**EWF design manual**: refurbishing structurally vacant office buildings into architectural attractive, low energy working environments.

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11/06/2015

**Abstract**

In this paper design tools are presented for the implementation of Ben Bronsema’s Earth, Wind and Fire concept that help architects and engineers with the refurbishment of structurally vacant office buildings in the Netherlands into architectural attractive, low energy, healthy, comfortable, productive and durable working environments. A model is presented that contains boundary conditions, design criteria, tools and possibilities for technical, architectural, functional and economic points of view for the assessment, conceptual and preliminary design phase. The results are obtained by analysing 104 master student projects in which the EWF concept is implemented on existing buildings. With a literature study the restrictions and possibilities of structurally vacant office buildings for EWF and visa versa are discovered. Furthermore it is researched what buildings need after refurbishment in order to comply with changing demands of tenants over time. Altogether this paper could function as a design manual and shows the potential of the EWF concept to become a generic architectonic solution that bridges the gap between architect and engineers.

**Keywords**  
Office redevelopment, vacancy, structurally vacant, Ben Bronsema, EWF, Earth, Wind and Fire
Introduction

Earth, Wind and Fire (EWF) concept

Research and technological innovation over the last decade have determined a significant improvement of performances of specific building elements like the building envelope and building equipment’s. Whilst most building elements still offer some opportunities for efficiency improvements, the greatest future potential seems to lie with technologies that promote the integration of “dynamic” and “adaptive” building elements with building services, which have been defined as Responsive Building Elements (RBE) (IEA Annex 44 2009). Supporting this point of view the EWF research is aimed at the development of three RBE’s viz.

1. A Power Roof 3.0 which makes use of the acceleration effects of the wind due to a curvature in the roof and is equipped with vertical wind turbines (VAWT’s) and PV foil or PV panels in order to produce energy. Furthermore it is used for the supply and extraction of air.
2. A Climate Cascade, a heat exchanger in the shape of a vertical shaft, in which the outdoor air is dehumidified and cooled or humidified and heated by direct contact with chilled water pumped through sprayers at the top of the shaft (B. Bronsema, et al, 2011). It is the heart of the system which makes sure that there is always a supply of air without using fans.

Besides the fact that the three RBE’s can also be applied separately in new and existing buildings and that a case study has been carried out showing the potency of the concept, the EWF concept can bridge the gap between architects and engineers. Climate control systems – often regarded by architects as a necessary evil, and thus hidden in shafts and ceiling voids – will become integral elements of a building, having been designed by the architect. In order to help architects applying this new approach I started this paper. Climate control technology is then no longer subordinated to architecture, but it is architecture, on an equal footing with the load-bearing structures of the building. Apart from energy issues, a substantial reduction of building costs and failure costs is therefore to be expected.

The EWF concept is a natural air conditioning system that gives a good IAQ (Indoor Air Quality) as well as basic cooling and heating. Additional cooling and heating for temperature control at the workplace is provided by a separate system. According to Bronsema radiation cooling and heating with inherent short response time is most suitable. IAQ is part of IEQ (Indoor Environmental Quality) with which issues like individual control of the inner climate at the workplace by the user, draft, sound and such are of importance.

Problem statement

Vacancy is the biggest problem at the Dutch real-estate market. At January the 1st 2015 there was 7.285.000 m² (15-17%) of vacant stock in the Netherlands (Bröcker, 2015). Around half of the vacant space is defined as structural vacant (H. T. Remøy, Voordt, T.J.M. van der, 2014). The discrepancy between supply and absorptions of office space is caused by the economic crisis, another vision on the way of working, demographic developments and the usage of digital tools & new techniques have resulted in different ways of dealing with accommodations by employees (Bröcker, 2015).

The mismatch has a quantitative and a qualitative aspect. Quantitative, because there is an oversupply on the market. Qualitative, because ‘old’ office spaces do not fit the current demand of tenants. They have a poor performance in terms of user comfort and energy consumption and organizational concepts and architectural designs of that era are not accepted by today’s office staff anymore (Ebbert, 2010). In the third chapter I will elaborate on this emphasis.
There are four ways to deal with vacancy: consolidation, renovation, conversion or demolition (Koornneef, 2012). Since the largest part will have to be demolished, consolidation is not a structural solution and conversion is only suitable for a very small share of the stock (Zadelhoff, 2006), renovation is the most feasible option for redevelopment.

A lot of the vacant buildings are older than 30 years (Ebbert, 2010). The lifespan of the building services do not exceed 30 years (Wamelink, 2007) which means that these buildings are in need for new installations. Besides that, facades are outdated and have poor technical performances. The structural frame is the durable part of the building and can exceed the lifespan of several centuries, allowing for adaptation to changing demand during time with the right methods applied. Elaboration on the assessment of structurally vacant office buildings in order to explore its problems and possibilities and boundary conditions that EWF gives to a building is done in the first chapter.

