Copenhagen Technical Academy

Double Skin Façade

Evaluating the Viability of the Component

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Abstract

This dissertation discusses the double skin façade building component. It describes the concept briefly and four different typologies are identified for classification. There is a debate of whether or not the double skin façade is environmentally friendly or if it has failed to achieve that goal. Researchers and practitioners have mixed opinion about if the system decreases the energy usage of a building of not. This thesis looks into some detailed researches made to identify the actual energy efficiency of a double skin façade. The results are not unanimous bet some conclusions can be made by analyzing those studies. The cost efficiency is also analyzed in details to try to identify if the system is an economically viable solution. Then other benefits that can be achieved by utilizing the double skin façade are compared to the conventional façade. The aim of this thesis is to identify whether the double skin façade is a viable alternative for buildings. Numerous factors are identified and compared to conventional façade and all this is summarized in the conclucion.

Introduction

This dissertation discusses a building element known as double skin façade. The motivation for using the double skin façade concept in building mainly comes from the encouragement for sustainable design. In recent years, the building community has integrated sustainable design concepts that can improve indoor air quality while conserving energy in buildings.

Double skin façade concept is a construction element that is intergraded in buildings to achieve several properties that can increase the performance of a building. It is a European architectural trend that is currently gaining momentum throughout the whole world. The basics of the system are that an additional skin is applied to the building with cavity between the external wall and the outside façade. The outer layer of the double skin façade is constructed with glass panes mounted on a structural grid. The façade has to be close to fully glaze to optimize the function of the system. There is often intergraded a shading device in the system to gain control over the solar radiation.

This dissertation will focus on the double skin concept and evaluate the utility of the system. It will evaluate the functionality of the system in comparison to conventional façade by studying literature review and researches. This thesis will emphasize on whether it is practical for developers to choose this system for buildings by comparing environmental and economical benefits to conventional structure. To work out if the system a practical solution for developers the question is raised:

- Is the function and affects of a double skin façade are great enough, compared to economical aspects, for it to be considered as a viable alternative for buildings.

Classification and typology

There are many ways to classify different types of a double skin façade. The most common way of categorizing different types of the system was made by Oesterle *et al.* In fact, Oesterle's definition is used by almost all researchers to classify the system. It is therefore natural to use their classification in this thesis. Oesterle *et al.* identify four different systems that are classified by the kind of form the intermediate space is divided into and according to the desired ventilation function.

Box window type	Shaft – box façade	Corridor façade	Multi – story façade

Box window

The box window was the first type of a double skin façade introduced in the building industry. The inner leaf of the system is an inward opening window and the outer leaf is a single glazed skin. In the external skin, there is an opening that allows fresh air to flow into the cavity. This allows ventilation for both the intermediate space and the internal rooms. The form of the system can either be divided horizontally along the building, with vertical divisions, or for each window speratly. Oesterle *et al.* describe the usage and the general functions as:

> *"Bow-type windows are commonly used in situations where there are high external noise levels and there special requirements are made in respect if the sound insulation between adjoining rooms. This is also the only form of construction that provides these functions in facades with conventional rectangular openings."* [1]

Oesterle e*t al.* are mostly interested in the acoustic benefits of the double skin façade and therefore they mention those properties specially. Box type windows are also commonly used for retrofitting buildings to improve their performance. It is relatively easy to apply this type of a double skin façade to older buildings.

Shaft – box facades

The shaft – box type is a system based on the box type window. It was developed by the Alco Company and the idea is to develop a more sophisticated system that will utilize the stack affect by harvesting solar radiation. The system consists of box type windows horizontally divided on the building and vertical shaft segments. The horizontally divide box type windows are connected to the vertical segments on every story by special openings. The stack effects utilized in the vertical segment draw air from the box type windows and create airflow in the whole façade. Sometimes a mechanical airflow system is also intergraded into this system to assist with the air flow. Oesterle *et al.* describe the usage and the general functions as:

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[1] Oesterle *et al.* 2001 (p. 13)

> *"Shaft-box facades require fewer openings in the external skin, since it is possible to exploit the stronger thermal uplift within the stack. This also has a positive effect in terms of insulation against external noise. Since, in practice, the height of the stack is necessarily limited, this form of construction is best suited to lower-rise buildings. An aerodynamic adjustment will be necessary of all the box windows connected to a particular shaft are to be ventilated to an equal degree."* [2]

The vertical segment if the system can be situated anywhere in the façade. Oesterle *et al.* state that there are some limitations to how high a building with a double skin façade can be because of constraint due to stack effects. They are assuming that the double skin façade is only naturally ventilated, but these limitations can be overcome by adding a mechanical ventilation system to power the airflow partially.

Corridor facades

The third system classification made by Oesterle *et al.* is the corridor façade. The corridor façade is only divided horizontally by each floor so the cavity is open along the horizontal length of the building. The only closures are possibly at the corners where in some cases there is a great difference in air pressure are. The ventilation can be both natural and mechanical. In mechanically ventilated systems there is a mechanism on each division that controls the air flow, commonly known as "fish head". Again Oesterle *et al.* describe the usage and the general functions as:

> *"The air-intake and extract openings in the external façade layer should be situated near the floor and the ceiling. They are usually laid out in staggered form from bay to bay to prevent vitiated air extracted on one floor entering the space on the floor immediately above. Where a corridor façade constructed is used, the individual spatial segments between the skins will almost always be adjoined by number of rooms."* [3]

One of the advantages for corridor facades over the other two mentioned is that corridor facades do not limit the height of buildings. However they do not utilize the stack effects as much as a shaft – bow window because the intertwine effects will be terminated on each floor.

Multistory façade

The final type of double skin façade is classified as multistory façade. This type of system uses different approach to the functions and structure. The systems in not divided horizontally, and in some cases it is not divided at all. In a way it can be said that it combines the typology of both the corridor façade and the shaft – box. The air intake is close to the bottom and the top to optimize the stack effects throughout the system.

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[2] Oesterle *et al.* 2001 (p. 13)
[3] Oesterle *et al.* 2001 (p. 20)

> *"Multistory facades are especially suitable where external noise levels are very high, since this type of construction does not necessarily require openings distributed over its height. As a rule, the rooms behind multistory facades have to be mechanically ventilated, and the façade can be used as a joint air duct for this purpose"* [4]

There are some cases where the multistory facade system has omitted some of the ventilation of buildings. It is quite common that the system is used as an addition to the building. That makes it possible to reduce the load on the service systems of the building.

ONGOING DISPUTE ABOUT THE DOUBLE SKIN FAÇADE

The double skin façade can be traced back to the early 1900. However, little or no progress was made in a double skin glass construction until the early 1980´s. Then, in the early 90´s, this kind of construction gained a momentum when architects begun to have a greater interest in energy efficient buildings as political demands grew in that matter.

From recent deliberation, it is clear that practitioners are divided in two opposing groups: "pro" or "con" double skin façade. It is fair to say that the history of the double skin façade is relatively short and therefore there is not a very long experience with how well the system works. Many of the discussion topics are more theory than facts which actuates the debates.

There is quite a lot of recourse material available which addresses the double skin façade as a good system. The strongest argument is that this system is very environmental friendly because it has the potential to minimize the energy use of a building. By using the cavity as a ventilation system (natural or mechanical) it optimizes the energy needed to impel the ventilation. The Stack affects becomes a driving force for the air flow and less or even no energy is used to circulate the air. The cavity also plays a big role in cooling the building down simply be mitigating the heat gained from the sunlight. At the same time the air cavity can provide a good thermal insulation to the building. Researchers maintain that a double skin façade can reduce energy consumption be as much as 65% and CO^2 emissions by 50%[5]. Those who disagree with the conclusion of this study claim that are inaccurate because there is a very wide range of quantities that have to be taken in consideration: Embodied energy, maintenance, durability, operation cost and construction cost. It is also clear that when comparing the double skin façade system to a high level curtain wall that uses spectrally selective day lighting and has very high U-value would result in a much less statistical distortion between the two different systems.

Skeptics of the double skin system point out that the vast need for glass can in fact have negative effects on the environment. The embodied energy in glass is quite high and glass pro is very polluting.

