building system has already matured. If we look into Schüco's recent technology, "TipTronic SimplySmart", it originally started from the hiding the fittings, adding more functions with automated devices. [53] Already decades years ago, the window industries developed the 'opening and closing' by automatic devices. The recent issues of these industries are not only the opening, but also they are finding the optimized contributions to total building systems and occupants' conveniences. Traditionally as mentioned at chapter 1, windows, facades should fulfill only basic functions such as keeping inside from outer environments. However even these industries themselves belong to traditional manufacturing, they should correspond to advanced technologies such as 'smart building'. If smart building system is a big processing work-station, the windows have to take their parts for total building management. The system would like to operate the optimized ways with total grid system; the windows should provide the information and must carry out the orders of central processor. Probably these windows run for the following the command when the system wants to control its surrounding's lights, temperatures, ventilations, securities, humilities, and finally noises. However, the noise problems often had conflictions with natural ventilation or temperature controls by manual ways. If this ANCW could support as one component for the entire smart building system, it could solve one of the serious conflictions and absurd.

Table11. A summary of Schüco building automation system platform [53]

	Components	Explanation
Basis Function	Central Control Unit	Work by user wishes or sensing data
	TipTronic SimplySmart	Automated opening
	Rain/Wind/Temperature Sensor	Working depends on the weather
	Momentary Contact Switch	Cost effective
Extension	SHEVS	Smoke extraction and ventilation
	VentoTherm	Optimizing temperature and ventilation
	LightSkin and Brightness Sensor	Depends on the brightness sensing, It change the light colours
	Solar Shading	Automated shading
	Door Control System	Access control
	Dynamic Glass	According to the brightness sensor, it change the colour of glasses