Furthermore there is an increased focus on sustainability of the Dutch government and the building industry in general. Due to the introduction of stricter European legislation (EC, 2010) and rising energy prices the energy performances of buildings will have to improve. This means that the existing stock of old office buildings will have to be upgraded to stay useful, attractive and lettable. But there are little refurbishment strategies at hand. In the Dutch market situation the refurbishment of offices can solve many of the current problems, such as oversupply, greenhouse gas emissions, vacancy, and social problems (of redundant office parks). The question is: how are we going to refurbish these buildings? Ben Bronsema’s Earth, Wind and Fire concept has potential, but there is no further research done on the ways of applying it on existing buildings. The possibilities and design criteria of the concept are described in chapter two.

The results of this paper can be used as a design manual for the EWF concept in the assessment, conceptual and preliminary design phase in order to guide the possible design alternatives before the project actually commences. This guidance leads to options that facilitate the early planning phase, helps cutting costs, and leads to more appropriate solutions for each building project. Thus, the potential of the concept for structurally vacant office types is researched, and as such, more knowledge is gained about refurbishing with Earth, Wind and Fire.

Research question
The different aspects discussed before can be enclosed in the following research question: “What should designers take into account when they use the EWF concept to refurbish structurally vacant office buildings in the Netherlands into architecturally attractive, low energy, healthy, comfortable, productive and durable working environments?” Sub questions are:

- What are the restrictions and possibilities of structurally vacant office buildings for EWF and of EWF for structurally vacant office buildings?
- Which design criteria can be formulated for the EWF concept in order to work properly and what are possible design variants?
- What does a building need after refurbishment in order to comply with the changing demands of the tenants over time and how can the EWF concept contribute to this?

Method
This paper deals with improving the qualitative aspects of structurally vacant office buildings. The paper is part of a larger research for which the lay-out of the proven refurbishment methodology of Aste and Del Pero (Aste, 2012) is used as a research framework. The red boxes in figure 1 show at which parts of the research this paper focusses. As shown this paper should help architects and engineers in designing admissible design strategies.
Figure 1. The process design of the larger research based on the energy retrofit strategy of Aste and Del Pero. The red boxes are the parts on which this paper focusses.

With a literature study the restrictions and possibilities of structurally vacant office buildings for EWF and visa versa are discovered. Furthermore, the results are derived from analysing a database of 104 student projects in which EWF is applied on existing buildings during a master course at the Delft University of Technology. Together with Bronsema’s dissertation and several conversations with Ben Bronsema in the spring of 2015 this led to the boundary conditions, design criteria, design tools and design database for the EWF elements. At last, another literature study was used to research what buildings need after refurbishment in order to comply with changing demands of tenants over time.
Results
The results can be summarized in a model (figure 2) that shows the different aspects you have to take into account when dealing with EWF. By analysing the student projects a good understanding about the different applications methods for EWF was gained. The projects gave information about possible design choices in the assessment, conceptual and preliminary design phase.

Figure 2. Design support model for EWF implementation.

Building assessment
This first chapter will focus on the outer ring of the model (figure 2). This ring focusses on the assessment phase of the design process that deals with the assessment of the building and its location. In order to find out for which buildings EWF could be a solution we have to raise the question: What are the restrictions and possibilities of structurally vacant office buildings for EWF and of EWF for structurally vacant office buildings? To answer this question I will start with a
Definition
A large part of the buildings is defined as structurally vacant, meaning that the building has been vacant for more than three years (Hek, 2004). Vacancy as a result of this mismatch on the office market is a natural phenomenon and equals 3% to 8% of the total supply of the office market (Tse, 2003; Wheaton, 1999). Considered healthy, this type of vacancy is called frictional vacancy, caused by friction between supply and demand. However, in an unbalanced market (as today’s market), vacancy can rise substantially, caused by a significant mismatch between the demand and supply of available office space. In markets with continuous high levels of vacancy, structural vacancy will occur (Zuidema, 2010). In the coming years the amount of structurally vacant offices will grow and the relative quality of the office stock will decrease, because tenants will move to new(er) buildings. New construction is seen as inevitable, because the available office supply is lacking high quality office buildings and there are too little refurbishment strategies to upgrade the existing stock into high quality office buildings. With a high demand for ‘Grade-A’ office space it will become more difficult to rent out older (30-40 years old) buildings (Ebbert, 2010). These buildings have to be upgraded to ‘Grade-A’ offices to make them attractive for the real estate market again.

Characteristics
It is hard to conclude that one specific combination of characteristics is most common. Though Remøy describes in her dissertation the location and building characteristics that most increase the odds of structural vacancy (H. T. Remøy, 2010). In general the location characteristics are: mono-functionality, lack of status and lack of facilities. The building characteristics that are most closely associated with structural vacancy are: bad external appearance, bad internal appearance and low layout flexibility. What has to improve in order to make the building attractive again for the real estate market is:

1. Increase the amount of facilities and functions.
2. Enlarge the flexibility of the building.
3. Improve the status of the building.
4. Improve the interior quality (including IEQ) and appearance.
5. Improve the technical performances (including energy performance).