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[4] Oesterle *et al.* 2001 (p. 23)
[5] Battle McCarthy, Environmental Engineers

> *"…Most remarkable however, is that these 'green' projects are introduces in the guise of the glass-tower, a form often interpreted as an enemy of ecological sustainability"* [6]

It is also pointed out that in many cases the design of the system is insufficient and that can result in the system doing more harm than good. Maintenance cost is an issue that seems to have been under estimated in many projects. 'Pro' practitioners place a great emphasis on the fact that the system can provide a good thermal comfort as well as transparency (for sunlight and visual effects) and acoustic insulation. Those are some of most important qualities, when designing a building. But to what extent double skin façade provide these qualities, is a matter of discussion.

ECONOMICAL ASPECTS

When evaluating a new type of building component, cost efficiency will always be one of the most important factors in deciding whether or not it is a viable alternative. A new building component will always be compared with traditional building methods and materials. In many cases it can be difficult to realize witch comparison is reasonable in order to get true results. To evaluate cost efficiency we must take into consideration investment cost, operation cost and maintenance cost and then compare that to buildings with conventional facades. In the case of the double skin façade it is a complicated task to evaluate the ultimate cost efficiency especially when taking the long term cost into consideration.

Construction cost

There is not a consensus among researchers and practitioners about whether the construction cost of a double skin façade is more or less expensive than traditional building methods. It seems to be a matter of what kind of comparison is made each time. To complicate matters even further, i other benefits can play a significant role in the comparison. To simplify this comparison of construction cost, all other that can influence it will be disregarded here.

A double skin façade does have a lower construction cost when compared with technical glazing systems such as photochromatic panes or similar systems.[7] It this case the assumption is that the competing system is a single glazed façade where technical additives or components are used to improve the performance of the glass panes. These systems are expensive to produce and in most cases the double skin façade can provide better result than the other system. It can also be argued that in some cases a double glazed façade can be less expensive than a conventional façade that will have the same thermal quality. Not all researches agree on this point. Straube and Straaten claim that reducing glazing area and increasing the quality of the glazing product leads to lower construction and operating cost and still has comparable

[6] Diprose and . 1994 (p. 1)
[7] Poirazis 2006 (p. 113)

environmental affects[8]. Straube is here referring to optimized 3 layer glass panes possibly with some enhance components.

The comparison of the construction costs is complicated as it depends heavily upon different variations of conventional construction. In most reviews about the double skin façade the comparison is made between a single and a double skin façade. In this case it is quite obvious that the double façade will always be more expensive in construction. But there is a great controversy about whether there is a significant difference in the construction of a single and a double façade. The Environmental Engineering Company, Battle McCarthy claims that:

> *"…when compared to advanced single skin building. Cost exercises have shown that buildings employing a double skin may cost as little as 2.5% based on Gross internal floor area."* [9]

In this case it is not very precise what the preconditions for these calculations are and it can be hard to take this statement without some measure of doubt. This may sound remarkably little when adding a second external façade to a whole building. In a case study for the Braun Headquarters in Kronberg they calculated the additional cost of constructing a double skin façade and then reduced the cost of omitted HVAC system. The results showed that the additional cost for that building is only 3% of the total construction cost[10]

Other researchers are not as optimistic. According to Jager (2003) the construction cost of a standard façade in Central Europe is 300 - 500 €/ m^2 and the cost for a double skin façade is 600 - 800 €/ m^2. When the double skin façade is equipped with more mechanical installations the prize goes up to 700 – 1000 €/ m^2 and when the system has open able sashes, the price goes as high as 1300 €/m^2. [11] And some practitioners are even more pessimistic. In their article on the use of multiple glazing systems, Werner Lang and Thomas Herzog write that:

> *"In central Europe, twin-face facades are about twice the price of conventional curtain walls. In the U.S., they are likely to be four to five times more expensive. The extra costs are racked up by the expense of engineering these systems, the amount of special glass required, and an unfamiliarity with these systems among the trades, which leads to higher installation costs."* [12]

It is tempting to assume that by choosing a ventilated double skin façade, the possibility of reducing the air conditioning plants (heating, ventilating and cooling). Some would claim that the double skin façade could, if well designed, eliminate some sections of the HVAC system like the internal ventilation system or the cooling system. This is indeed not the case when comparing a double skin façade with a single skin façade fitted with external blinding systems, and this cannot be confirmed without deliberation when comparing

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[8] Straube and Straaten 2001 (p. 11)
[9] Wigginton & McCarthy 2000
[10] Cody 2006 (p. 24)
[11] Poirazis, 2006 (p. 127)
[12] Lang and Herzog 2008

double façade with single façade fitted with internal blinds.[13] Some buildings with a double skin façade have also been built without heating system where as the building relies on other internal gains and solar gains. This obviously eliminates large amount of the building cost, but if estimated occupancy is not reached, there is a risk that the comfort temperature rate is not reached. In some other cases the heating load can be significantly reduced, but the size of the boiler will still be nearly the same. In those cases the construction cost of the double skin façade will not be reduced by these elements.[14]

There not a whole lot of studies that focus with accuracy on the difference between building a single and a double skin façade. In fact it should be fair to say that the difference between the two systems can only be evaluated for each project separately. The functional design of the double skin system can either be simple, with few mechanical segments, or with a complex technical design that will increase the construction cost by a great deal. Not to forget the additional design cost that comes with more complicated designs. It is therefore important to evaluate all factors and effects for each project before concluding that one system is better than the other. In this comparison conventional façade system has the upper hand simply because it is a challenging task for designers and developers to have an overview of both systems. There must be other factors concerning cost efficiency that make the double skin façade a viable alternative. Many practitioners point out that economic analyses of these two systems have to take in to account both the actual construction cost and the operation and maintenance cost in order to get the correct outcome.

If the double skin façade is to make more momentum and establish itself as a viable alternative it has to be a preferable alternative to investors. As an investment, the building will always be evaluated with construction cost, operational cost and maintenance cost, as well as life durability. If we give our self that the construction cost of the building will always be higher when using double skin façade, there must be some other encouragement for investor to choose this solution. In most literature and case studies the overall cost of the building is evaluated with the operational cost. Many claim that by reducing heating and/or cooling load the additional construction cost is retrieved with less operational expenses.[15] Sometimes this does not benefit the investors because the tenants are the ones paying for the operational expenses. However the owner of the building will carry the load of the maintenance cost, so if that is higher because of the double skin façade, then this in pure addition for him. So the investors have to pay additional cost for making the system but sometimes they don't benefit from it. If this is true then there is a good possibility that the lack of motivation for investors will outcome in slower development of the system and how investors see it as an alternative.

In those cases there is a need to find another encouragement for investors. Oesterle *et al.* have warning words for investors when evaluating the cost of this alternative.

> *"In estimating the costs of double-skin facades, there is a great risk attached to using lump-sum estimates without sufficient knowledge of the relevant cost determinants or without giving them adequate consideration. Practical*

[13] Magali and Gratia. 2004 (p. 6)
[14] Magali and Gratia. 2004 (p. 7)
[15] Cody 2006 (p. 20 – 29)

examples are known where there was a difference of nearly 50% between the estimated cost and the tender price. Cost estimate should, therefore, be made only be competent and experienced professionals." [16]

Operational cost

The operational cost of the double skin façade system is one of the aspects where the system could have the upper hand compared to conventional building methods. The basic idea is that optimizing the properties of the cavity between the two facades can result in a decreased need for service installations and mechanical service systems in the building itself. However the many different types and functions of the double skin façade make it difficult to evaluate whether the operation cost for a building is in fact lower when double skin façade is used. It must be emphasized that it is assumed that a decrease in heating and cooling load can be directly converted into lower operational cost where less energy used for operating the building means less running cost. Most available researches focus on finding out if the double skin façade is more energy efficient and therefore environmentally friendly

One of the main objectives of the double skin façade is to design the most optimal energy efficient buildings by minimizing heating and cooling load as well as providing ventilation for the building. If in fact these objectives are achieved it is quite natural to assume that the operation cost will be lowered as well. If there is a possibility to mitigate the need for mechanical ventilation systems and heating and cooling in a building then it would result in less expense of operating these systems. The big question is if the operation cost can in fact be lowered by the use of a double skin façade. It is also a concern how much is gained in capital by lowering the operational cost for a building because that will always be at key issue when evaluating the cost efficiency of each and every building. If the investment is going to be too expensive, developers will not see it as a desirable benefit and the stimulation needed to prefer this system is maybe not enough. Practitioners do not agree on if the operation cost is a benefit, even though in many cases researches have shown good results in lowering the operation cost. Harris Poirazis writes:

"Comparing the Double Skin and the Single Skin type of façade, one can easily see that the Double Skin type has higher cost regarding construction, cleaning, operating, inspection, servicing, and maintenance." [17]

The statement above only takes in to consideration the basic comparison between having to operate a single and a double skin façade. In order to make a reasonable comparison we have to dig deeper and evaluate whether the double skin façade provides any benefits for operating the building.

