New building concept should minimize the consumption of natural resources to a high level and generate on-site a significant amount of renewable energy. These should be done through a number of innovative approaches. The aim is to find an intelligent façade design that responds to the climatic conditions found on the site. The idea is to implement features in the façade which produce energy, so that the energy consumption of the buildings changes to an energy production. Therefore my research includes an overview of energy generating façade systems. Many of my examined technical features for the production of energy within the façade are uncommon in buildings today, but they will be commonplace in years to come. This potential needs to be discovered. To demonstrate the current stand of technic in the field of using renewable energies in the building skin I compared innovative case studies. Some of these case studies are built examples, others are only developed and proven in prototypes. As result I will show the different kind of technical energy generating innovations in the field of façade constructions and give an outlook which influence these different kinds of technic can have for the design, especially in the urban area.

**Keywords:** Renewable Energies, Facade, Innovation, Energy Production, Climate

The façade fascinates me because it shows most dominant the architectural value of a building. It is the visible statement to the world and it gives a face to the building. The building with its skin is a part of the public space, it determines and forms it. Moreover, the façade has to fulfill today’s demands and provide a functional and attractive contribution to society. In the following paper I want to answer the question:

*How can an active intelligent building skin generate energy and which potential has this climate construction program for the design?*

The idea to facilitate energy with the building skin is not new. To reflect the current stand of techniques in energy generating façades I searched for interesting examples and compared them in order to discover how innovative technic can be transformed into architecture. As result, I found a wide range of possibilities which support an energy producing design concept. The “polyvalent wall” from Mike Davies is one of the most popular inventions out of the past which has a high potential till now for a more sustainable future. Lots of the new concepts are based on this old idea. In 1981 Mike Davies idea of a “polyvalent wall”, which he wrote down in his article “the wall for all seasons” till now acts as driving force for new façade technology. His concept isn’t realized till now and Davies’ idea isn’t meant as a realistic product example, but as one possible way to go into a more sustain-
able future. A “polyvalent wall” is a multifunctional element out of thin layers which controls the flow of energy from the outside to the inside. (Fig.1) At the same time it works as absorber, reflector, filter and transmission-mechanism. It is equipped to decentralize micro-logical and sensory intersections which are linked to a controlling processor. This processor must have the necessary information about application plans, habits and environmental wishes of the user in order to fulfill the requirements for a comfortable environment. This will lead to good energy consumption and major possibility for the comfort. Mike Davies mentioned that this different functional thin layer will become the envelope of the building and “remove the distinction between solid and transparent”. Moreover, the wall will continuously adapt and change to the surrounding conditions and act as a filter in both directions, interior and exterior. (Davies 1981: Die polyvalente wand) His idea of the polyvalent wall and its realization are one of the most fascinating topics in the field of façade constructions up to now.

In the following I will describe the façade as a boundary between outdoor and indoor climate. Therefore, I did a literature study to explain the terms of outdoor climate and indoor room conditions. I will point out which indoor circumstances influence the comfort of buildings and which relation they have to the façade. Moreover, I will reflect the renewable energy sources of the earth and their potential for the energy production in the façade. Then, I will give an overview of case studies to reflect the current stand of techniques on the field of energy generating façades. In conclusion, I will point out their potential and further development and give an outlook which influence these techniques can have for the design especially in the urban area.

Building skins are necessary to eliminate variation of the outdoor climate and to guaranty the comfort. (Fig.2) The performance of the building skin has a mayor influence of the room climate and comfort. It is necessary to focus on climate influence factors on specific site for the energy concept to achieve optimal comfort conditions and the most energy efficient performance. The term outdoor climate means the conditions of the atmosphere on a specific site which can be determined by meteorological dimensions. On the earth there exist different climate zones and more than one system for their classification. Climate zones can be classified according to these systems in mathematical or solar climate zones, which separate according to different temperatures and the zones run parallel to the equator and in true or physical classification, whereby the zones will be organized according to their climate type. (comp.: Bilow 2012: 39) Most popular is the Köppen climate classification, which focuses
by the division into zone on factors like temperature, precipitation and annual cycle. Köppen divides the earth into five main climate zones: The climate zone $A$, which is named the “Tropical rain climate/equatorial”, the climate zone $B$, which is called “Dry climates/arid”, the climate zone $C$, which is labeled “Warm moderate rain climates/warm temperature”, the climate zone $D$, which is termed “Boreal or snow forest climate/snow” and the climate zone $E$, which is entitled “Snow climates/polar”. (Fig. 4) These five groups have a complexity of further differentiations. The Netherlands for example are counted to the climate zone $C$, “Warm moderate rain climates/warm temperature”, and can be further divided into “C-fb”. The term “C-fb” stands for maritime temperate climate with warm summer. (comp.: Bilow 2012: 39 or Köppen 1918: Klassifikation der Klimate nach Temperatur, Niederschlag und Jahreslauf)

Furthermore, the term climate itself can be divided into spatial dimensions: First in microclimate, which is the climate for a specific location in a high of 2 m; second the mesoclimate, which is the local climate which spread from 100 m till 100 km; and third the macroclimate, which spreads over a weight of more than 500 km. Also important are the climate factors, the climate determined processes or conditions which form the climate characteristics from a special location, for example radiation, temperature, air humidity, air pressure. These elements are meteorological data which have measurable properties and a high importance for the building’s concept. (comp.: Hegger 2008: 52)