Measures 2-5 can be solved by adding a new façade. Measure 2 and 5 can be realised by replacing the existing installations for the EWF concept. “Planners have started to understand façades and technical installations as complementary functions of a buildings that demand an integral planning (Ebbert, 2010).” By combining a new façade with the RBE’s an integrated architectural design solution could be found to tackle a building’s problems. In order to check whether this is possible in an existing building the building should be assessed on its context, building shape, façade, load bearing structure and present natural forces from an EWF point of view. Some focus points of this assessment are discussed in the following paragraphs. A distinction is made between boundary conditions that lead to an expulsion of a building for EWF – indicated with [EX] – and boundary conditions that might need optimization when EWF is implemented – indicated with [OP].

Context
The building has to be preferably higher than its surroundings in order to make the Power Roof 3.0 work properly (Bronsema, 2013) [EX]. Especially in inner cities this is important because here the air layer above the city is slowed down at lower levels due to a higher turbulence intensity. Furthermore the direct surrounding around the building should be assessed in terms of available
space and the most potential position of the EWF elements [OP]. Especially in inner cities designers should be aware of the scale and the grain of the city. The student projects show that by positioning the elements at a highly visible and public area the working principle could be communicated and the area could be upgraded with this architectural intervention.

**Building shape**

The building height should preferably be over 15m in order to gain sufficient pressure differences for the Climate Cascade and the Solar Chimney (Bronsema, 2013) [OP]. A lower building height might be possible but this will negatively influence the performance of the elements. If the load bearing structure allows for it, performance problems could be prevented by adding floors to the building. Furthermore niches in the shape of the building could be filled up with EWF elements. In this way façade surface can be reduced which could enhance energy performances.

**Façade**

The largest energy savings can be achieved when the façade is stripped completely and renewed (Miert, 2012). With the transformation to low energy buildings, large building procedures should not be avoided. On the contrary, it offers a lot of chances. Enlarging the facade openings has the largest effect in both architectonic as technical sense (Miert, 2012). In combination with a small façade grid for the new façade the flexibility of the building could be enlarged (H. T. Remøy, 2010). Furthermore thermal bridges that could cause severe problems like condensations and mould, influencing the health of users, could be tackled. In his dissertation, Ebbert concluded that in The Netherlands the prefabricated suspended parapet with windows and other (unitized and stick-) curtain wall systems represent 44% of the total office market (Ebbert, 2010). This is by far the most common and they are relatively easy to replace. This shows the large potential for integrating the EWF elements with a façade change. Despite the high costs, façade replacement is in most cases the best solution (Ebbert, 2010), because it can solve many problems:

- Often load bearing fittings for façade elements are considered unreliable.
- Bad insulation and air tightness.
- Toxic (PCB-containing) material used for fittings has to be removed.
- Reduce the dead load on the structure.
- Bad outer appearance.
- Insufficient glass qualities (g-value and U-value).

**Load bearing structure**

Considering the structure of vacant office buildings the flexibility should be assessed. Blok and Oudenaarden offer a tool to determine this flexibility on three basic properties: the independency, load bearing capacity and space within the structure (Voordt, 2007). Questions that should be asked for the assessment are:

**Independency**

- Is a separation of functions possible? Needed if one wants to increase the number of functions.
- Are there any load bearing façades or walls? [EX] These make the adaptability smaller and load bearing façades might give problems with the amount of daylight in the building.¹
- Are mutual connections demountable or not? Easy disassembly increases the flexibility.
- Are there any poured pipes in the floors? This could decrease the level of flexibility.

1 This would not only exclude buildings for EWF but for refurbishment in general.
**Load bearing capacity**
- Is it possible to add larger or extra installations? **[EX]** This should be possible to install the Power Roof 3.0. The solar chimney could also have a separate load bearing structure.
- Is it possible to pour a new floor without removing an old layer?
- Is it possible to add floors on top of the building? **[OP]** This increase in height should be considered to optimize the performance of the EWF elements.
- Is it possible to suspend heavier façade elements to the load bearing structure?

**Space**
- Is there enough space for different building functions? A larger column grid would create more space and so more possibilities.
- Is there enough space that can be used? **[OP]** The free floor height influences the possibilities for the distribution of the air. If the free floor height is too low, façade ducts should be considered to optimise the air flow.
- Is there enough available vertical shaft space? **[OP]** This influences the location of the climate cascade and air distribution ducts.