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[16] Oesterle 2001 (p. 184)
[17] Poirazis 2006 (p. 67)

Double skin façade in temperate climate

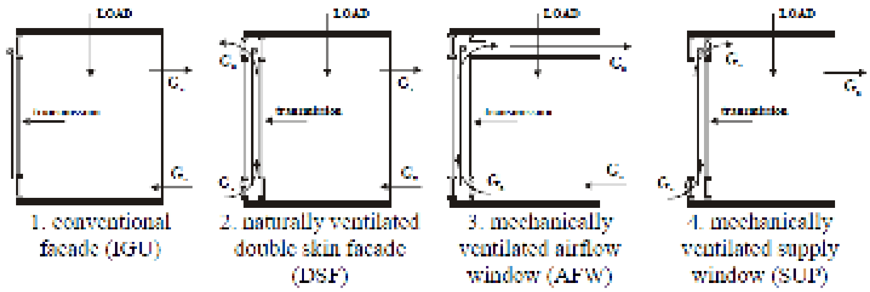
To find out the different in operation cost between the two types of facades we must look at researches that have been made directly for this topic and that compare the two different types of constructions. One of the first to make such a specific comparison was Dirk Sealens et al. They claim that:

> *"Some authors sum up the working principles and ideas to improve the energy efficiency without providing calculation results or experiments […] correctly points out that only few simulations have been made and that only few measurements are available to support the claimed benefits. Other researchers provide models to simulate specific MSF [multiple skin façade] typologies. They, however, do not link the envelope level results to the building energy performance or do not couple the model to a building energy simulation program"* [18]

They also claim that other researches made so far do not compare the different variety of a multiple skin façade to the conventional single skin façade. Most studies show that one of the major benefits at a double skin façade is the reduction of the transmission losses. Studies also show that there is a direct link between the decrease of U-factors and increasing air flow rate. Some researchers concluded that there was a problem with the excessive solar heat, but it would only result in a small penalty on the cooling load of the building.[19]

Sealens et al. made a computer simulation to calculate the efficiency of the various types of double skin façade. Then they coupled it with another computer model that is a commercially used energy simulation program. The scenario was a single person office situated in Belgium with the glass to wall ratio of 56%. All types were equipped with solar blinds of the same type. Four different types of façade systems were compared; single skin façade, naturally ventilated double skin façade, supply window double skin façade and airflow window double skin facades. They divided the results in to two categories; heating demand and cooling demand. The result showed that when heating loads were taken into consideration, the naturally ventilated double skin façade required 22% more heating than the traditional single skin façade. However the two mechanically ventilated double skin facades demanded far less energy than the single skin facades – from 18% less to as little as half of the energy used by single skin facades. When it came to the cooling load, however, it was a different story altogether. It seems that a single façade with blinds is by far the best option for reducing cooling loads. The ventilated double façade had 32% more cooling load and the supply window system had four times the cooling load compare to a single facade. The report also shows that there is a substantial difference between different proportions of the ventilated cavity.

[18] Sealens *et al*. 2003 (p. 1)
[19] Sealens *et al*. 2003 (p3)



The result of Sealing *et al*. research is that the heating load of a building can be reduces greatly if the correct design is used. However it will result in an increase of the cooling load and the increase can possibly be more than the benefits gained from the minimized heating load. It is interesting that the system with natural ventilation does not come well out of these researches at all. Sealing et al. conclude that it is not possible to lower both heating and cooling load of a building by choosing one typology of a double skin system. It is only by combining the benefits of different systems that plausible result can be achieved. In order to obtain that goal, the mechanism of the system must be very sophisticated and diverse. In order to evaluate whether the chosen system is energy efficient or not, it is necessary to look at both the heating and the cooling load. Moreover it is important to take all other enthalpy changes of the cavity air and study the transmission losses closely for the building as a whole.

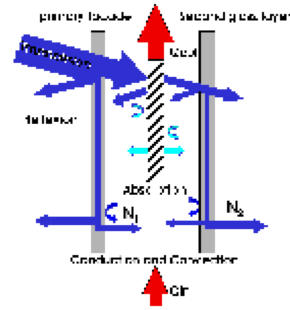
Double skin performance in hot and moist climate

M. Haase (2006) made a similar research to compare single and double skin facade. In his research the conditions were the warm and moist climate of Hong Kong. Haase states that the buildings in Hong Kong are accountable for over 50%[20] of all the energy consumption and he wanted to find out whether a double skin façade system could help reducing this amount, in this warm and humid climate. His preconditions are that the air layer in the cavity of the double skin façade helps to insulate the building and then reduce the cooling load. This applies mainly to the colder climates where winters are cold. Haase also claims that the stack affect generated in the cavity of the system could help reducing solar heat gain and thereby supporting the air-conditioning system of the building. Haase recognizes that several other researchers have made calculation models to simulate thermal behavior and he says that the most detailed model recently developed is Sealens research mentioned earlier in this report. Haase writes:

> *"The results are however not easy to transfer to a hot and humid climate and he [Sealens] simulated only single-story DSFs [double skin facades]"* [21]

Haase chooses to compare a naturally ventilated double skin façade with different types of a single glazed curtain walls. The variations for the single glazed façade are clear glazed, reflected glass and solar control

[20] Haase 2006 (p. 1)
[21] Haase 2006 (p. 3)



glazing. He also compares three different wall-to-window ratios for both systems. His results are quite interesting when comparing the two different systems that have the same window-to-wall ratio.

Unlike Sealens results show the naturally ventilated double skin façade seems to be a lot better for lowering the cooling load. There was a significant difference in different window to wall ratio. When comparing single façade (with solar shading system) and double façade (with two clear glass panes) with the same window to wall ratio, it showed correlation between higher ratio and lower cooling load for the double skin façade. When comparing a wall to window ration of 0.32 the double façade had around 7% less cooling load and when the ratio was 0.911 the lowering in cooling load was around 13%. It was only when comparing a double skin façade with a window to wall ratio of 0.911 and a single skin façade with a window to wall ratio of 0.32 that the cooling load was the same.

These results are askew with the results that Sealens got from his research. It is not clear why the difference is as large as showed but the preconditions were in fact not the same. There was also some difference in the modeling calculations for the two different researches. Haase's researches are mainly focused on finding environmental friendly solutions for buildings and his approach is to lower the operational cost by making the building more energy efficient. Haase concludes that by designing an energy efficient double skin façade system, the amount of heat gain can be reduces significantly. The system uses the ventilation in the cavity to hinder heat gain. Haase only took into consideration a naturally ventilated system and he recognizes that further researches must be made with other typologies of the double skin façade.

Comparing the two systems in different climates

Stelios C. Zerefos published a report on research about double skin façade in 2007[22]. In his research he compares double façade with single façade regarding heating and cooling load and uses examples from different cities in different climates. Zerefos' approach to the comparison is different from that of Sealens and Haase, and his calculation methods and modeling scenario are considerably different. Zerefos' comparison in many ways includes the factors that Sealens and Haase did not take into account. In many ways he is closer to the actual usage of many building cases than the other two researches. He is also aware of what is the optimal scenario for using double skin façade.

Zerefos quotes Oesterle *et al*. to identify what method there are to estimate double skin performance.