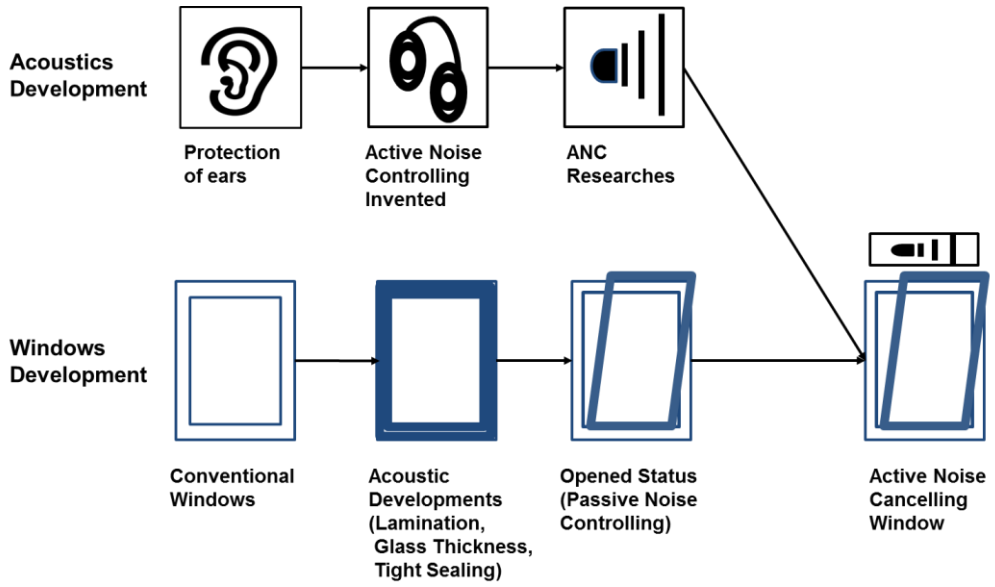


Fig64. The process of thinking, the ANCW

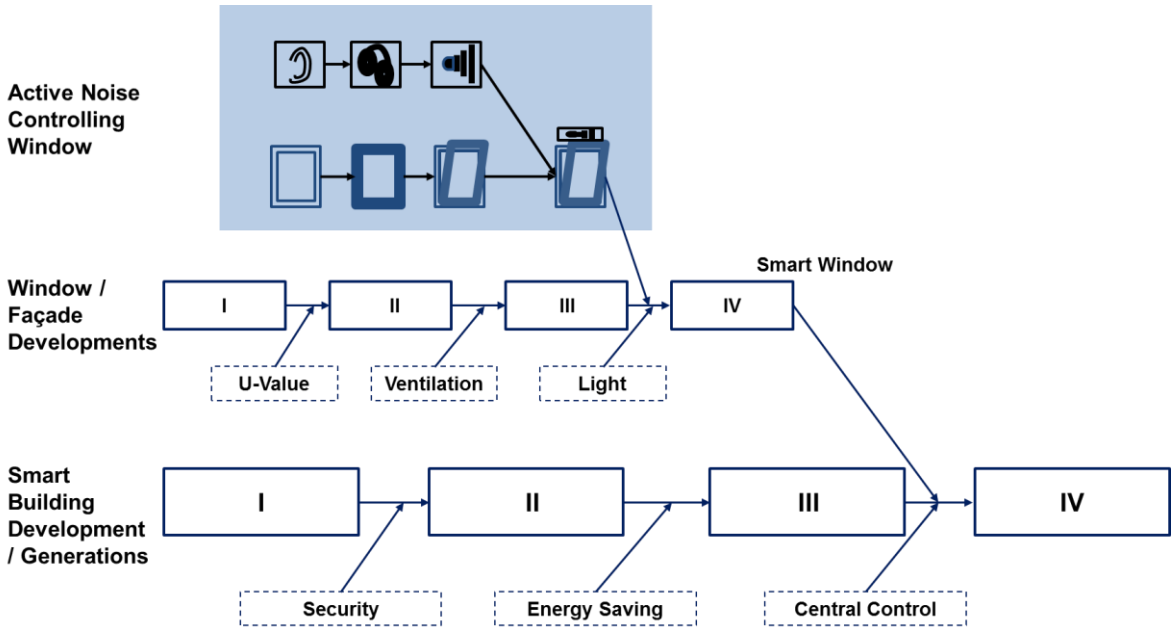


Fig65. The ANCW and the developments of windows could join to the smart building generations

NOTE

- **This ANCW could be one essential part of wearable technology, smart windows and smart building solutions.**

5. Summary

This research started two main raising problems. First, many people are suffering from noise pollutions and those occur not only the diseases but also they make the people dead. Especially huge percentages of people exposed to traffic noises due to their living beside transportation roads, railways, or near around airports. Those people cannot open their windows to feel their own freedom. The noise pollution has been stealing their rights of ventilations and calm environments of their daily lives. Second, even though the window industries have tried to solve the problems sometimes, to fulfill the regulations – the Hamburger Windows are the examples – unfortunately the present window technologies cannot 100% solve the problem itself and even the suffering from the noises.

Therefore during this study, it initially chased the active noise control. Because it originally began to help the people, who could have the hearing loss, or for the people who were exposed to the massive noises. In the meantime this paper searched several researches or institutes who tried to graft this active noise cancelling technology to the window fields.

The active noise controlling technology is basically very effective to the lower frequency band. That means it definitely could work to traffic noises which harm most of the residents' hearings. However even previous researchers were trying to verify the technologies, still the commercial products did not come into the world. Therefore this paper took the attention on this point and tried to suggest a proposal of the product outlines. The tools of the product suggestion were a 'new product development processes, by R. Cooper and P. Trott. Here the author omitted industrial designs and the output sound-powers, however if there is potential attempt to develop, it could continue to do it. Rather this study focused on the purpose, usability and future possibilities of extensions and connections to other technologies such as a smart building.

Of course the performances would meet the basic requirements, however to satisfy the accuracy of the noise cancelling, the directional controlling or analyzing the user behavior would be helpful to the basic functions of the ANCW.

From the start to the end of the study mostly emphasized the noise cancelling-windows as one element of building materials. Nevertheless it should connect to the entire building material industries or it should contribute fundamentally to human conveniences which has the responsibility

for physical and psychological health.

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Bibliography

[1] LONGMAN DICTIONARY OF CONTEMPORARY ENGLISH ONLINE: [accessed: 14-03-2017]. Available at: http://www.ldoceonline.com

[2] WORLD HEALTH ORGANIZATION EUROPE: *Night Noise Guidelines for Europe*. Copenhagen, WHO Europe, 2009. - ISBN 9789289041737, p XVII

[3] UMWELTBUNDESAMT: *Data on the Environment* [online] 2015-06. [accessed 2017-03-18]. Available at: http://www.umweltbundesamt.de/publikationen/data-on-the-environment-2015

[4] KRIMM, Jochen; TECHEN Horger; KNAACK Urlich: Updated urban facade design for quieter outdoor spaces, in *Journal of Facade Design & Engineering* (2017), Vol. 5, No. 1, p63-75