In general overcapacity means flexibility. Most structures are over dimensioned which makes it possible to add one or two layers on the buildings (Voordt, 2007). This increase of square meters could pay back for radical changes in the buildings and the increased height could improve the performance of the EWF concept. Research makes clear that it is hard and costly to make changes within the structure itself (Koornneef, 2012). A realistic possibility for all floor types is to remove floor elements from beam to beam (Voordt, 2007). The extra space could be used for the climate design. For instance by using it for the distribution of supply or exhaust air and/or to position the climate cascade.

**Natural forces**
EWF focusses on designing a building as “climate machine” which is activated by earth mass and the combined forces of sun, wind and gravity (Bronsema, 2013). In order to make the natural forces work as good as possible some boundary conditions are preliminary defined. In every case designers and engineers should make an analyses of the urban context. A sun and wind study should be conducted and the possibility of cold and heat storage should be researched (Bronsema, 2013) **[OP]**. The WKO-tool, developed by the Dutch government, helps to quickly examine the possibilities in a certain area (WKO-tool, consulted at 18-05-2015). If cold and heat storage is impossible other solutions like PCM or aquifers should be considered. Especially PCM is interesting, because it is a passive system which is one of the criteria at which the EWF concept is based. Furthermore the solar chimney has a high priority with the choice for an urban environment, because it has a huge potential contribution on the heat usage of the building (Bronsema, 2013).

**In conclusion**
The introduction and this chapter the restrictions that the buildings give to EWF and the boundary conditions that could be defined for buildings by EWF were described. We could define two boundary conditions that would exclude a building for refurbishment with EWF in specific. First, when a building is lower or has the same height as its surroundings. In this case the natural forces of the wind and sun influence the building to a small extent. Second, when it is not possible to add larger or extra installations, because this is a must for the Power Roof 3.0.

The most potential buildings for the application of the EWF concept are structurally vacant buildings of approximately 30-40 years old. First of all, because they are in need for a façade change – to tackle the problem of thermal bridges which were often underestimated in those times – and new
buildings services (Ebbert, 2010). Second, the implementation of the RBE’s demands radical changes in the building that are only possible when there are no tenants in the building. Third, these buildings are probably not monumental which enlarges the possibility for large changes.

Figure 3. Overview of the restrictions and possibilities of EWF for a building and of a building for EWF. See appendix for a larger image.

**EWF design**

Chapter one gives a better understanding of assessment phase. This chapter focusses on the conceptual and preliminary design phase (see figure 2) and elaborates on the question: Which design criteria can be formulated for the EWF concept in order to work properly and what are possible design variants? The results are derived from a database of 104 student projects in which EWF is applied on existing buildings during a master course at the Delft University of Technology, Bronsema’s dissertation and several conversations with Ben Bronsema in the spring of 2015. The results are brought together in a design database (see appendix 1 en 2) that shows possible design variants for different concepts.

Design criteria and possibilities

For the preliminary design phase it is important to know which design criteria have to be taken into account when applying the EWF on existing buildings. The following paragraphs the criteria are discussed. The database shows how a designer can play with these criteria.
In general
- The system is developed for Western climate conditions.
- When thermal bridges are present in a chosen building it should be investigated how the building physical quality could be improved. In general the designer should be aware of the intimate relation between the façade and the buildings services.
- The sizes of shafts and ducts are significantly larger than with traditional mechanical systems due to lower air speeds and pressure losses. The integration of ducts is a necessary strategy for realising an efficient air distribution within the building. There is a generic system needed for the implementation of the EWF concept to keep the building flexible and adaptable. Possible solutions are shown in figure 3. The preferred solutions are decentralized supply and centralized exhaust or centralized supply and decentralized exhaust.

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<th>Distribution of Air</th>
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<td>Decentralized supply, centralized exhaust</td>
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Figure 4. Integration concepts for the distribution of air.
- Operable windows are possible within the EWF concept. Just like traditional air-conditioning systems windows have to stay closed with high temperature differences between inside and outside and when the wind is pointed directly on the façade in order to make the system work properly. To arrange this some intelligent automatic control systems might be needed.
- Revolving doors on the ground are needed in order to control airflows.
- When the air quality is bad (at higher levels) an electrostatic air filter is the only filter that could be used (due to high performance and low air resistance).

Climate cascade
- For the design of the climate cascade the desired ventilation capacity and inner climate conditions are leading. The calculation tool has been developed to calculate the sizes of the cascade (Bronsema, 2013). Global dimensioning can be done based a ventilation capacity of $5 \, m^3 \, m^{-2} \, h^{-1}$.
- With high rise it should be considered to place a climate cascade on every sixth floor or the plural of it to improve the COP (Bronsema, 2013).
- The database of the student projects shows the huge architectural potential of a transparent climate cascade. The climate cascade works more constant with closed isolated walls, but if well insulated a transparent cascade is possible. In figure 4 an overview is given of the different design possibilities of the climate cascade from explicit designs till implicit.
For the design of the solar chimney/façade the thermal and energy performance are leading (Bronsema, 2013). The calculation tool has been developed to calculate the sizes of the solar chimney (Bronsema, 2013).