> *"Three methods of calculating energy performance of double skin facades can be identified, each with its benefits and drawbacks […]. The first and most accurate method concerns energy calculations after a building has been completed, a time consuming and expensive process. The second method involves the*

[22] Zerefos 2007

> *construction of a mock-up façade element and its use as a testing platform for energy calculations. However, the accuracy of this method, although less time consuming and expensive than the previous one, depends on the size of the mock up façade, while the calculations usually involve software simulation to compensate for the non-constructed elements. The third method for calculating energy performance on a double skin façade relies mainly on software simulation." [23]*

Zerefos chooses to use the third method mentioned. He uses software simulation to calculate the comparative results and find difference between heating and cooling load for a double and a single skin façade.[24] He starts by calculating the U-values of both the double and single façade. He then uses the results and implements them in a 3D computer model which then with the addition of additional data, computes annual heating and cooling load. Zerefos carefully makes sure that most factors of the system are built up the same way, so the only variations are two different types of facades. To begin with he uses neutral climate conditions that have been standardized in a BMS standard. This is done in order to make reasonable comparison between the two systems. Then Zerefos compares the two systems in different environmental conditions. It is interesting that Zerefos seems to choose to have the shading device in the cavity of the double skin façade, but at the interior of the building for the single skin façade. This is a different approach from Haase and Sealens and one could argue that this is not the best way of utilizing this component.

Zerefos modeling is also a bit different from the two previous researches. He models a whole office building and then uses one office on the middle of the building to get his data to get real life results. The geometry of the room in all three researches is nearly the same so in that way should be relatively comparable. In his calculations the HVAC (heating ventilation and air-condition) system is turned on during operating. Zerefos also sets up two different scenarios for buildings. One is that an existing building is retrofitted with a double skin façade and then the before and after scenario is evaluated. The second comparison is a basic comparison between a single and a double skin façade.

In the first part of this research the outcome shows that the double skin façade has a much lower U – value and thermal efficiency. The second part of the research is where we find the interesting part of the study. First Zerefos compares heating and cooling load where there is only a shading device on the double skin façade. The results show that in the warm climates of the Mediterranean and Arid, the double skin façade had between 30 and 40 % less heating and cooling load. However in colder climates like in England and Moscow, load for the double skin façade was only between 2.9 to 8.3 % less than for the single skin façade.[25] The difference is quite significant and shows without a doubt that the cooling load in this comparison is the main driving factor. Zerefos then compares the two different systems when both of have a comparable shading device. In those results the difference is not as great. But there is still a substantial difference and that shows that the double skin façade has less heating and cooling load then a single skin

[23] Zerefos 2007 (p. 226)
[24] Zerefos 2007 (p. 222)
[25] Zerefos 2007 (p. 226)

façade. The difference in the hotter climate zones was between 5.3 to 7.4 % and in the cooler climates the difference was around 2.8%.[26] Zerefos explains this difference by saying:

> *"since in the cooling season it permits less solar energy into the building and thus reduces the energy consumption for cooling. The opposite occurs in the heating season, where solar energy is needed for heating. In this case during the daytime, the single skin façade consumes less energy for heating since it allows more solar energy to enter the building. However, at night time this difference is compensated by the better U-value of the double skin façade."*[27]

Zerefos concludes his research by saying that the double skin façade significantly reduces the solar radiation impact on the building and therefore lowers the cooling load of the building. This certainly has greater impact on Mediterranean and an Arid climate where the cooling load has a bigger effect on the building. During the night hours the added U - value also helps lowering the buildings energy demand. In temperate and continental climate the additional U – value and the stack effects has a very positive effects on the energy efficiency of the building. Even though there is less heat gain from solar heating, other properties overwhelm that factor and produce better performing system.

Other researches

There are some other researches available that focus on comparing the double skin façade to a single skin façade. There are even more studies made as case studies for individual buildings. Most of them are not a neutral comparison like the three studies discussed in this dissertation. One of these studies is about the Medical School's Biomedical Science Research Building (BSRB). Navvab made a study on that building by comparing the south fazing double skin façade with an alternative single skin façade[28]. He uses complex and sophisticated computer programs to retrieve his results. His preconditions are a building with a south fazing double skin façade, situated in Michigan, USA. The double skin facade is equipped with a shading device and the building has heating, ventilation and air-conditions (HVAC) system.

The results are that are that the double skin façade reduces the annual energy consumption of the building by 2% for every 2°C increase in cooling temperature and a decrease of 4% in heating when comparing with a single skin façade. Navvab concludes that:

> *"…this DSF [double skin façade] building show that this design reduces the annual energy consumption of the office zone more as compared with a conventional façade. This highly insulated façade would reduce the building energy loss in winter and heat gain in summer. The amount of energy reduction*

[26] Zerefos 2007 (p. 226)
[27] Zerefos 2007 (p. 227)
[28] Navvab 2005 (p. 831)

is a function of building operation and its energy management systems' capabilities and limitations."[29]

The result from Navvab's case study show that in this case the BSRB building benefitted from having a double skin façade. There are certainly many more case studies like this one, but since each and every case has its different variations, it is not relevant to take them all into consideration.

What can be reasoned from these researches?

It is quite clear that researches do not all agree on if the double skin façade performs better in reducing energy consumption compare to the single skin façade. However if we look only at the most recent researches then it seems to be main stream that the energy efficiency o the double skin façade is better than for the single skin façade. Then the big question is how much is the gain of having a double façade system. That question will not be answered by making general researches because it is depends so heavily on different each building's situation. One thing we can say for sure is that it is well possible to reduce the energy consumptions and therefore operation cost of a building by designing it with a double skin façade.

Maintenance cost

The two biggest factors that have to be taken into consideration when designing a double skin façade have been evaluated. Those factors, however, do not tell the whole story. Maintenance cost is always a big issue when dealing with a building and in some cases it can be a very big factor when formulating the whole cost. It is a wide spread assumption that the mechanical cost is far greater for a double skin façade then a single skin façade. Poirazis states in his literature review:

> *"Additional maintenance and operational costs: Comparing the Double Skin and the Single Skin type of façade, one can easily see that the Double Skin type has higher cost regarding construction, cleaning, operating, inspection, servicing, and maintenance."* [30]

It is necessary to divide the maintenance cost into several different categories to get a clear view of how the cost will affect each building. Here the maintenance cost will be divided into mechanical maintenance, inspections and cleaning the system.

Mechanical maintenance

Mechanical maintenance can be one of the most costly annual expenses for a building with a double skin façade. But that varies greatly between different cases and the factors are many. First of all the question is if there is in fact a mechanical system intergraded in the double skin façade. In some cases there are almost

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[29] Navvab 2005 (p. 831)
[30] Poirazis 2006 (p. 119)

no mechanical devises in the system and obviously then there is little or no mechanical. Naturally ventilated systems are often equipped with traditional windows that the occupiers open manually and in those cases the mechanism is minimal.

Most systems have a shading device and the shading device is most often mechanically or manually operated. The rule of thumb is simply that the more moving part intergraded in the system, the higher maintenance cost follows. But in this case when making a comparison with a single skin façade both systems have the same type of devices and therefore the maintenance is not grater in either case. In favor of the double skin façade the shading device is most often situated in the cavity and therefore not exposed to external affects. This reduces the maintenance of the shading devise to some extent and extends the life expectancy of the elements.

In a mechanical ventilated double skin façade system the maintenance frequency is much higher. In these systems there is a controlling station to control the circulation of the air and where it exhausts. The most common mechanically ventilated system is box window type and corridor façade type. Both these systems are divided with a horizontal partitioning which also directs the airflow in or out of the building[31]. These systems are sometimes called "fish - heads" (named after a popular shape of the mechanism). The functionality of the fish - head varies between systems, but they can direct the air up to three different ways. In those cases the mechanism has many moving parts and that is directly linked to increased volume of maintenance.

To make a reasonable comparison of the maintenance between the double skin façade with a mechanical ventilation system and single skin façade it must be evaluated how much of the traditional HVAC system is dispelled or mitigated. Magali *et al.* states that this is not true in case of cooling or heating systems. They say that the building will in most cases have a heating or cooling system and even though the system might have less velocity the existence of the system will always require similar amount of maintenance.[32] There are still some incidences where the double skin façade can replace a ventilation system in the building and in this case there should not be substantial increase in mechanical maintenance.

But every project has different and a detailed maintenance schedule must be made for each and every case. Only then can we truly evaluate the increase or decrease of mechanical maintenance cost.