The term indoor climate means the conditions in the interior of buildings and is closely linked to the term indoor comfort. The human comfort feeling in the inside of buildings is based on the perception of extraneous causes. Next to measurable physical quantities, also individual appraisal criteria influence the decision about the comfort ability of indoor climate and the wellbeing. Therefore, the comfortableness is difficult to estimate. In the following I want to focus only on the physical measurable factors to elaborate the indoor qualities of buildings. For the completeness, I want to mention, that there are also intermediate terms and physiological conditions which influence the human evaluation of the indoor comfort. To create living and working conditions most comfortable, the room climate has to be optimized in terms of thermal, acoustic, visual and olfactory factors. (comp.: Hegger 2008:54)

The thermal conditions are most important for the people because they influence the heat balance of the humans and dominant the energy consumption of the building most. The thermal conditions inside the rooms are also linked to the human body itself, because the human body is a heat production. The human body enhances the room temperature by transpiration from the body, convection of heat from the body, conduction of heat from the body and heat radiation from the body. Therefore, in every good climate concept the heat production of the human body has to take into account. Measurable features for the thermal comfort are the room temperature (optimal winter: 20-22°C; summer: till 26°C), the room air humidity (optimal 40%-60%), the airspeed (optimal 0.15 m/s) and the temperature of the room encircling surface. The ratio of room temperature and the temperature of the room encircling surface are important for the comfort fee-
ling; as smaller the difference is, as more comfortable is the feeling for the people inside. The ideal case is a difference from not more than 3 K. (comp.: Hegger 2008: 57) The encircling surface temperature is directly linked to the construction of the façade. The performance of the façade influences this temperature. (Fig. 5) Moreover, important is to secure an ideal level of air humidity. Therefore, a high storage potential of the building mass is necessary. For the proof of the optimal air speed airtight building details are needed to avoid infiltration through points of leakage. All these points, which influence the thermal comfort, are linked to each other and an analysis in detail is necessary as well as an optimized façade construction to secure the thermal comfort for the living people inside.

Other important points for the indoor quality of rooms are the visual comfort and the comfortableness. An optimal visual comfort has to be adjusted to the room conditions, the illuminated conditions and the optic task. Therefore, it needs natural light as well as artificial light. Natural light leads to more comfort because it includes more spectral color. Moreover, the illumination level is important as well as the color and composition. The glare from outside has to be controlled and the incoming sunlight has to be adjustable in order to fulfil the specific needs. In terms of the visual comfort the façade plays a major role, with its performance the visual comfort can be achieved or not.

The acoustic comfort bases on the auditory cognition of vibration transfer of the surrounding air (airborne sound) or from solids (structure-borne sound). The acoustic comfort is linked to the noise level from the outside, noise insulation of the building skin, noises from the building services, form or size of rooms and their surface properties and furniture. The building skin is a key factor in the insulation of noise pollution from the outside as well as noise transfer from floor to floor. In order to achieve comfortable acoustic comfort in the inside the new energy generating façade has to deal with these circumstances.

The olfactory comfort is secured by a good ventilation concept. The olfactory comfort means the quality of the air. Measurable features for this are the CO₂ concentration as well as the olfactory, which measures the strengths of pollution source like people or out of emission of building components. With its opening in the skin the façade also secures a sufficient ventilation of the rooms and enhances so the comfort in terms of air quality.

To secure the room quality and the comfort of living people inside the building, good concept, in which the façade carries the main part for the living environment inside as well as for the energy efficient of the whole building, are necessary. The façade is the division from the surrounding outside climate and the desired indoor climate. It controls and organizes the flow of energies between these two climate conditions. The façade leads natural light into the rooms but protects them from glare with shading devices. Furthermore, it is linked to the ventilation system and supplies fresh air into the building, directly or indirectly. Moreover, it controls the loss and the gains of thermal energy with its insulation and airtightness. An active intelligent building skin can achieve best comfortableness for the living or working people inside. Even if the primary function of the building skin is the protection against weather conditions like wind, rain, sun radiation and surrounding conditions like noise pollution, the façade’s main assignment in our days is the regulation of the climate functions. The façade is in the focus of technical considerations and artistic design. It has to provide secure, healthy and comfortable inner room conditions for the related use. The challenge of the building skin I want to focus most in my further work process is linked to the facilitating function of the façade. I want to examine the production of energy within the building skin out of renewable energy source to achieve a building concept which switches from energy consumption to energy production and which implementation is possible in an urban context.

The decision for the renewable energy source and the technical systems which should transform renewable energies into thermal or electric energy for the use in the building is very important. The understanding of energy, their form of appearance on earth and their classification in renewable or non-renewable energy is basic: Energy can be transformed, stored and transported nevertheless, it is not a solid or a material.
Energy refuses the sensual perception, only the form of appearance or the energy carrier can be determined. All energy streams, suited on earth, are recharged out of three sources: geothermal energy, gravitation and solar radiation. With 99.9% the solar radiation mirrors the biggest amount of energy of these earth-sources. The Geothermal energy reflects 0.02% of the earth energy and the input of gravity is minor about the factor ten. (comp.: Hegger 2008: 44) The forms in which the energies appear on earth can be divided into renewable and non-renewable energies. All of the renewable forms of energy are spread out of these three energy sources. The non-renewable energies in form of nuclear power or fossil fuels will be mentioned here for completeness. The fossil fuels are originated from past solar radiation, but they will be summarized to the non-renewable energies. For the renewable energies which occur on earth it is difficult to determine their origin. Some renewable energy forms can’t identify their source. For example, the wind energy which originates from a cooperation of atmospheric movement, caused by solar radiation and rotation of the earth. All in all, the sun radiation lead to the most forms of renewable energies appear: The global radiation, the geothermal energy next to the surface, the thermal energy of the atmosphere, the wind energy, the thermal energy of the ocean, the energy out of the ocean current, the energy out of the wave movement and the energy out of biomass. The second earth-source is the geothermal energy and this leads to thermal energy deep under the surface of the earth. The third earth-source is the gravitation which causes the energy out of the tides. (comp.: Hegger 2008: 43)