- Over dimensioning of the chimney should be considered, because it gives higher energy yields, less operating hours for the auxiliary ventilator and the possibility to temporarily increase the amount of extraction.

- The orientation of the solar chimney/façade could be south, southwest or southeast.

- During the heating season the solar chimney delivers enough and stable thermal draft (also without sun), due to the difference between space temperature and the outside temperature. Besides that the venturi-ejector in the Power Roof 3.0 delivers a considerable aerodynamic draft in this season due to generally higher wind speeds.

- In general the solar chimney should be at least 0,65m deep in order to make cleaning from inside possible.

- The performance of light thermal inner walls is 10% higher than heavy thermal inner walls. This is function dependent, in case of an office that is not used during the night this is true, because with a heavy thermal inner wall the by day accumulated heat in the wall is wasted as heat loss when the ventilation is stopped at the end of the day.
- Choose glass for the solar chimney with a high $g$-value for maximum transmission of solar radiation on the absorber and a low $U$-value to reduce the heat loss to the outside air.
- The exhaust shunt may not be directly connected to the solar chimney, because then the thermal draft on higher levels will become lower. So the extracted air needs to be supplied at the bottom of the chimney.
- The exhaust shunt should be directly connected to the roof, in order to lead the exhaust air out of the building when there is no solar radiation. Furthermore recirculation should be considered. In this way the solar energy could be used to heat up the building for free when it is not in use.
- The usage of a solar facade could make the usage of hardened glass needed. This would raise the costs, though it might be possible to use bypass dampers to prevent the need for hardened glass.
- The database of the student projects (figure 5) shows the huge architectural potential of the solar chimney. There are many design variants for explicit and implicit concepts possible without influencing the performances hugely.
Power Roof 3.0

Within the EWF database there were 3 of the 104 projects that focused on the Venturi Roof. There were no projects that focused on the Power Roof 3.0, because it is a new variant that is currently researched at the TU/e and seems to be the most realistic option from a financial point of view. Because there were no student projects that showed the design possibilities of this roof I searched for reference projects. Starting point for this search was that these roof had to produce both wind and solar energy. The Power Roof 3.0 should also suck air out of the building via the venturi-ejector, but that is not taken into account for the reference projects since it has never been used for as far as I know. Figure 6 gives an overview of possible design variants.
Changing demands

With a good application of EWF a low energy, healthy, comfortable and productive working environment can be created. In this part I want to elaborate on the importance of comfort improvement. Furthermore I want to explain that in order to create a durable working environment, designers have to go further than an improvement of the comfort and energy performances. In order to create a durable building a good architectural design and an increase of the flexibility are needed in order to comply with changing demand of tenants over time. The sub question is: What does a building need after refurbishment in order to comply with the changing demands of the tenants over time and how can the EWF concept contribute to this?

Comfort

Nowadays it is important to realise that when buildings are renovated not ‘the stones’ are central, but the user and his employees. Besides energy savings, health and comfort are considered as the most important sustainability aspects by these employees (Miert, 2012). “It is no longer purely about assets, but about the management of it. Final users can choose, because the market of demand and supply has turned over. Besides that, companies in the current market listen more and more to their employees. Accessibility, sustainability of the building and workplace, health, childcare and sociability have become keywords for the location of an office and the furnishing of it.” (Bröcker, 2015) Comfort could be subdivided into visual, acoustic, thermal comfort and individual control (Ebbert, 2010). EWF covers much of these ground since it improves the sub-optimal quality of the indoor climate and environment in many office buildings, caused by fan noise, cold draught and insufficient air quality, resulting from polluted air filters and ducts. These factors not only compromise the human comfort but also the productivity of office staff. Especially for knowledge based companies with expensive employees, an improvement of the workers productivity can lead to a large increase of revenue. In this way there is a business case, because sustainability and productivity go hand in hand.

Circularity

The focus within the building industry will increasingly lie on circularity. The office market is changing. There is a larger focus on sustainability and quality, both for the building as for the people who have to work in it. This means that he focusses on the whole chain like in the Cradle to Cradle philosophy (Braungart, 2007). It is about the closing of cycles for materials, energy and water. About
being aware of the fact that things return when the period of use for a certain application is over. By making agreements with suppliers and manufacturers that they will retake materials at the end of their lifespan, building materials represent value. In this way buildings become material banks of the future. This means that buildings have to be designed to redesign by designers and engineers and a database has to be created to register the place of different elements which could easily be done with BIM software (Hattum, 2015).

Braungart and Mc. Donough are advocates and practitioners of bioclimatic architecture. Bioclimatic architects use conventional tools from the architectural repertoire that should be taken into account besides the RBE’s of EWF, like: lay-out, location and orientation, glass percentage of the façade, implementation of windows and sun shading, thermal insulation and the accumulation capacity of a structure (Givoni, 1994).