The problem with evaluating the difference between the two systems is that in most cases a project does not make these comparisons and therefore the data is not available. Only by making a comparative calculation for each project we can truly find out what the increase or decrease of energy consumption is. This should be an ordinary practice when designers are evaluating whether or not to choose a double skin façade is a preferable alternative. The maintenance cost may not be the largest factor in the cost estimation but in large scale project this can be a significant amount in the annual budget for a building.

[31] Oesterle *et al.* 2001 (p. 13 - 20)
[32] Magali *et al.* 2004 (p. 6 – 7)

Cleaning cost

A building with large glass panels must always be regularly cleaned to optimize the performance of the glass. All building must undergo a cleaning procedure some time in its lifetime, but glass is the one building element that needs by far the most cleaning. In order to optimize the properties that we seek in glass cleaning must be executed regularly. This is not just to retain the visual quality of the glass but it is also a very important for all aspects of solar affect on the building. Most cases where double skin façade is used in a building, the glass in the façade has a high ratio. In fact many of the larger scale projects have a glass to wall ratio of over 90%.[33]

It is then sure to say that cleaning a double skin façade is much more expansive then cleaning a single skin façade. But the equation is not a simple as that. Oesterle *et al.* made a comparison between the two systems concerning cleaning. There is says:

> *"The cost of cleaning double-skin facades is inevitable higher than that for single-skin façade because of the two additional surfaces involved:*
> - *the inner face of the outer skin and*
> - *the outer face of the outer skin."* [34]

In their book they make their own precondition to set up an equation for calculating the cleaning cost. It is fairly simple and strait forward that more surface area equals greater cost for cleaning. They estimate that in a double skin façade the external face is cleaned twice a year and the three other faces cleaned once a year. They also estimate that the shading device inside the cavity is cleaned once every 4 years. For the single skin façade the same principles apply: outer face twice a year and inner face once a year. But the shading device is cleaned once every 3 years. Oesterle *et al.* come to the conclusion that it is around 30% additional cleaning cost in cleaning a double skin façade. However this does not accumulate into a high cost. If an office building is 5.4 m deep, the cost will be roughly around €0.13 / m^2 per year. It must be taken into consideration that these figures are from the year 2001 and do not apply today. But it shows that the annual cleaning cost is not an extremely high proportion of the maintenance cost.

Oesterle *et al.* made a very basic comparison between the two systems where they estimated the frequency of the cleaning. Magali and Gratia made a much more detail estimation in 2004. They note that it is often assumed that the cleaning cost of the double skin façade is higher because of the risk that condensation can form on the inner face of the outer skin.[35] This is not true unless the condensation occur frequently and in well ventilated systems this will not transpire. Magali and Gratia state that there are no evidence to confirm in the cavity will be exposed to heavy soiling from the air coming from outside. It

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[33] Tenuhen *et al.* 2001 (p. 8)
[34] Oesterle *et al.* 2001 (p. 186)
[35] Magali *et al.* 2004 (p. 3)

seems as even close to streets with heavy traffic the double skin façade does not have to be cleaned more frequently than a single skin façade.[36]

They also compare cleaning of the shading device between the two systems. They take into consideration two commonly used types of shading device; fabric blinds (screen) and venetian blinds. Their results show that blinds on a single skin façade should be cleaned once every year, but when the blinds are in a cavity, the cleaning is only carried out once every 5 years. Not only is the cleaning rarer in the case of double skin façade, but the shading system is also much more accessible which means that the cleaning procedure is less expensive. Magalie's and Gratia's calculation show that the cleaning o the double skin façade is in fact almost 30% less expensive than cleaning of a single skin façade[37]. Despite that there are two more surfaces throughout the whole building, frequent cleaning of the shading device for the single skin façade and harder to access makes substantially more costly.

Magali and Gratia conclude in their report that:

> *"According to our calculation and the literature, the cost of cleaning facades manly depends on the shading position and on the cleaning frequency. Indeed, the shading cleaning costs are so high that the frequency of this cleaning governs the total cleaning cost."* [38]

Cleaning components in a double skin façade is certainly an important operation. In buildings that do not have a vast glass façade like the double skin has, cleaning generally does not have a big impact on the interiors or function of the building. It is therefore critical that cleaning is executed according to each buildings need. Most buildings have a detailed operational and maintenance manual where these matter are carefully expounded and if the manual is enforced correctly the systems should operate sufficiently. There are some reported incidents where lack of cleaning damages moving parts and ruin the optimized function of the double skin façade.[39]

Inspections

The last maintenance segment discussed in this dissertation is the overall inspection of the system. There should always be a scheduled inspection for all buildings. The scope of the inspection differs from building to building. Magnitude, usage, geographical position and complexity of building elements play the largest role in volume of the inspection necessary. For buildings with a double skin façade, it is always important to schedule frequent inspections to make sure that all systems function properly and that the desired properties of the glass façade are as good as they can be.

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[36] Magali *et al.* 2004 (p. 4)
[37] Magali *et al.* 2004 (p. 5)
[38] Magali *et al.* 2004 (p. 12)
[39] Boake (p. 10)

Oesterle *et al.* emphasizes on the importance of regular inspections for a double skin façade. They say that the work involved in the inspection and maintenance mainly depends on the weather and to what extent the system contains moving parts. The Construction guarantees inspection and maintenance in the first years. After that period a detailed inspection and maintenance manual has to be made and operated by the building owner to insure that all elements of the systems are kept in order.

> *"In practice, where a façade is well planned and executed to a high level of quality, this approach can be perfectly economical. For larger projects and facades with moving parts, however, contracts will normally be made with the construction firms to cover inspection and servicing, and – to a limited extent – maintenance work."* [40]

According to Oesterle *et al.,* the annual cost for maintenance and inspections can vary from 0.5 – 3% of the total investment cost. The percentage varies considerable depending on the scale of the building, quantity of moving parts in the system and of course the quality of the building parts and works.[41] Other practitioners and researches agree with them when it comes to the percentage of the annual cost. So it should be safe to assume that these figures are accurate. But it must be emphasized that every building has a different scenario and it can cause a large distortion in the economic calculation if these factors are not established for each and every building.

EFFECTS ON THE BUILDING

In order to have a fair comparison between a double and single skin façade, we must consider what affect it has in the building and on the occupiers. When dealing with advantages and disadvantages of the double skin façade, we have to find out what the motivation of having a glazed façade is. The physical benefits of a glass façade are possibly the factor that most developer seek when considering a double skin façade. But there are other issues that have to be addresses when evaluating benefits of a double façade.

Indoor climate

It is becoming more and more important for buildings that the indoor climate is as good as possible. Both developers and official authorities are placing greater and greater emphasis on the importance of a good working or living environment. A direct link has been established between people's health, both physical and mental, and the quality of their working environment. Because of that, optimizing the indoor climate is one of the tasks that are most important for a designer's to consider when designing a building. The U.S Environmental protection agency defines indoor climate as:

[40] Oesterle *et al.* 2001 (p. 187)
[41] Oesterle *et al.* 2001 (p. 187)

> *"Temperature, humidity, lighting, air flow and noise levels in a habitable structure or conveyance. Indoor climate can affect indoor air pollution."* [42]

In other words all physical and mental effect on the occupiers that occur in buildings. There are in fact many more factors that influence a building – among them design functions and materials. It is quite clear that in modern times this is one of the most important assets that a building can possess. The condition and wellbeing of people using the building must be one of the highest priorities that developers try to achieve when designing a building.

Brian Cody made a case study for Braun Headquarters building in Kronberg. In his study the office has an 800 m^2 area per floor. He estimates that because the building has a double skin façade, the indoor climate is improved substantially and that results in a 1% annual increase in productivity. This amount sums up to be 60% of the total additional cost of constructing a double skin façade.[43] So just by incorporate the improved indoor climate he assumes that the investment will pay off within two years. It can be difficult to evaluate how much improved indoor climate will affect the productivity of the workforce, but the conclusion of Cody's study is plausible. And it is undisputable that bad indoor decreases productivity.