In Mike Davies’ concept the energy generating layer in the façade abstracts the energy from the renewable energy source sun. Even with our current stand of techniques the polyvalent wall isn’t realized. For the development of an energy creating building skin we need to expand the field of renewable energy sources which are possible energy provider:

The sun is a powerful renewable energy source which is useable for an energy generating façade. There exist several sufficient technics to provide electric and thermal energy in the layer of the façade. For example, the sun radiation in the Brettenzone is around 360000 J/cm². (Climate Consultant: Clima Data Amsterdam) Another possibility is the wind, which can also be used as power source for the energy production in the envelope. It has a power of 5, 5-8,0 m/s in the Brettenzone with its main wind direction of north/west. (Climate Consultant: Clima Data Amsterdam) It is quite new to use wind in the production of electric energy in the building skin and only a few examples worldwide exist, but wind offers diverse possibilities and has a high potential. Moreover, water as source of renewable energy provides a plurality of possibilities if we think about waves, tides or hydrogen power. For the generating of energy in the façade the heat storage potential and the heat exchange potential of water in combination with the warming up by the sun is most interesting. Therefore, in the following context I focus on the possible absorbability and availability of water in the façade in order to generate thermal energy. Another source is Biomass, which is quite new in the use as renewable energy source on building side, but the potential to generate energy with it in the building skin is given and will be shown in the following. Theoretically it is possible to generate thermal energy with Biomass as well as to produce electric energy external in the biomass production. Moreover, air, integrated in a buffer-zone within the layers of the façade and in combination with the warming up by the sun, can generate thermal energy in the interspace of the façade. Furthermore, natural green can be integrated in the building skin in form of a green layer around the building. This vegetation layer can be used for the production of oxygen as well as for the evaporative cooling. The second mention means, that the greenery is able to provide thermal energy. In conclusion, the renewable energy sources in form of sun, wind, fluid, biomass, air and green are interesting for the technical system of an energy producing façade.

Next to the used renewable energy sources the constructive involvement of these energy creating technics in the building skin are important for my further work process and the classification of energy generating façades: Building envelopes form, together with the structure and the building technique, energy effective subsystems on the building. They influence each other and can be connected with each other in order to achieve the best performance. In the following, I want to focus mainly on the subsystems building skin and building technique which stands for an energy generating innovation. Interesting for me is the assembling of an energy generating façade and the potential of the new innovative energy providing technics for the building skin and for the architectural value.

For the constructive involvement of an innovative energy supplying subsystem into the façade we can district between decentralization, integration and conflation and I used this classification for my case studies.

Decentralization means that the energy generating technic can be seen as complete separated element in relation to the façade. The energy generating system distances itself from the building skin. It is a system, which will be added to the façade. The constructive involvement in form of the integration means, that the
energy generating system will be merged to the subsystem building skin. The building technology subsystem, which is here an energy generating system, is one component of the building skin. It adapts one function of the building skin. For example the building technical system can be used as weathering protection and so it is an integral component of the system building skin. The conflation means the merge of technical system and building skin. This is possible if the technical system can take over all functions of the building skin. These concepts unify building technical components and the façade in one element.

In the further enumeration of case studies the classification, according to the renewable energy source and the constructive involvement of these innovative energy supplying subsystems into the façade, are used.

The following content is an exemplary collection of energy generating façade-technology:

**Case Study I: The conflation - Liquid Glass**

**Case Study II: The conflation – Building Integrated Photovoltaics (BIPV)**

**Case Study III: The decentralization – Solar Farming**

**Case Study IV: The integration – Light Farm Concept**

**Case Study V: The decentralization – Wind Wall, Headquarter Building**

**Case Study VI: The integration – Bio responsive facade, Smart Material House**

**Case Study VII: The decentralization – Green, Bosco Vertical Mailand**

**Case Study VIII: The integration – Buffer-zone Double Shell Facade**

Fig. 6 Prototyp Fluid Glass

Fig. 7 Facade of the Solar office Doxford

Fig. 8 Sketch of the Solar Farming Prototype

Fig. 9 Prototyp of the Light Farm

Fig. 10 Wind Wall the Headquarter Building

Fig. 11 Bio responsive facade of the Smart Material House in Hamburg

Fig. 12 Green facade of the Bosco Vertical Mailand

Fig. 13 Double Shell Facade
The European research group follows Mike Davies’ steps. They start by presenting the concept of a layered façade prototype which integrates the building technology in between the glass layers. The constructive involvement of this energy creating subsystem into the façade is done by conflation. This means the merge of the technical subsystem and the building skin into one system with a layering composition. The energy allocating system uses water in combination with the potential of the sun as renewable energy source and provides so thermal energy. The research group developed a glass façade element in which a fluid circulates. With the adjustment of the temperature of the fluid, the heat transmission from the exterior and the interior can be controlled and with the coloring of the fluid the transparency of the façade can be changed. Fluid has a high storage potential and it has the characteristic that it can flow. A dynamic storage has a different quality as a static storage. It is possible to transport the energy from one place to another. The fluid is an infrared absorber, which means that 50% of the solar radiation is absorbed from this transparent material. The idea is to lead the light in, absorb the energy and transport it with the fluid layer. This is the idea from an ideal glass-façade: it can transport energy, it can control the flows, it can compensate inequalities and it can collect solar gains as well as act as heating/cooling element.