Flexibility
Due to quickly changing demands of tenants, flexibility has become more crucial. This flexibility is demanded on many levels. The workplace must be able to adapt to individual demands which could largely differ through generations (Chilton, 2012). Besides that the rented space is also used more efficient and lease agreements for existing buildings have become much shorter (0-5 years instead of 10-20). Another trend is project based use of office space, in which employees of different companies and departments temporarily work together on the same project in a part of an office building. These trends enlarge the possibilities for tenants to change locations and a tenant change often demands interior changes in buildings. If these changes can easily be facilitated, this enlarges the marketability of the building. Another change is that a working day from nine to five on the ‘common’ working days has become less common and multi-tenant buildings become more popular. At last, sustainability has become increasingly important. “Sustainability goes much further than saving on energy. Sustainability can be found in experience, location and layout possibilities of a building. In short: flexibility. Considering the office of the future people should create a healthy mix of energy efficiency, affordability, comfort and fun.” (Bröcker, 2015) The EWF concept should be integrated in the design of the building in such a way that it can easily adapt to lay-out changes.

Conclusions & discussion
This paper could be used as a design manual in the assessment, conceptual and preliminary design phase of which the tools can be found in the appendix. It could function as a checklist for designers in order to check whether EWF is applied in the right way. The database gives possible design directions and could function as a toolbox for architects and engineers during their design process. This paper described how the EWF concept can be used as a generic architectonic solution to upgrade the existing stock into high quality office buildings. In this way new construction could be prevented. Especially the structurally vacant buildings that are difficult to rent out are interesting for the concept. Here the reason for this statement will be summarized.

The main research question in this paper was: “What should designers take into account when they use the EWF concept to refurbish structurally vacant office buildings in the Netherlands into architectural attractive, low energy, healthy, comfortable, productive and durable working environments?” In order to answer this question I formulated sub questions that would lead me to the answer.

With regard to the first sub question it is important to assess a building at the five points as presented in figure 2. It could be said that the EWF concept demands two things from structurally
vacant office buildings: a certain buildings height compared to its surroundings and a certain overcapacity of the load bearing structure to add extra installations. Furthermore, the restrictions of structurally vacant office buildings could be tackled with applying the EWF concept. These buildings are commonly 30-40 years old and in need for a façade improvement and new installations in order to stay to useful, attractive and lettable. For the refurbishment design it is important to realise that façades and technical installations as complementary functions of a buildings that demand an integral planning.

Concerning the second sub question we can conclude that the design criteria that were formulated and the database that is created will help architects and engineers during their design process. The manual could function as a checklist for designers in order to check whether EWF is applied in the right way. The database gives possible design directions and could be expanded as more designs are made or projects are realised.

With regard to the third sub question we can say that creating durable working environment concerns more than the improvement of the comfort and energy performances. An appealing architectural design, focus on circularity and an increase of comfort and flexibility are needed in order to comply with changing demand of tenants over time.

So with all the knowledge that is provided a broader scope is given of what designers have to take into account with the application of the EWF concept. The EWF manual and database are developed in order to make the application of the concept easier for architects and engineers. EWF can create low energy, healthy, comfortable, productive environments and with the broader view a durable environment can be created. The architectural interpretation still is up to the architects, but with this concept the climate control technology is no longer subordinated to architecture, but it is architecture, on an equal footing with the load-bearing structures of the building.

Limitations

This research only focusses on completely structurally vacant office buildings, but an important future assignment lies in the renewal of the existing stock without dislocating tenants. Furthermore it is important to mention that the concept has not yet been realised in a building, but it has been tested and validated and the results are promising. The first zero energy hotel in the world with EWF will probably be realised in 2016, so then we will know whether it can certify its promises. At last, the designer manual has not yet been tested, this will be done during my graduation project.

Further research

Since the concept is rather new there is a lot to be researched yet especially concerning the architectural consequences. This research is rather wide and offers a designers manual that contains tools and a database that offer a lot of hooks for further research. The architectural possibilities of the Power Roof, Solar Chimney and Climate Cascade for instance could all be researched further in the fields of morphology, performance and materialisation. Besides that, more research can be done on how EWF could be implemented on a building without dislocating tenants. At last, it would be very interesting to see how the system influences the workers comfort levels and productivity. Promising protecting factors have roughly been studied, such as improving the ion balance in the indoor air by the waterfall effect and improving the indoor air quality by ozonisation of the spray water. The findings are speculative but interesting enough for further research.
References
Appendix 1
EWF designers manual

- Checklist for architects and engineers to check whether all EWF aspects have been taken into account.
- Design support model for EWF implementation.
- Overview of the restrictions and possibilities of EWF for a building and of a building for EWF.
### Assessment phase