The down side to choosing a double skin façade in a building is that when the design is not carefully implemented,the system does not work properly. There are several things that can go wrong. If the U – value is not sufficient and the heating system does not cover the heating load, it is inevitable that the building will not reach the optimal heat level. The same applies with if the building gets too hot. It the g – value is not sufficient or the shading device does not keep up with the solar radiation and the cooling system is insufficient, then the building will get too hot. And the correct temperature is very important for the indoor climate. For every degree that is more or less than the lean temperature, more people feel uncomfortable and this might worsen their performance. Given the delicacy of this matter it is crucial to estimate the actual function of the system in order to get preferable results. Just as important is that maintenance and service is carried out sufficiently in order to keep the full function of all systems.

Another crucial component that potentially can be mismanaged is the ventilation part of the double skin facade. There are many varieties of ventilated systems in a double skin façade but it is possible to divide them into two main categories; naturally ventilated and mechanically ventilated. In a naturally ventilated system there are not many things that can malfunction because there are usually not many moving parts intergraded. However if the design of the natural ventilation is insufficient and the airflow inadequate, people will sense a lack of clean air in the building. It will also affect the temperature and humidity inside the building. The same applies to the mechanical ventilated system. Faulty design can cause the building to lack air flow in current condition. Also, if the system is not maintained and serviced, there is a great risk that it will affect the indoor climate of the building. An example of this is found in a report made by Boake and his students.

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[42] www.epa.gov/OCEPAterms/iterms.html
[43] Cody 2006 (p. 21 - 22)

> *"A recent visit to the Hooker Building in Niagara Falls, New York, allowed us to take a close-up look at the cavity of this close to 20 year old building. The construction of the new "Aquarium Attraction" that will directly connect to this building resulted in the unplanned for intake of much construction dust into the cavity. The sun shading louvers were obviously excessively dirty. As a result, the intake grilles at the base of this continuous height cavity have been closed off, causing the HVAC system to malfunction. An interview with security people at the building revealed that the building was always either too hot or too cold."* [44]

This is an obvious case of a deficient design and it stresses the urgency of a well developed design. In cases where developers have realized that fact the function of the double skin façade is often very good. And combined with other advantages that come with the double skin façade can add to the indoor climate and assist with creating a building where occupiers have a good physical and mental environment.

Visual properties

In modern architecture visibility properties are always an important aspect of the building's design. Of curs it differs from project to project how much of the ratio of the façade is preferable transparent but in general it is taken as a feasible alternative to have high volume of glass as a façade. But problem occur when dealing with a fully glazed façade. The low U – value of the glass can make it difficult to reach the sufficient goal of the buildings energy frame. At the same time problems occur with solar radiation heating the building to much. That will increase the cooling load of the building and that comes down on the energy frame as well. In modern times the energy efficiency of all building is controlled to some extent by the authorities of each country. Of course it differs a lot form country to country what the requirements are made. In many European countries there are very strict regulations on how much sunlight is supposed to be at every working station in a building. These regulations differ somewhat between countries. This regulation derive from the fact that natural daylight is the best source of light and, having natural light at workstations, improves the indoor climate considerably. The only way to achieve this however, is to have as much of the façade made of glass as possible. It is therefore always a challenging task for designers to incorporate desired visual properties and at the same time make sure that the building is energy efficient.

The concept of a having a building with a glass façade first emerged in the nineteenth century, at the time of the Industrial revolution. However it did not gain a great momentum until the early 20th century. Some of the leading architects in this were Le Curbusier and Mies Van der Rohe[45]. The following decade glass facades were considered a high cultural phenomenon. Later in the 20th century the glass façade concept struggled with critique that it was not a sustainable approach for buildings. Some reviews even labeled the

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[44] Boake (p. 10)
[45] Diprose and Robertson 1994 (p. 7)

“glass tower” concept as environments worst enemy. Diprose and Robertson summarized there reading of negative and positive metaphors for ecologically responsible design (ERD):[46]

Negative Metaphors for ERD	**Positive Metaphors for ERD**
Transnational corporations	Health
Centralization	Education-progress to 'high culture’?
High movement/energy-use society	Artifice? (Human achievement)
Anti-contextual/commoditization	Catalyst of social transformation
Short-term planning	Religion – 'truth'?
Unrestrained development	
Technological optimism	
Patriarchal culture	
Masculine/anthropocentricism	
Disconnected from nature	Safety from nature? – contemplation
Sick Building Syndrome	

These are all rhetorical statements and many of them were responded by introducing numerous ways of designing a building with a glass façade that is still environmentally friendly. However there will still always be a dispute about the sustainability of the “glass tower”.

In another report from Diprose and Robertson question the psycho – cultural benefits that a double skin façade brings. They claim that the concept of bringing the user of a building closer to nature might be jeopardized by adding an extra skin to the building. They point out that:

> “If a seamless transition between human and nature is preferable, do multiple layers of glazing assist in softening the transition between inside and out? Might this second envelope be considered a further barrier - visual transparency disguising its true reality?” [47]

They also claim that if a double skin façade is equipped with automatic functions and objects then the buildings physical affects will cause the occupiers to feel disconnected with the facility and alienated.

But at the same time natural light in buildings became more important factor for designers which inspired developers and designers to maximize the use of glass in the façade. Using a double skin façade is only one of many solutions that have been developed to do this. It provides the possibility to have a close to 100% glazed façade that will optimize visibility and harvesting natural light. When looked at this way one can say that other benefits that come with the double skin façade are additional aspect to a building. This of course is an oversimplification, but an interesting point to consider at the same time.

[46] Diprose and Robertson 1994 (p. 6)
[47] Diprose and Robetson 1996 (p. 4)

Appearance

There are some mixed opinions about whether or not the outside appearance of a double skin façade is a benefit or not. Some say that the option of having a fully glazed façade is an excellent property and in many areas where official requirements demand certain energy efficiency, a double skin facade is a feasible way of acquiring both of those aspects. Others point out that the double skin façade limits the diversity of what type of façade is chosen for a building; the appearance will always be a glass panes and metal frames. There will, in all likelihood, be a continuing disagreement among designers on this issue and to try to reason one solution over the other is not an issue in this thesis.

It is a simplification to state that a double skin façade has only one appearance. In many of the researches mentioned above some of the examples assume that the inner leaf of the building is a conventional façade. In those cases the building has a façade of any type and is then fitted with as additional façade on the outside of the building. If the glass in the outer façade is very transparent then the inner leaf does certainly influence the appearance of the building. A brick façade and a concrete façade will have much different appearance, even though they are behind a glass wall. The double skin façade will probably reduce the visibility of the inner leaf but that should not be considered only as a downside. This provides and opportunity of additional diversity to the façade types.

Probably in most cases when a double skin façade is used, both the outer and inner leaf is close to be fully glazed. This certainly limits the diversity of how the external appearance will be. But that does not mean that all buildings with double skin façade have to look the same. The fact that a glazed wall is a curtain wall where the load bearing system is separated, provides a new option of geometry that is not bound with traditional building physics. In modern times when architects are using more and more sophisticated computer programs to draw building, the shape of a building is no longer and obstacle. Using a curtain wall in a building with complicated geometry is often preferred and implementing a double skin façade is directly transferable from a conventional curtain wall.

Materials in a double skin façade are most often glass panes supported on a metal grid. The structural grid can be made of any construction metal, but they often look the same. In fact the only visible variation could be a painted surface of the metal. The glass can have some variations. It can range from a completely transparent glass to a very reflective glass and everything in between. Glass also comes in several colors and even with slightly different surface treatment. So a building can have quite a lot of different appearances despite the limitation of the outer leaf of the system.

It seems to be a common practice, mostly for smaller size projects, to have a double skin façade only on a limited area of the façade. Most often the system is on the south facing façade to optimize the solar and natural light gain (for the northern hemisphere). It can be stated that this implementation combines the properties of both conventional construction and the double skin façade. It also has interesting effects on the appearance of the building and in a way increases the diversity of façade design. When all factors are taken into consideration it is maybe an oversimplification to say that the double skin façade limits the exterior design of the building.

Acoustic

Sound insulation is becoming more and more important for buildings. In urban areas where traffic and other sound polluting aspects have an impact on the internal environment; it is one of designer's main projects to fit the building with sufficient sound insulation. Oesterle *et al.* say that in their opinion the sound insulation properties of a double skin façade are the most important reason for using the system.[48] There are several topics that have to be considered when evaluating the acoustic properties of the double skin facade. It can be divided into main categories; external acoustic and internal acoustic transmission.