Till now the system is only proven in several prototypes. (Fig. 14) The Fluid Glass prototype consists of two fluid filled layers separated by a thermal separation in between a glazing system. A triple glazed insulation glass unit is used for the fluid construction: Two 6 mm thick glass sheds with an interspace of 2 mm for the fluid. This pane forms the outer and inner completion of the prototype. It exists twice. The outer pane has the function to absorb the radiation whereas the inner pane acts like a cooling or heating element. In between these two panes there are two layers of 16 mm thickness, filled with Krypton gas to insulate. The separation of these two gas chambers constitutes a 6 mm thick glass layer. Low-E coatings are on the inside surface of the outer pane and on the outside surface of the inner pane of the insulation glass unit. All in all, the result is a total thickness of the glazing system of 66 mm. (Fig. 15) The fluid flows in both chambers from the bottom and leaves it at the top of the façade element. Four inlets and four outlets are placed on the glass of the interior and exterior side for each chamber. The fluid enters the chamber perpendicular to the flow direction. Spacers are included in between the fluid layers to resist against the static pressure. The distance between the spacers is 100 mm and their diameter is 2 mm. For a window element with the high of 2,50 m the pressure is around 0,25 bar. Therefore the fluid interspace between the layers is set into under-pressure. The spacers should later be glued between the glass layers. (comp.: Gstöhl 2011: 2) Till now they are hanging on copper wire. This operation mode is chosen to minimize the glass thickness, since stress resulting from the pressure difference between water and surrounding air can be supported by small columns between the windows. The fluid will flow over a contraction choke into the interspace which guaranties a balancing laminar stream. For the coloring of the fluid magnetic particles were used and

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Case Study I: The conflation - Liquid Glass

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Fig. 14 Prototyp Fluid Glass Facade

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7  Case Study I: The conflation - Liquid Glass
showed a good performance in the testing phase. (Fig. 16) They also control the solar irradiation by adding or removing them. Both liquid layers have their own separated circuits with particle feeder, particle separator pump and heat exchanger. The pumps are located downstream of the façade element. (comp.: Oppliger 2012: 6-7)

The basic operation modes are the following: (Fig. 17) At a summer day the sun protection is given by adding particles into the fluid. Compared to other shading devices the absorbed solar radiation is not lost. By the fluid it can be transported to another place or storage in the ground. At the shadowed building side no particles will be given through, so that maximum daylight can get into the rooms. The outer layer will absorb the solar radiation and act like a thermal collector linked to a heat exchanger and a storage system. The fluid is used as sun collector. It can occur stagnation temperature from the outer fluid layer of 45°C - 70°C by solar radiation values of 400 W/m² and 1000 W/m². With a fluid temperature of 40°C which is secured by a solar radiation of 600 W/m² in the outer fluid layer the collector is operating with a collector efficiency of 50%. The cooling will be done by the inner fluid layer. The inner fluid layer also removes heat from the adjusted room and transports it to the storage system. Due to a good thermal insulation between inside and outside fluid layer in form of two gas filled chambers the heat exchanges between the fluid layers is less. In the summer night heat gains from the solar radiation to the outer layer and from the inner layer out of the cooling system they can be transported out of the building over the outer liquid layer. This night cooling is energetic better than conventional air-conditioning. In the winter day maximum solar gains will be let into the building because the particles are extracted and the solar shading is switched off. The inner fluid layer acts as a radiator. Because of the heating over the façade no asymmetry will occur in the rooms which lead to a maximum comfort. (comp.: Gstöhl 2011: 6/7)

The concept of the fluid glass façade system could be proven with this prototype. The transparent façade can increase the energy efficiency of buildings in every climate zone and it is active controllable and so useful for every building type. Also interesting is that the whole area of the façade is used as collector for renewable energy.
The conflation means the merge of technical system and building skin. This is possible if the technical system can take over all functions of the building skin. These concepts unify building technical components and the façade in one element. Building integrated Photovoltaic (BIPV) is a common example to use solar gains with the activating of the building skin. The Solar office Doxford in Newcastle designed by Studio E architects in 1998 is one of the first examples which used BIPV to produce energy within the building skin. The resulting façade was the largest assembled one at that time with a BIPV surface of 646 m². (comp.: StudieE 1998: Solar Energy Convention)