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| An analyses is made of the urban context. | \[\]
| The building has to be preferably higher than its surroundings in order to make the Power Roof 3.0 work properly. | \[\]
| The direct surrounding around the building are assessed on (1) the possibilities for adding elements outside the building and (2) the most potential position of these elements. | \[\]

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</thead>
</table>
| The building height should preferably be over 15m in order to gain sufficient pressure differences for the Climate Cascade and the Solar Chimney. | \[\]
| Furthermore niches in the shape of the building could be filled up with EWF elements. In this way façade surface can be reduced which could enhance energy performances. | \[\]

<table>
<thead>
<tr>
<th>Facade:</th>
<th>Check</th>
</tr>
</thead>
</table>
| If possible a facade replacement is considered. | \[\]
| If not, the possibilities for enlarging the facade openings are investigated. This would have the largest effect in both architectural as technical sense. | \[\]

<table>
<thead>
<tr>
<th>Flexibility of the load bearing structure:</th>
<th>Check</th>
</tr>
</thead>
</table>
| **Independency** | \[\]
| Is a separation of functions possible? Needed to increase the amount functions. | \[\]
| Are there any load bearing façades or walls? These make the adaptability smaller. | \[\]
| Are mutual connections demountable or not? Easy disassembly increases the flexibility. | \[\]
| Are there any poured pipes in the floors? This would decrease the level of flexibility. | \[\]
| **Load bearing capacity** | \[\]
| Is it possible to add larger or extra installations? | \[\]
| Is it possible to pour a new floor without removing an old layer? | \[\]
| Is it possible to add floor on top of the building? | \[\]
| Is it possible to suspend heavier façade elements to the load bearing structure? | \[\]
| **Space** | \[\]
| Is there enough space for different building functions? A larger column grid? | \[\]
| Is there enough space that can be used? A large free floor height? | \[\]
| Is there enough available vertical shaft space? | \[\]

**In general overcapacity means flexibility.**

<table>
<thead>
<tr>
<th>Orientation:</th>
<th>Check</th>
</tr>
</thead>
</table>
| A sun and wind study are made. | \[\]
| The possibility of cold and heat storage is checked. | \[\]

### Conceptual phase

<table>
<thead>
<tr>
<th>Check</th>
</tr>
</thead>
</table>
| The EWF database is consulted to check for possible design variants for the chosen concept (which is either explicit or implicit). | \[\]
### Preliminary design phase

<table>
<thead>
<tr>
<th>Design tools:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- ...</td>
</tr>
<tr>
<td>- ...</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Design criteria:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>In general</strong></td>
</tr>
<tr>
<td>- When thermal bridges are present in a chosen building it should be investigated how the building physical quality could be improved.</td>
</tr>
<tr>
<td>- The ducts are integrated for realising an efficient air distribution within the building. The preferred solutions are decentralized supply and centralized exhaust or centralized supply and decentralized exhaust.</td>
</tr>
<tr>
<td>- When operable windows are applied intelligent automatic control systems are considered for automatic closing of the windows when needed.</td>
</tr>
<tr>
<td>- Revolving doors on the ground are used in order to control airflows.</td>
</tr>
<tr>
<td>- When the air quality is bad (at higher levels) an electrostatic air filter is used.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Climate cascade</th>
</tr>
</thead>
<tbody>
<tr>
<td>- The calculation tool is used to calculate the sizes of the cascade. Global dimensioning can be done based a ventilation capacity of $5 , m^3 , m^{-2} , h^{-1}$.</td>
</tr>
<tr>
<td>- With high rise the use of several climate cascades on every sixth floor or the plural of it is considered.</td>
</tr>
<tr>
<td>- The database is consulted to check the different design possibilities for the climate cascade.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Solar chimney</th>
</tr>
</thead>
<tbody>
<tr>
<td>- The calculation tool is used to calculate the sizes of the solar chimney.</td>
</tr>
<tr>
<td>- Over dimensioning of the chimney should be considered, because it gives higher energy yields, less operating hours for the help ventilator and the possibility to temporarily increase the amount of extraction.</td>
</tr>
<tr>
<td>- The orientation of the solar chimney/façade is south, southwest or southeast.</td>
</tr>
<tr>
<td>- The database is consulted to check the different design possibilities for the solar chimney.</td>
</tr>
<tr>
<td>- The chimney is at least 0,65m deep in order to make cleaning from inside possible. If it is less deep the a solution is found for the cleaning of the chimney.</td>
</tr>
<tr>
<td>- The chosen glass for the solar chimney has a high $g$-value for maximum transmission of solar radiation on the absorber and a low $U$-value to reduce the heat loss to the outside air.</td>
</tr>
<tr>
<td>- The exhaust shunt is not directly connected to the solar chimney. The extracted air is supplied at the bottom of the chimney.</td>
</tr>
<tr>
<td>- The exhaust shunt is directly connected to the roof.</td>
</tr>
<tr>
<td>- With a solar facade design the use of hardened glass or bypass dampers are considered.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Power Roof 3.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>- The database is consulted to check the different design possibilities for the Power Roof 3.0.</td>
</tr>
</tbody>
</table>
context