External sound

External sound transmission is becoming a greater problem in city centers. In some cases architects have integrated sound barriers to encounter these problems. Double skin façade usually provides a building with a good acoustic insulation because of the outer leaf of the system. In a naturally ventilated system occupiers can open a window at the same time as the outer skin is providing acoustic insulation. At the same time the inner leaf of the double skin façade does not have to have as much acoustic insulation requirements. There are many cases where a building has been retrofitted with a double skin façade just to compensate for sound pollution. In some special circumstances a building is designed with a double skin façade that work only as a sound barrier. These cases are often a box type window or a corridor façade and the ventilation aspects are not necessarily intergraded in those systems.

Oesterle *et al.* developed a calculating method to estimate the influence of adding a double skin façade to a building. There methods are to combine established calculations and with their own. They set up preconditions which can theoretically be confirmed under certain circumstances. They illustrate criteria for a noise level scenario in an office building. The criteria are that for one percent of the time noise coming to the building is more than 70 dB. The preferable noise level in and office is around 35 dB. If the partition of the double skin façade reduces the sound level by 40 dB, then the noise level in the office will be 30 dB. In that case the productivity of the occupier is estimated around 95%. When the partition reduces the noise level of 30 dB and the noise in the office is 40 dB, then the productivity reduces to 50%. And if the partition only reduces the sound level by 20 dB then the occupier can hear everything and the productivity goes down to 0%.[49] This is just an artificial criteria but it shows the importance of the efficiency of the sound barrier.

With all these preconditions and calculation given the authors make two case studies to demonstrate what can be expected from a double skin façade to work as a sound barrier. The case studies are real life project and the authors did measurements to confirm their calculations with the outcome. There objective is to see how much the double skin façade can improve the sound insulation for the building. Oesterle *et al.* come to an interesting conclusion:

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[48] Oesterle *et al.* 2001 (p. 34)
[49] Oesterle *et al.* 2001 (p. 38)

> *"Empirically, one knows from the measurement practice described here as well as from other measured examples that external façade skins which ensure an adequate fresh air supply (i.e. usually with an 8 – 10% opening area) can improve the sound insulation by roughly 5 – 8 dB. The opinion sometimes expressed […] that reductions in sound level of more than 4 dB are possible only where the opening area is smaller than 5% or only where additional sound absorbers are installed cannot be confirmed."* [50]

The results are interesting because they show that the double skin façade can give more sound insulation while at the same time an increase for ventilation potentials.

Poirazis describes the acoustic insulation as one of the advantages of the double skin façade. He states that the type of the double skin façade and the number of openings in the system is crucial variation points that have to be considered be designers. He quotes number of researchers that have calculated the performance of the double skin façade concerning acoustic insulation. The general conclusion is that the system provides a good insulation from outside noise.[51]

Straube and Straaten have a different approach to evaluate the acoustic insulating affiance of the double skin façade. They claim that:

> *"The addition of a third pane of glass to a façade, along with asymmetrically sized air spaces results in reduced sound transmission relative to typical double-glazed sealed units. The sound transmission of sealed triple-glazed glazing units with asymmetrical airspace sizes is almost always superior to a DF, since there is no direct air connection of the exterior air cavity to the outside air. The DF can provide better sound control if the windows are the primary ventilation opening. Dedicated ventilation openings provide the best in sound performance."* [52]

The results from researcher certainly differ and the main reason for that is that the comparison is not the same. Developers and designers must have a clear idea of what alternatives are available before they can determent how to evaluate one component over the other. Only then they can make a dissension that optimizes each project to get the best results.

Internal sound

There are other considerations when dealing with double skin façade and internal sound transmission. Poirazis claims that the double skin façade can reduce sound transmission between rooms. He also mentions that one of the disadvantages of the double skin is that it can have internal sound transmission problems if it is not designed properly. He mentions that the sound insulation can be a problematic issue

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[50] Oesterle *et al.* 2001 (p. 46)
[51] Poirazes 2006 (p. 113)
[52] Straube and Straaten 2001 (p. 5)

when dealing with a corridor façade and a multi story façade. In these cases additional measures must be made to react against the possible sound transmission.[53]

Oesterle *et al.* identify two main problems with internal sound transmission when dealing with a double skin façade.

The first one is that rooms side by side bring up the problem of sound to transferring in the cavity space and affecting each other. One could assume that the affects would be the same as sound transferring through the corridor between the rooms. But corridors usually have greater acoustic damping and that absorbs the sound. Glass is not a good material to absorb sound and that creates a significant difference. Another factor is that windows have a psychological factor for the occupier. The person in the room will not expect to hear people on the next room via the window and it does disturb more than hearing something form the corridor. The second problem with sound transmission is when the sound travels between rooms from floor to floor. This is often a problem when dealing with a corridor façade. In situations where the double skin façade does not have a horizontal partition, the risk of internal sound transmission will always be greater.

Similar to the calculation for external noise, Oesterle *et al.* crated a calculation scenario and added their own method to estimate the impact of internal sound transmission. There are many variations in this matter and different scenarios call for different solutions. I general the authors concluded that there are some problems concerning internal sound transmission which are difficult to overcome because of the nature of the system. They provide optimized calculation which can be incorporate to most building cases and in that way used to estimate the risk of internal sound transmission. By analyzing this risk factor before at the design phase of the building it provides the possibility to mitigate the negative effects.

Ventilation

The ventilation system of a building is one of the important factors for create and comfortable indoor climate. In a double skin façade there is a potential to utilize the cavity of the system to ventilate the building. One way of defining the double skin façade is to put it into two categories: natural ventilation and Mechanical ventilation.

In the early days of developing the double skin façade the natural ventilate cavity was most often the preferred system. It is still more often used for smaller size projects and when retrofitting a building. The function of natural ventilated double skin is the same principles as for conventional buildings. The only difference is that windows are opened into a controlled climate. Naturally ventilated systems use the cavity to control the airflow with stack affects and pressure from wind effects. These effects can be calculated and therefore evaluated at the design phase like Sealens and Hens describe in their paper.[54]

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[53] Poirazes 2006 (p. 121)

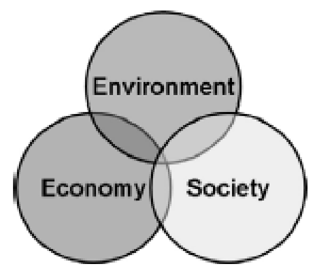
[54] Sealens and Hens 2001 (p.124)

The mechanical system can function in several different ways. Two systems are mostly used in this situation: airflow window and supply window: In principles the system mechanically supplies the building with air from the double skin cavity.

Many developers attempt to minimize and even dispense the ventilation system by introducing a double skin system to the building design. This approach applies often when a mechanical façade system is used because it can be controlled more efficiently. To achieve this carful and detailed calculations have to be made to ensure that the efficiency of the double skin façade is enough for the building. Failure to comply with the building need will come down on the internal climate. In some cases it has resulted in creating a very unpleasant climate and that will come down on the occupiers of the building.

Sustainable design

Most researchers, that take interest in the double skin façade, attempt to identify the performance and the energy efficiency of the double skin façade. Buildings contribute for roughly around half of all the energy consumption from cities. In modern times sustainability is becoming one of the most challenging tasks for designers to consider, especially when it comes to buildings. Today there is a worldwide stimulation to have buildings as energy efficient as possible to contribute to the today's demand on a sustainable environment.



In many minds sustainability means simply that a building is as environmentally friendly as can be. But sustainability also includes living and working environment for people and economic aspects. To be fully considered as a sustainable design, a building has to consider all of these elements and the design has to try to incorporate as much of these elements as possible.