[5] LGHAUSYS: *Five main functions of windows* [online] 2016. [accessed 2017-03-14]. Available at: http://www.z-inmall.com/w/contents/fivePoint.zin

[6] SCHÜCO: *Technical Information* [online] 2017. [accessed 2017-03-18]. Available at: http://docucenter.schueco.com/web/main/SinglePageApp.php?PN=-1&LID=en#756750

[7] WEINLÄDER, H; EBERT, H.P; FRICKE, J: Vacuum Insulation Glass. in *7th International Vacuum Insulation Symposium 2005* (2005), p7

[8] KIM, Jaesoo: *Architectural Acoustics*. Seoul, Sejin Publish, 2010. – ISBN 9788971217214

[9] KANG, Sunghoon: *Spatial Acoustics*. Goyang, Sound Media, 2012. – ISBN 9788994314037

[10] MCMULLAN, Randall: *Environmental Science in Building*. Hampshire, Palgrave, 2007. – ISBN 9780230525368

[11] AGC INTERPANE: *Glass Unlimited*. Lauenföde, 2014.

[12] FASOLD, Wolfgang; VERES, Eva: *Schallschutz und Raumackustik in der Prxis*. Berlin, Verlag für Bauwesen, 1998. – ISBN 3345005492

[13] SCHÜCO: *Technical Information*. Bielefeld, 2013.

[14] GUARDIAN EUROPE: *Acoustic Insulating Glass*. Luxemburg, 2009.

[15] GETHER, Horst: *Active noise cancellation: Trends, concepts, and technical challenges* [online] 2013-10-08. [accessed: 2017-03-18]. Available at: http://www.edn.com/design/consumer/4422370/Active-noise-cancellation--Trends--concepts--and-technical-challenges

[16] LEE, Sangwoo: *How the noise cancelling removed noise* [online] 2016-01-21. [accessed: 2017-03-21]. Available at: http://thegear.co.kr/10653

[17] DIN DEUTSCHES INSTITUT FÜR NORMUNG E.V.: *Akustik, Lärmminderung und Schwingungstechnik 4 Geräuschimmissionen am Arbeitsplatz*. Berlin, Beuth Verlag, 1999. – ISBN 3410144935

[18] BOSE: *QuietComfort35 Wireless Headphones* [online] 2017. [accessed 2017-04-06].

Available at: https://www.bose.de/de_de/products/headphones/over_ear_headphones/quietcomfort-35-wireless.html

[19] OLDHAM D. J.; DE SALIS M. H.; SHARPLES S.: Reducing the ingress of urban noise through natural ventilation openings, in *Indoor Air 2004* (2004), p118–126

[20] CARMER, Christian, et al.: Reducing the ingress of urban noise through natural ventilation openings, in *Inter-Noise 2016*. (2016), p3061-3063

[21] OH, Wonkeun: *An experimental study on the simple active noise control windows, 3rd International conference on Innovative Engineering Technologies (ICIET'2016) Thailand*, [accessed: 2017-02-17], Available at: http://dx.doi.org/10.15242/IIE.E0816052

[22] KWON, Byungho; PARK Youngjin: Active window to reduce the exterior noise flowed through the open window. in *Transactions of the Korean Society for Noise and Vibration Engineering* (2011), Vol. 21, No. 9, p820-827

[23] GLÄSER, Hans-Joachim, et al.: *Funktions-Isoliergläser*. Ehningen, Expert Verlang, 1992. – ISBN 3816906648

[24] DE SALIS, M. H.; OLDHAM D. J.; SHARPLES, S.: Noise control strategies for naturally ventilated buildings. in *Building and Environment* (2002), Vol. 37, p471-484

[25] LEVENTHALL G.; WISE S.: Active noise attenuation in ducts, indoor air quality and energy conservation. in *Institute Of Acoustics (IOA) Acoustics Bulletin* (1997), Vol. 22, p8-10

[26] BAI, M.; LIN, Z.: Active noise cancellation for a three-dimensional enclosure by using multiple-channel adaptive control and H infinity control. in *Journal of Vibration and Acoustics—Transactions of the American Society of Mechanical Engineers (ASME)* (1998), Vol 120, p958–64

[27] RENSON: *Window Ventilators*. Waregem, 2017.

[28] SCHÜCO: *Schüco Vario Air.* Bielefeld, 2015.