“The building is ‘V’ shaped in plan with extreme ends of the ‘V’ splayed away each other and a central core located at the apex of the ‘V’.” (Pearsall 1998: 1) The south façade design is optimized for the use of BIPVs and is raked with an angel of 60°. All in all the length of the south façade is 66 m and it incorporates the main entrance. Behind the façade there is a three storage high atrium placed which supports the natural ventilation concept. The photovoltaic elements are semitransparent or opaque modules and act also as shadow device. Moreover, they support the natural ventilation concept of the building. The BIPVs are polycrystalline silicium cells which are placed in a glass-glass-module construction. The modules are rectangular shaped and trapezium shaped. All in all the façade is constructed out of nine different size designs. They are divided with ligaments of clear glass to guaranty the outlook as well as sufficient day light inside the rooms. The BIPVs are integrated in the south façade and have a rated power of 73kWp and produce 55,000 kWh/a under the specific local conditions. This mirrors one third of the total energy consumption of the building. The BIPV are linked to a holistic energy concept of the building, which is designed in low energy standard of 85 kWh/m² annual. (comp.: StudieE 1998: Solar Energy Convention)

The BIPV-system of the south façade is split into four sub arrays, two on each side of the entrance and with slightly different orientations. “The two west sub arrays are orientated 5 digress off south towards the west, whilst the two east sub arrays are the same angle off south towards the east. This enhances the visual aspect of the façade, but, in practice, results in only a very small difference in output between the different sides of the array.”(Persall 1998: 3) The produced electricity is useable in the building itself and the rest can be fed in the public power supply system. Next to electricity the BIPV also provides waste heat which will be used to preheat the air for the ventilation. Conflicts between the low energy measurements of the building construction and the photovoltaic installation occurs. The compensation for the lack of thermal capacity in the façade materials and their relative poor insulation properties are necessary. The solution in the design is a balance between these respective requirements, for example the ventilation of the façade which prevents overheating, the introduction of additional thermal mass and the reduction of heat losses through the façade. (Fig. 20) Moreover, office windows are integrated in the north, north east and north west façade to control the heat from the solar gains of the morning and evening sun. In front of the south façade there is the car park placed to secure that...
the south façade will not be shadowed by any street furniture or other buildings which are placed too close. The building has a control system which collects operational data to allow analysis of both: the BIPV system performance and the interaction with the other low energy features of the building. (comp.: StudieE 1998: Solar Energy Convention)

The building integrated photovoltaic systems offer architectural pleasing within the context of a building and adapt well overall modularity. The visual aspect of grid can be enhanced and a satisfactory composition in the façade can be created. BIPV generates an innovative concept for the façade. (comp.: Studio E 1998: Understanding building integrated photovoltaics)

Case Study II: The conflation - Building Integrated Photovoltaics (BIPV)

![Fig. 19 South - Facade from the inside with the BIPV of the Solar office Doxford](image1)

Stack for natural ventilation
Wind paddles to ensure negative pressure at extract vent positions
Automated top and bottom vent to solar facade
Automatically controlled windows with manual override
Well insulated, low air leakage construction
Automatically controlled wind paddles to ensure negative pressure at extract vent positions
Thermal mass provided by precast concrete and masonry construction
Good daylight factor
Automated top and bottom vent to solar facade
Stack induced natural ventilation
Building integrated photovoltaics

Case Study II: The conflation - Building Integrated Photovoltaics (BIPV)

![Fig. 20 South Facade - overall energy concept](image2)
The interest in Hybrid systems of solar thermal collectors is growing in the last years. This means that the systems integrate the function of photovoltaic and solar thermal collector all in one. Mostly the thermal systems function as thermal absorber and cool the PV cell down and use its waste heat. The recovering of waste heat from the PV cell also increases the efficiency of the PV cell. The Solar Farming is a concept which works with this hybrid system; it uses the sun as renewable energy source and provides electric energy as well as thermal energy. The constructive involvement of this energy generating system in the façade is in form of decentralization. This means, that the energy generating technic can be seen as element which is completely separated from the façade. The New York Center for Architectural Science and Ecology CASE developed this solar farming system named IC Solar Façade System and tested it in prototypes of different versions on side.

The technical approach of this system is to use the direct solar irradiation directly in the building surface to generate energy for the building. The components are miniaturized concentrated solar cells, lenses in glass pyramid shapes and a transparent tracking system. The irradiation will be concentrated by the lens, which magnify light nearly 500 times and direct it to a postage stamp size solar cell made of highly efficient gallium arsenide. The cell is fixed on a receiver which includes a coolant flow to maximize the performance of the PV cell and to absorb the waste heat. The concentrator hangs on a transparent construction which can move up and down and orientates itself to the sun. The modules are placed within a glass façade or atrium roof and mounted on an accurate, but inexpensive tracking mechanism. (comp.: Trubiano 2013: 123) The spectrolab cells have a lab efficiency of 38.2 % and reach a production efficiency of 30 %. The cooling system captures the heat and uses it for the building service. (comp.: Dyson 2010: Interview PV magazine) “All together it will be expected that either in the form of electricity or usable building heat, the system will reach 60-80 % of the sun’s energy – including light and heat.” (Dyson 2010: Interview PV magazine)

This Solar Farming concept is not only useful for the production of electric and thermal energy. It is also designed to bring daylight in the building while deflecting heat and glare and it is also possible to use it for the cooling. Till now it is only proven in diverse prototypes but the Institute of Technology in New York plans to install the solar collector façade in its student center. The IC Solar Façade System can be added on top of the façade but it is also possible to integrate it in the interspace of a double shell façade to protect the system against weathering.
Case Study IV: The integration - Light Farm Concept