The double skin façade system was introduced to the building industry as a supplement to traditional building components to optimize the potential of a building. One of these potentials was that the double skin façade is contributing to the idea of sustainable building by decreasing the energy use and at the same time increasing indoor climate quality. But there are some skeptical drifts about the consequences of utilizing the double skin concept. It has showed to be popular to apply the double skin concept to high rise office building. These buildings often have high energy requirements due to high occupation during office hours. Diprose and Robertson bring a rhetorical question about that in their paper and they quote numerous of authors to verify that merit. In their paper they are only discussing the glass tower and its pros and cons, however the double skin façade in a part of that concept. They state that:

> *"In spite of these favorable interpretations, a number of negative associations lay siege to 'tower' as a metaphor of ecologically responsible design. The 'tower' may be read as the 'flagship' architecture of transnational corporations […] which are identified as an enemy of sustainability […] The 'tower' remains the icon of the early Modern movement's vision of 'mechanized utopia' and centralization […] which is at odds with an ecological design goal of low movement and low-energy use society […]. Similarly 'tower' perpetuates an*

undue technological optimism […] which threatens the realization of sustainability […] The tower as an international image/commodity […] acts as an enemy of the local context in which it is placed, an hence is an enemy of sustainability. Moreover the tower representing free market capital is closely associated with short-term gains and unrestrained development, whereas ecologically responsible design stresses foresight, long term planning and human restraint when interacting with non-human nature." [55]

All of these predications are made between 1975 and 1994 and the show that practitioners were skeptic on the idea that a building could have a fully glazed façade. Diprose and Robertson also contribute with positive intake on the glass concept. They establish the potential of retrofitting a building with a double skin façade can increase its performance and they identify the importance of building having as much transparent façade as possible for indoor climate.

One of the most important concerns that are involved to sustainable design are the embodied energy of construction the construction materials. Many critics reveal that glass, which is the main construction material of the double skin façade, has a relatively high embodied energy. It is essential to evaluate the circumstances of each case to compare the benefits and downside of using a glass as a building component when concerning embodied energy. This table shows where glass stands comparing to other building materials when it comes to embodied energy.

Material	Embodied energy MJ/kg	Material	Embodied energy MJ/kg
Aggregate	0.10	**Glass**	**15.9**
Stone (local)	0.79	Fiberglass insulation	30.3
Concrete	1.3	Steel	32.0
Concrete precast	2.0	Zinc	51.0
Brick	2.5	PVC	70.0
Cellulose insulation	3.3	Copper	70.6
Aluminum (recycled)	8.1	Paint	93.3
Steel (recycled	8.9	Linoleum	116.0
Plywood	10.4	Polystyrene insulation	117.0
Mineral wool insulation	14.6	Aluminum	227.0

This table shows that glass is indeed close to be in the middle of the conventional façade systems. Indeed the table does not include the fact that it is relatively ease and efficient to recycle glass and potentially that factor might lower the total embodied energy.

[55] Diprose and robertson 1994 (p. 5)

Conclusion

As shown above it is a complicated task to evaluate the efficiency of the double skin façade. Researchers have simulated the performance of the system by using advanced computer modeling. It is interesting that it seems that early researches show that the efficiency is not great enough to reduce both heating load and cooling load for building. However more resend researches show that in certain condition the double skin façade can reduce the energy consumption of building substantially. One thing is certain that computer analyses are getting more and more advanced and we can assume that as calculation methods get more precise, we can expect more precise results. It is also clear that development of the double skin façade has made it more efficient.

The question arises if the double skin façade is cost effective or not. Employing a double skin façade in a building does include additional investment cost. Researchers have divided ideology of how much the additional investment cost is, it varies from 2.5 – 30%. It has been showed that when the system is carefully designed it results in reduced operational cost and when energy prices are higher than ever before that certainly is a benefit. It has also been showed that the double skin façade can increase the indoor climate resulting in increase productivity of the occupiers. Most resent published papers agree on that when the system is designed and utilized in a proper way, the results are that the long-term cost will be less that when using a conventional façade.

IT has been showed that the double skin façade has economically viable when looking at the long term cost. However the question remains if it is a viable choice for developers. In many cases the developers are not the occupiers and therefore do not benefit from lower operational cost or increase in productivity. So the system may not have attraction to some developers as desired.

It is the author's opinion that the benefits of the double skin façade indeed make it a viable alternative for buildings. With proper design and careful planning the system can bring economical and environmental benefits. It is also the author's opinion that the double skin façade is not often enough introduced to a project as and possible alternative. It has been showed that development of this system introduces more efficiency and if the system is not utilized more, the risk is that the development gets to slow. It is possible that authorities should reword developers more for utilizing environmental components in the building industry. More research is necessary to increase interest in the system. The double skin façade might not be a solution to sustainability, but it certainly can be a step into that direction.

Bibliography

Boake, Terry Meyer; *"The Tectonics of the Double Skin: Green Building or Just More Hi-Tech Hi-Jibx?"* University of Waterloo, School of Architecture. http://www.architecture.uwaterloo.ca/faculty_projects/terri/ds/tectonic.pdf (downloaded 02.09.2008)

Cody, Brian; *Double Skin Building Envelope"* ATIC, Brussels 2006 http://www.atic.be/F/documents/10_Cody2_english.pdf (downloaded 01.10.2008)

Diprose Peter and Robertson Graeme; *"Ecologically Resonsible Design, Solar Architecture and the Mythology of the Glass Tower"* University of Auckland, Department of Architecture 1994. http://www.diprose.co.nz/publications.cfm/publicationsectionid/1 (downloaded 12.09.2008)

Diprose Peter and Robertson Graeme; *Towards a Fourth Skin? Sustainability and Double-Envilope Buildings"* University of Auckland, Department of Architecture 1996. http://www.diprose.co.nz/publications.cfm/publicationsectionid/1 (downloaded 13.09.2008)

Haase Matthias; *"Design considerations for Double-Skin Facades in Hot and Humid Climates",* Department of Architecture, The Hong Kong University 2006. http://matthiashaase.cgpublisher.com/ (downloaded 26.09.2008)

Lang, Werner and Herzog, Thomas. *"Using Multiple Glass Skins to Clad Buildings."* Architectural Record 2000. http://www.archrecord.com/CONTEDUC/ARTICLES/7_00_2.asp (downloaded 10.09.2008)

Magali, Bodart and Elisabeth, Gratia; "*Ventilated Double Facades Project - Maintenance and durability of Ventilated Double Facades". Architecture et Climat,* Université Catholique de Louvain 2002. http://jen.sagepub.com/cgi/content/abstract/25/2/101 (downloaded 26.09.2008)

Navvad Mojtaba; "*Full Scale Testing and Computer Simulation of a Double Skin Façade Building".* The University of Michigan 2005. http://www.ibpsa.org/proceedings/BS2005/BS05_0831_838.pdf (downloaded 05.10.2008)

Oesterle, Lieb, Lutz & Heustler. *"Double Skin Façade – Integrated Planning".* Prestel Verlag 2001

Poirazis Harris; *"Double Skin Façade or Office Buildings – Literature Review".* Lund University, Lund Institute of Technology 2006. http://www.iea-shc.org/publications/downloads/Task34-Double_Skin_Facades_A_Literature_Review.pdf (downloaded 16.09.2008)

Sealens D., Carmeliet J., and Hens H., *"Energy performance Assessment of Multiple Skin Facades."* International Jurnal of HVAC&R Recearch, Vol. 9, nr 2, pp.167-186. http://www.kuleuven.ac.be/bwf/common/data/JP_2003_HVACR_Saelens_1.pdf (downloaded 09.09.2008)

Sealens Dirk and Hens, Hugo; *"Experimental Evaluation of Airflow in Natural Ventilated Active Envelopes"*, SAGE Journals Online 2001. http://jen.sagepub.com/cgi/content/abstract/25/2/101 (downloaded 21.09.2008)

Straube, John F. and Straaten, Randy van; *"The technical Merit of Double Facades for Office Buildings in Cool Humid Climates"* University of Waterloo 2001 http://www.civil.uwaterloo.ca/beg/Downloads/DoubleFacadesPaper.pdf (downloaded 26.09.2008)

Tenhuen O., Lintula K., Lehtinen T., Lehtovaara J.,Viljanen M., Kesti J. And Makelainen P.; *"Double Skin Façades – Structures and Building Physics"* Helsinki University of Technology 2001 http://www.tkk.fi/Yksikot/Rakennus/Teras/9NSCC.PDF (downloaded 29.09.2008)

Zerefos Selios C; "*On the Performance of Double Skin Facade in Different Environmental Conditions"*. International Journal of Sustainable Energy, 2007. http://www.informaworld.com/smpp/content~content=a788264241~db=ai~order=page (downloaded 21.09.2008)