[29] COOPER, Robert G.: *Winning at new products*. New York, Basic Books, 2011. – ISBN 9780465025787

[30] TROTT, Paul: *Innovation management and new product development*, Harlow, Pearson Education, 2017. – ISBN 9781292133423

[31] United Nations: *World Urbanization Prospects*, New York, United Nations, 2014. – ISBN 9789211515176

[32] BIZEE SOFTWARE LIMITED: *DegreeDays.net Custom Degree Data* [online] 2016. [accessed 2017-04-11]. Available at: http://www.degreedays.net/

[33] BERNHARDT, Horst; JEITER, Wolfram: *Unfallverhütungsvorschrift „Lärm" Erläuterungen, Durchführungsregeln, Anmerkungen Kommentar*. Berlin, Erich Schmidt Verlag, 1975. – ISBN 9783503040971

[34] WHYTHON, M: *Whython active noise canceller* [online] 2016-06-27. [accessed 2017-04-07]. Available at: https://www.youtube.com/watch?v=-pzdn0Dtd2U

[35] MAUE, Jürgen: *0 Dezibel + 0 Dezibel = 3 Dezibel*. Berlin, Erich Schmidt Verlag, 2003. – ISBN 3503074708

[36] HONG, Tianzhen; YAN, Da; D'OCA, Simona; CHEN, Chienfei: Ten questions concerning occupant behavior in buildings: The big picture. in *Building and Environment* (2017), Vol. 114, p518-522

[37] MORROW, Wayne; RUTLEGE, Burr; MANICCIA, Dorene; REA Mark: High performance lighting controls in private offices: A field study of user behavior and preference: in *World Workplace* (1998), p1-5

[38] JEONG, Bongchan; JEONG Jaewon; PARK J.S.: Occupant behavior regarding the manual control of windows in residential buildings. in *Energy and Buildings* (2016), Vol. 127, p206-215

[39] BURATTI, C: Indoor noise reduction index with open window. in *Applied Acoustics* (2002), Vol. 63, p431-442

[40] BUNA, Bela; ULLRICH, S.: *Verminderung des Verkehrslärms*. Berlin, Springer Verlag, 1998. – ISBN 3540168672

[41] RANJAN, Rishabh; HE, Jianjun; MURAO, Tatsuya; BAHN, Lam; GAN Woon Seng: Selective active noise control system for open windows using sound classification. in *Inter Noise Hamburg 2016* (2016), p1-10

[42] RIES, Al; TROUT, Jack: *Positioning: The Battle for Your Mind*. New York, McGraw-Hill, 2001. –ISBN 0071359168

[43] CITY POPULATION: [accessed 2017-04-21]. Available at: https://www.citypopulation.de

[44] HAMBURG BEHÖRDE FÜR STADTENTWICKLUNG UND UMWELT: *Hamburger Leitfaden „Lärm in der Bauleitplanung 2010"* [online] 2010. [accessed 2017-04-05]. Available at: http://www.hamburg.de/laermleitfaden-2010/

[45] HAMBURG BEHÖRDE FÜR STADTENTWICKLUNG UND UMWELT: *Broschüre „Schallschutz bei teilgeöffneten Fenstern"* [online] 2011. [accessed 2017-04-05]. Available at: http://www.hamburg.de/contentblob/3303900/data/schallschutz-bei-teilgeoeffneten-fenstern.pdf

[46] EILENBURGER FENSTERTECHNIK: *Hafencity-Fenster* [online] 2016-12. [accessed 2017-04-05]. Available at: http://www.eilenburger-fenster.de/EFT/hafencity-fenster/

[47] HUECK: *Sound Proofing and Ventilation.* Lüdenscheid, 2016.

[48] BAY, Karlheinz; LEISTNER, Philip: Lean transducers for ANC applications. in *The 21st International Congress on Sound and Vibration (ICSV21)* (2014), p1-6

[49] MAILLARD, J.; GUIGOU-CARTER, C.: Study of passive/active control on openings for natural ventilation in buildings. in *InterNoise 2000* (2000), p1-5

[50] PATEL, Jayneel: *Everything you need to know about Wearable Technology* [online] 2014-06-12. [accessed: 2017-06-09]. Available at: https://www.openxcell.com/everything-need-know-wearable-tech

[51] MARVEL STUDIOS; FEIGE, Kevin(Producer); BLACK, Shane(Director): *Iron Man 3*. United

States, 2013.

[52] QUIETON: *Find Your Silence* [accessed: 2017-06-09]. Available at: http://www.quieton.com/

[53] SCHÜCO: *Schüco TipTronic SimplySmart.* Bielefeld, 2015.