available space

building height

building shape

building height

façade

transparancy

façade grid

natural forces

natural wind impact

restrictions or possibilities of the building for EWF (soft)

restrictions or possibilities of EWF for the building (hard)

restrictions that lead to an expulsion of a building for EWF (hard)
Appendix 2

EWF database
This database shows the design possibilities of the different EWF elements and possible design strategies for the distribution of ventilation air. Heating and cooling is not taken into account, EWF focusses on natural airconditioning only.
The EWF database consists of 104 design projects of students that were created during the MSc 1 course Delft Seminars of Building Technology at the Delft University of Technology. The assignment for these projects was to renovate or renew an existing building with respect to structural, construction and climate design in which the EWF concept is the starting point. The assignment has resulted in a manifold of plans that show the application and design possibilities of the concept and that could serve as inspiration for designers and engineers. The ideas are structured according to two main concepts: explicit designs and implicit designs.

<table>
<thead>
<tr>
<th>solar chimney design</th>
<th>explicit</th>
<th></th>
<th>connected to the building</th>
<th>in the facade</th>
<th>on the roof</th>
</tr>
</thead>
<tbody>
<tr>
<td>separate from the building</td>
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<tr>
<td>connected to the building</td>
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<tr>
<td>in the facade</td>
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<tr>
<td>on the roof</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
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</tbody>
</table>
By making a cut out in the core of the building a space is created for the climate cascade. The inner ring is for the cascade, the outer ring for the supply of the air.

Also a cut out design but the supply and distribution of the air is done via the supply shafts. The climate cascade is transparant and climatic architectural element is created.

By surrounding the cascade with staircases the interaction of the cascade with building occupants is increased.

A round cut out might be more efficient for the load bearing structure. The supply shunt are accommodated in existing vertical shafts.

By creating more climate cascade design...

A cascade could be added built up from elements. The droplets inside the cascade could be visualised in the facade to emphasize its working principle.

Niches in the building could be filled up with climate cascade(s). In this way the amount of facade area is reduced which enhances the energy performance of a building.

A smart skin could be used. In this way transparancy is achieved without influencing the performance of the cascade.

An entrance can be enhanced by placing the cascades around it. The addition of a print on a glass panel could work as sun shading and function as a communication tool.

Space could be created by making a cut out in the facade. By using transparant surfaces in the facade the cascade is made explicit, but this design is subtle.

The cascade and the supply shafts could be visualised together by adding to ‘towers’ the building that are connected at the bottom.

The cascade could be made visible from both the inside and outside. Louvers could be used to reduce the heat load on the transparant surfaces.

ETFE panels with a sunshading layer. In this way transparancy is achieved without influencing the performance of the cascade.

Automatically controlable horizontal sunblinds could be used to reduce the heat load on the cascade. By using LED lights the working principle of the cascade could be emphasized.

By keeping cascades as small as possible, the needed pump capacity to pump up the water is reduced together with the duct sizes.

The cascades and ducts could be smoothly visualised by adding a layer around the ducts and EWF elements that changes the shape of a building.

The supply and exhaust ducts could be placed on the facade. This could be useful when the free floor height is limited.

A whole EWF unit could be connected to the building to control the natural airconditioning in the building.

Small cascades separate from the building with vertical supply shunts could be created. By the reducing the size of the cascade the performance is improved.

In this design a lot of small cascades and supply shunts are placed on the facade. In this way a verticality in the architectural design is achieved.
Within the EWF database there were 3 of the 104 projects that focussed on the Venturi Roof. There were no projects that focussed on the Power Roof 3.0, because it is a new variant that is currently researched at the TU/e and seems to be the most realistic option from a financial point of view. Because there were no student projects that showed the design possibilities of this roof I searched for reference projects. Starting point for this search was that these roof had to produce both wind and solar energy. The Power Roof 3.0 should also suck air out of the building via the venturi-ejector, but that is not taken into account for the reference projects since it has never been used for as far as I know. Figure one gives an overview of possible design variants.

<table>
<thead>
<tr>
<th>Full roof</th>
<th>Roof edges</th>
</tr>
</thead>
<tbody>
<tr>
<td>decentralized supply &amp; centralized exhaust</td>
<td>decentralized supply &amp; centralized exhaust</td>
</tr>
<tr>
<td>centralized supply &amp; decentralized exhaust</td>
<td>centralized supply &amp; centralized exhaust</td>
</tr>
</tbody>
</table>

For the distribution of the ventilation air it is logic to choose for one of the following combinations:
- decentralized supply and centralized exhaust, or
- centralized supply and decentralized exhaust.