5-2018

Solar Power in Architecture

Meagan Leeth
University of Arkansas, Fayetteville

SOLAR POWER IN ARCHITECTURE

SOLAR POWER IN ARCHITECTURE

Meagan Leeth

architecture honors capstone

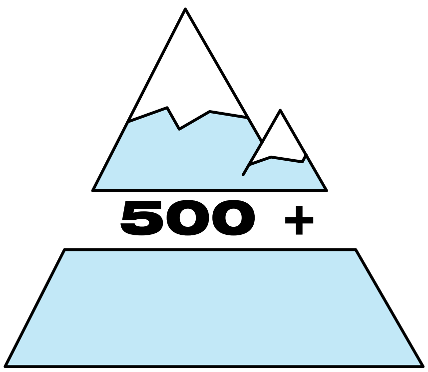
primary advisor: Dr Tahar Messadi

SOLAR: WHY SHOULD ARCHITECTS CARE?

Climate change is a major problem for our planet. To deny this any longer will only create insurmountable problems for future generations. There is ample evidence that suggests a direct correlation between carbon emissions and climate change, so the debate has to move to identifying effective measures to alleviate such a threat to our planet. Large, systematic change is long overdue, but where do we begin? To begin with, acknowledging that buildings account for 40% of energy use across the globe puts the onus on architects who need embrace novel solutions to bring this consumption to net zero, they must be a part of the solution. By virtue of the profession, architects are problem solvers at their core. Designing buildings and cities with energy use, material and water conservation in mind is bound to create a more sustainable future with regards the built environment. Beyond reduced consumption of energy, the sun provides the buildings with the potential to produce energy. The purpose of this study is to examine the barriers that have prevented a more aggressive use of solar power, and to determine strategies to promote the successful integration of solar power into architecture. Just examine this fact: to power the entire planet, we would only need to cover a surface area equivalent to that of Spain. So why hasn't solar power been widespread in architecture? What systemic changes are necessary to promote a more sustainable architectural environment using solar power? Hence, this purpose for conducting this investigation is to bring answers to these questions.

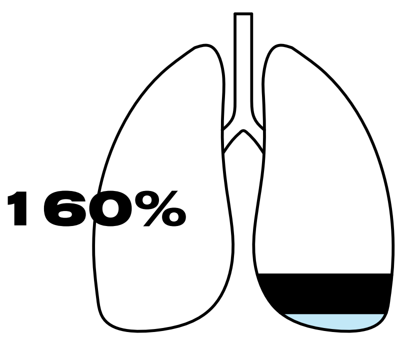
BEYOND CLIMATE CHANGE

Why abandon fossil fuels for solar alternatives? Beyond the issue of climate change is the other effects of these energy sources on our environment, including our cities. Architects design the human environment so why not design with human health in mind. Why not design without pollution? If climate change and energy savings are not enough incentive, let's look at the deadliest reasons to opt for solar.



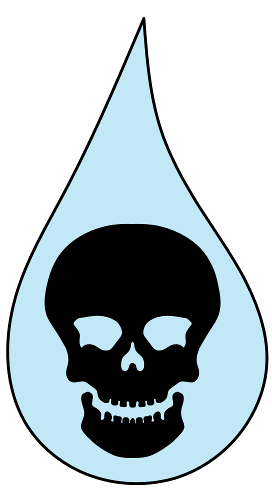
MOUNTAIN TOP REMOVAL

Ever dreamed of hiking the Appalachian trail? Designing a home in the mountains with picturesque views? That dream may die if we keep mining coal at the current rate. Mountain top removal coal mining is responsible for the destruction of over 500 mountains in the United States alone.



ASTHMA

Asthma rates in children are skyrocketing, increasing by as much as 160% in the last decadewith a direct coorelation to increasing air pollution, often caused by the burning of fossil fuels. If we want our cities to be safe for our children, we need to give them clean air, air free of fossil fuels.

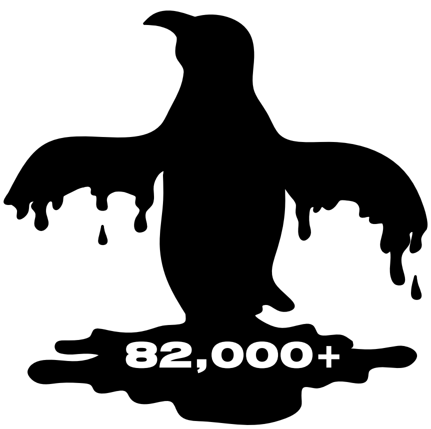


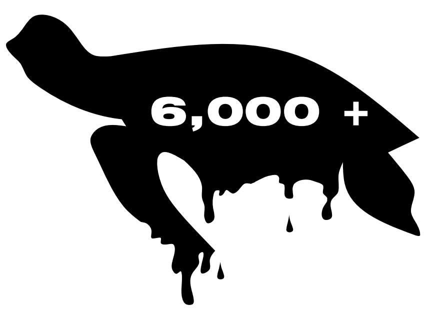
WATER CONTAMINATION

The burning of natural gas while "cleaner" than petroleum or coal contributes to air pollution, but also water pollution. Hydrolic fracturing can lead to the contamination of aquifers that people use to bring water into their homes. This contamination can go unnoticed for a dangerous period of time and permanently contaminate groundwater used in wells.

OIL SPILLS

In the BP oil, the eco system of the gulf was changed forever. in one of the most devastating spills in history, marine life was affected in an unprecedented way. More than 82,000 birds, 6,000 sea turtles, 25,900 marine mammals, and countless fish and vegetation have been harmed by this one spill. One of 320 offshore oil spills that have occurred. Beyond the ecosystem, this devasts the gulf economy and has significant impact on the seafood of the region.