The constructive involvement in form of the integration means, that the energy generating system will be one component of the building skin. It adapts one function of the building skin. The total system building skin only works with the component energy generating system. The Light Farm Concept designed by Mohsen Saleh is an example for a solar farming included in the building skin. It uses the sun as renewable energy source and provides electric energy as well as thermal energy. The energy generating system is one component of the façade construction. It forms the outer layer which is the weathering protection of the façade. It integrates Concentrated Photovoltaic Technology (CPV) in the façade to generate electricity and heat. With this system the light rays are concentrated by thin plastic Fresnel lenses which concentrate a large amount of sunlight on a smaller surface of PV cells to generate electricity. This system is more efficient than conventional PV arrangements and generates so electricity with a higher conversion rate. With the concentration of the sun light the amount of absorbed energy is enhanced also for the thermal collector. (comp.: Mohsen 2012: Hybrid solar thermal Facade) The design feature in this system is that it is possible to use colorful plastic sheets on these Fresnel lenses and transform the façade in optical art.
The constructive involvement of an energy generating system in the façade in form of decentralization means, that the energy generating technic is seen as an element, completely separated from the façade. One example for the use of the renewable energy source wind is the wind wall of the Headquarter building designed by KMD Stevens Architects in San Francisco. It is a sustainable innovation for an urban office building which provides and manages the use of water and energy for San Francisco. “What better organization than a major municipal power and water agency to create one of the most advanced buildings in green design in the U.S.” (comp.: Hobstetter 2012: Interview in Reuters)

In comparison to similarly-sized office buildings features, its carbon footprint is 50% less, it uses 32% less energy and it consumes 60% less water. The building with its innovative façade generates up to 7% of its own power needs from renewable energy sources with PV cells and wind turbines. The hybrid solar array and wind turbine installation can produce up to 227,000 KWh per year. The energy cost saving is around $118 million over 75 years and it will need 45% less energy to illuminate the interior through daylight compared to a typical class A office building. An intelligent computer based system included with measurement features in the raised flooring system collects the building’s data and an intelligent ventilation infrastructure and ventilation concept reduces heating, cooling and ventilation energy costs by 51%. An innovative water-conservation system leads to 60% less water than similarly sized buildings use. (comp.: San Francisco Public Utilities Commission 2012: Your New SFPUC Sustainable Headquarter)

In a study the architects tested to place three dozen turbines horizontally and vertically at the building and on top of it. With the increasing of the wind turbines the architects wanted to show the narrowed gap in relation of now installed PVs and wind turbines in the renewable energy mix. The San Francisco winds average is 6-14 mph. (comp.: Wind-Average: National Climatic Data Center)

The south façade fits with its design in the surrounding city center and responds to the local climate. Daylight is controlled by light shelves and climate controlled exterior blinds. The wind wall is placed on the north façade. The design of the north façade is optimized to maximize the energy generating potential of the wind turbines. The wind wall, which holds additional art installation, is constructed as autonomous façade part and placed in front of the main façade. The turbines form a whirling stack and each one rotates at a different pace. (King 2012: New PUC building - green, seems almost alive) The vertical array of four vertical axis wind turbines (VAWTs) is just inside this installation. The used wind turbines are from the type Windspire Extreme® wind turbines with a rated capacity of 1.2 KW. It corresponds to the natural forces at play and is designed in a curved shape that focuses wind into the wind-turbine tower. It is connected with the façade over platforms on each floor. It guides the wind through the turbines, minimizes turbulences and optimizes the wind speed. The design of the wind wall achieves both: the compatibility with the classical building style and the modern urban city shape.

In Case Study V: The decentralization – Wind Wall, the wind wall of the Headquarter building is a good example of how renewable energy can be integrated into buildings, not only for its environmental benefits, but also for its aesthetic appeal and functionality.
example to reflect the potential of wind turbines in the building skin. Other examples like the Oklahoma Medical Research Foundation work with vertical wind turbines on top of the roof to secure the trouble free urban life. The wind wall shows the performance of vertical wind turbines in the urban context and shows the usability and failure free operation, if they are included in an intelligent construction. Their wind turbine system utilized a ducted shroud to accelerate and control the wind around the building. This wind wall is an excellent example how a wind farm can be successfully implemented in the city.

Case Study V: The decentralization - Wind Wall
The bio-responsive façade designed for the Smart Material House in Hamburg by Splitterwerk architects is the first and most popular example of using biomass for the energy production in the building skin. The energy generating technic of the biomass is an integral component of the façade design. Biomass is a form of solar energy which is compared to the generating energy out of PVs cells storageable without noteworthy losses. The change from biomass into energy is CO$_2$ neutral, because the amount of CO$_2$ which is extruded by the burning is the same which the plants extract from the atmosphere during their growth. Microalgae transform the sunlight into biomass and they can grow in photo bioreactors. Photo bioreactors are closed transparent boxes which are filled with a cultivating medium. The development of the biomass façade of the smart material house ends in a design which uses these transparent containers as a translucent cover construction. This cover forms a double skin around the building. The flat microalgae collectors are integrated in the façade and generate both: solar heat and biomass, to supply the building with energy.

These flat collectors are filled with algae and water and include an airstream which causes turbulences inside the collector and so stimulates the CO$_2$ absorption as well as the light absorption of the algae. Moreover, the water movement inside the panel cleans itself from the inside. One collector measures 2,5 m * 0,7 m and is 18 mm deep and is filled with 24 l algae-water mixture. 16 panels form a water circle unit. The regulation of the intake and outtake of the panels is computer controlled as well as the measurement unit for the algae content and the temperature level. The heat, generated through the solar thermal effects, is absorbed by heat exchangers to prevent overheating and used for the building services or the storage. The system runs best with a temperature of 40°C. These collectors are also used as shading device. The Algae biomass, which is estimated to be 15 grams per square meter of façade and day, is harvest in regular intervals, stored and transported external to a fabric. The algae biomass can be use external through combustion or for the biogas production. The potential out of the biomass is around 30 kWh per m$^2$ and the solar gains are around 150kWh/m$^2$.a. In total the Smart Material House approx. saves 6t of CO$_2$ and additionally 2,5t of CO$_2$ is absorbed by the biomass every year. (comp.: Wurm in Detail 01/2013: 62)

Biomass is an innovative source for the fabrication of energy. Micro algae grow fast and provide so big amounts of energy in short time. The Bioreactor-façade is usable for all kinds of building types. The green color of the algae inside the Photo bioreactors shows the production rate of the algae and so the CO$_2$ absorption.

Case Study VI: The integration - Bio Responsive Facade
In the dense city of our days most the air pollution is most important. Therefore, new innovative concepts focus on the production of oxygen inside the city in order to enhance the quality for the people who live inside. The concept of the buildings, called Bosco Vertical in Mailand, follow the goal to offer a framework for the communication of the building between nature and city. The Bosco Vertical designed by Boeri Studio is the first example of the integration of trees in the building skin. The two designed residential buildings are surrounded by a green vegetation layer as building envelope which provides oxygen and at the same time evaporative cooling.

The Bosco Vertical consists of two residential towers of 110 and 76 meters height, which are realized in the center of Mailand, on the edge of the Isola neighborhood. They host 900 trees, each measuring 3, 6 or 9 m tall, planted to all building sides, apart from a wide range of 5,000 shrubs and 11,000 floral plants. (comp.: Detail Daily 2014: Vertikaler Wald – Vorzeigeprojekt in Mailand)

The used plants grow specifically for this purpose and are precultivated. The plants slowly got used to the conditions they are placed in on the building in terms of further growths. The trees also change in each season, depending on the types of plants which are involved. “As a new growth model for the regeneration of the urban environment, the design creates a biological habitat in a total area of 40,000 m². The creation of a number of vertical forests in the city will be able to create a network of environmental corridors which will give life to the main parks in the city, bringing the green space of avenues and gardens and connecting various spaces of spontaneous vegetation growth,“ said the Boeri Studio. (Boeri 2014: Bosco Verticale)

These plans should provide a microclimate and filter the dust particles out of the urban city to create a healthy living environment for the people inside. The vegetation will also provide urban habitats for birds and insects. Moreover, the diversity of the plants and their properties produce humidity, absorb CO₂ and produce oxygen as well as protect from radiation and acoustic pollution. Next to the improvement of the living space it also saves energy. Additional sustainable features in the concept are the water treatment and the Aeolian and PV energy systems.

This concept expresses the human wish to live in a green natural environment and therefore the vertical forest won the Best High-rise Award 2014. To use a vertical layer around the building to produce oxygen as well as evaporative cooling is an innovative concept and has a high potential in the further development. This is a new form of buffer-zone which we till now only knew from the double shell façade and it is green instead of air-filled. These façades provide an immense living quality for the people and animals in the city. Even if the floor arrangement only designs small room apartments in the city, the green additional outside rooms convince and enhance the whole concept.
Case Study VIII: The integration - Bufferzone

The constructive involvement in form of the integration means, that the energy generating system is one component of the building skin. Double shell façades offer an interspace filled with air in two layers of the façade construction. They exist in diverse forms of construction with horizontal or vertical separation per floor or building high. One of these diverse construction methods of a double shell façade is the corridor façade which I want to reflect exemplary for the use of air as renewable energy source in combination with the heat production of the sun. The case study building is a high-rise in Hannover designed by Herzog+Partner, which use the buffer-zone in between two glass layers for the preheating of air. This preheated air will be used for the ventilation strategy. Moreover, the thermal energy from this air in the buffer-zone is extracted over heat exchanger and used for the building services.
The built environment always reflects the innovative thinking of society. The energy transition leads to a conscientiously handling of the world energy resources in order to leave the world in good condition for the further generations. Renewable energies are from principle useable without any negative effects on the natural environment. They secure the climate protection as well as environmental protection because renewable energies are available in inexhaustible energy potential and in structural diversity. Also in our days both potentials are underestimated and till now not scooped. Crucial in the choice for one renewable energy source are the side specific climate factors, the typography of the location and the use type of the building, which will mirror the demand of different energies over the time. Also interesting is the comparison of the whole energy supplying system in terms of flexibility and adaption to changing conditions, for example the user behavior.

The search for a visual and aesthetic ideology of the integration of innovative technic into architecture is done in the case studies in several different concepts and basic rules. We saw examples where the transformation of an energy generating façade influences the image of the façade and so the architectonical value as well as examples with minor changes in their architectonical expression. The integration of an energy generating façade can be nearly invisible as we see in the Fluid Glass prototype. The layering concepts result in a glass façade with the thickness of a normal one. Here the integrated technic is for the observer not visible on the first look. The Fluid Glass enhances the efficiency of the whole building. For refurbishment of buildings an energy saving of 50-70% is expected. For new constructions of houses with the fluid glass in combination with Passivhouse standards 20-30% of energy savings are predicted. (comp.: Oberland Nachrichten 10/2013: Fluid Glass) Compared to Mike Davies approach this Liquid Glass concept is a more macroscopic and realistic one. It seems reasonable to integrate shading device, solar collector, cooling and heating elements into a glass layered façade composition. This new intervention can be a solution for the city of the future which uses the hybrid material glass for its building skin.

In the field of building integrated photovoltaic (BIPV) the building industry shows the highest stand of development, compared with the other case studies. There are existing a numerous of built examples, which use BIPV for the energy generation as well as for their architectonical language. But in terms of efficiency and design their capability is still expandable. In our days some architects start to discover BIPV for their façade design, but the aim is to convince a wide range of architects to design with it. The solar farming concepts are a quiet new innovation and symbolize the energy earning aspect most visible to the outer world. In case of BIPV the architectonical design is important for the acceptance of the façade design. Therefore the BIPV has a key role as a design element and needs to be respected. Moreover, facades, which are built out of BIPV need to stand in a surrounding which secures the shining from the solar radiation. Also future neighbor buildings have to be adjusted so that the façades are always protected against urban shadowing.

Build concepts with the integration of wind turbines within the building skin are rare. It is difficult to in-
egrate the immense power source wind in the building skin and protect the surrounding at the same time against noise or wind turbulence. Build examples mostly integrate wind turbines on the roof of buildings. Nevertheless, the wind wall of the Headquarter center in San Francisco shows, that it is possible to establish wind mills in an urban concept. The construction is optimized in order to catch as much wind speed as possible and to prevent disturbances. The wind wall is placed as a second exterior skin in front of the main façade and it also includes a media façade to enhance the attraction for the urban area. It is always difficult to find the perfect urban side for this kind of façades. To secure the performance of the wind extraction it is necessary to examine the wind streams around the building very exactly and to discover disturbances in the urban context. Therefore, an exact site wind analysis has to be done in order to secure the performance of the wind wall. This means that the surrounding area has to be examined and that future buildings have to be planned in order not to destroy the wind catch concept of the energy generating façade. All in all, wind turbines are possible in the urban context and we will see them for sure more and in mature performance in the following years.

The use of biomass for the energy production in the building skin has another high development potential for the future. Biomass is an innovative source for the fabrication of energy. Concepts in which the biomass is integrated into the façade are quite new. But the potential of biomass is immense. In the normal production of electricity, biomass is the second biggest renewable energy source after the electricity out of wind power. Micro algae grow fast and provide so big amounts of energy in short time. The Bioreactor façade is usable for all kinds of building types. The green color of the algae inside the photo bioreactors shows the production rate of the algae and so the CO₂ absorption. This places interesting green accents in the façade design and makes the sustainable approach visible for everyone. Compared with the Fluid Glass this type of energy generating façade is a visible statement to the world outside. Moreover, for me the harvesting of the biomass follows the concept of urban farming and reflects the approach from farming in the city on vertical walls or roofs. This new invention leads to a super green design, not only in its wording but also in its architectural outcome.

The vertical green concept differs from the previous mentioned energy generating concepts. It is not really a concept for an energy generating façade, it is more a concept to offer better natural living conditions for the people and animals in big metropolitan cities. Compared with the other façade types it can’t facilitate energy in thermal or electric form. It mostly provides oxygen. But for integrity, the greenery has a small influence on the thermal energy consumption of the building, because the trees help to cool the building down by the help of their natural evaporation. But for me this can’t be seen as an active energy generating process, like we will find it in the other energy generating façade concepts. But the big advantage for the urban area is, that this type of façade is able to provide oxygen in the dense and foggy metropolitan centers. Moreover, the green skin offers a beautiful surrounding and healthy living conditions. To enhance the greenery in the city this concept has a high value and I hope that in the future more green building skins will find the way in our metropolitan cities. The toolbox to create this kind of façade is given in our façade technology. Now the architects with their creativity have to design façades for the city with the natural spirit to join both: the city and the landscape into one façade. The concept of double shell façades are developed quite far. Using the interspace between two layers of glass as a buffer zone to preheat the air for ventilation or to enhance the insulation of buildings can be seen in various built examples. Also the types of double shell façades show a wide variability. The performance of a double shell façade is well known in the architecture in our days and also the architectonical expression is accepted and used for design concepts. Double shell façades will be also used in the future urban building industry, especially for urban high-rises. There already exists a toolbox to use these advantages of a double shell for an energy generating output. Nevertheless, further development potential in terms of efficiency and cost reducing construction methods is given.

In conclusion, the technical stand of an energy producing façade is theoretical quite far and also shown in some built examples. Nevertheless, out of my research, I can say, that the combination of different energy generating concepts in one building is useful to provide flexibility in changing conditions or uses. The mixture of different kinds of technics and also the connection between each other secure the performance also by changing outer weather condition or changing surrounding conditions. The advantage of a mixture is that it also leads to flexibility in use, because the changing demands can be secured. The renewable energy potential is diverse and therefore a mixture of diverse technical innovations for the building skin makes sense, to use this potential best. The influence which these technical innovations have for the architectural expression of buildings can, depending on the used technique, be immense or not. All in all, you can say, that these technical inventions give a wide range
of design tools which will support architects in their design process. The future architecture will not be determined by technical innovations or restrictions. It will be supported by them. Technical innovations have the capability to provide an enormous change for the design process of buildings. But they are still just one tool in the design process and should always serve the architectonical expression instead of replace it. For me the energy generating façade is a barometer recording the evolution of our society.
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