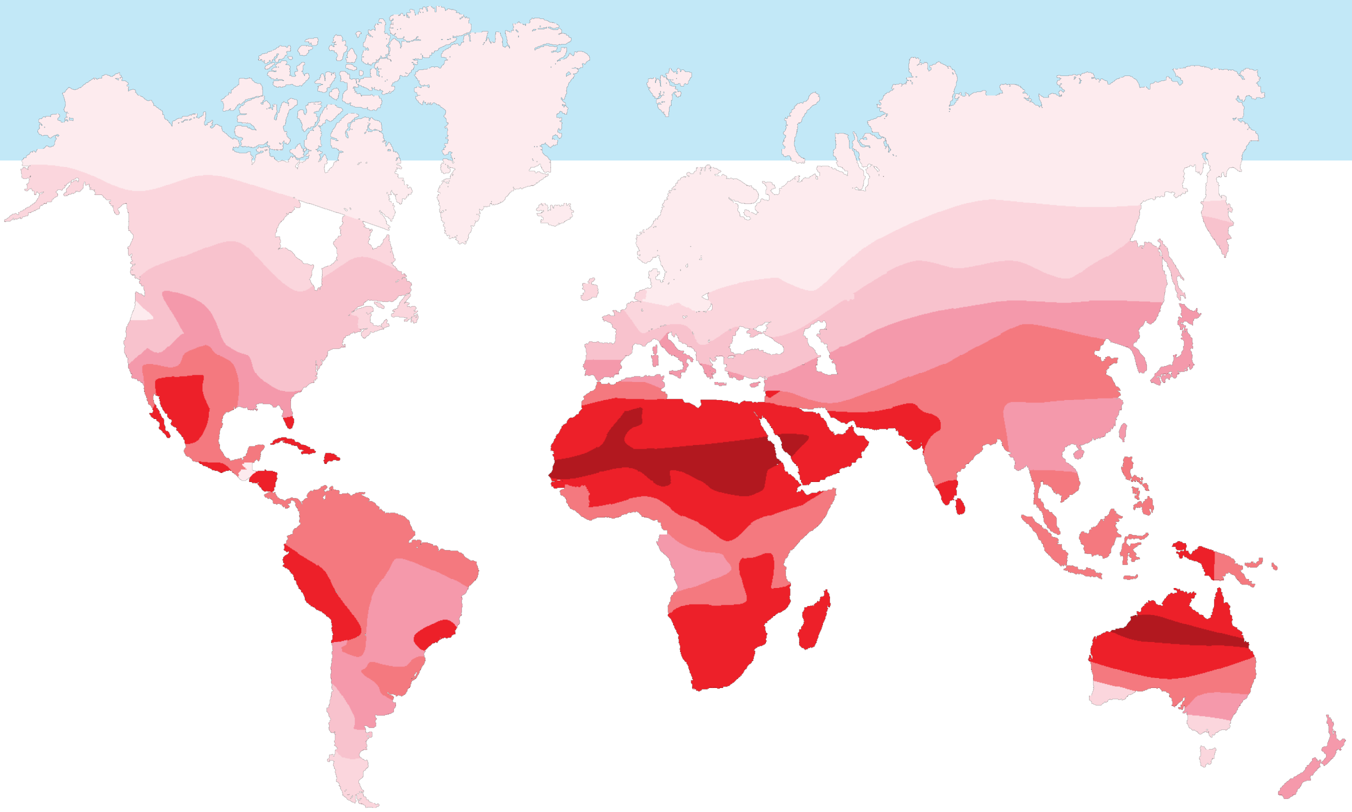


RADIOACTIVE WASTE

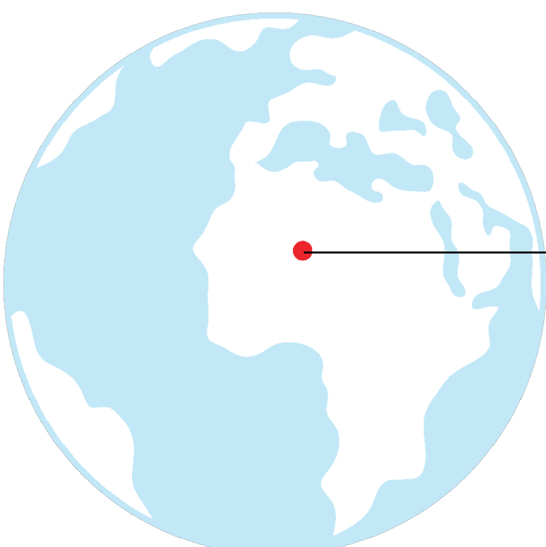
While often seen as a “cleaner alternative” to fossil fuels, nuclear power produces nuclear waste that can take up to 10,000 years to degrade to the point of non toxic radioactice status. This poses an obvious risk if the waste is not handled perfectly.

1,000 - 10,000 YEARS

SOLAR POTENTIAL



GLOBAL SOLAR RADIATION POTENTIAL

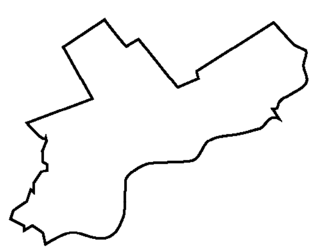


190,000 sq miles
of solar needed to
power the world

100 sq miles
of solar needed to
power USA

PHILIDELPHIA

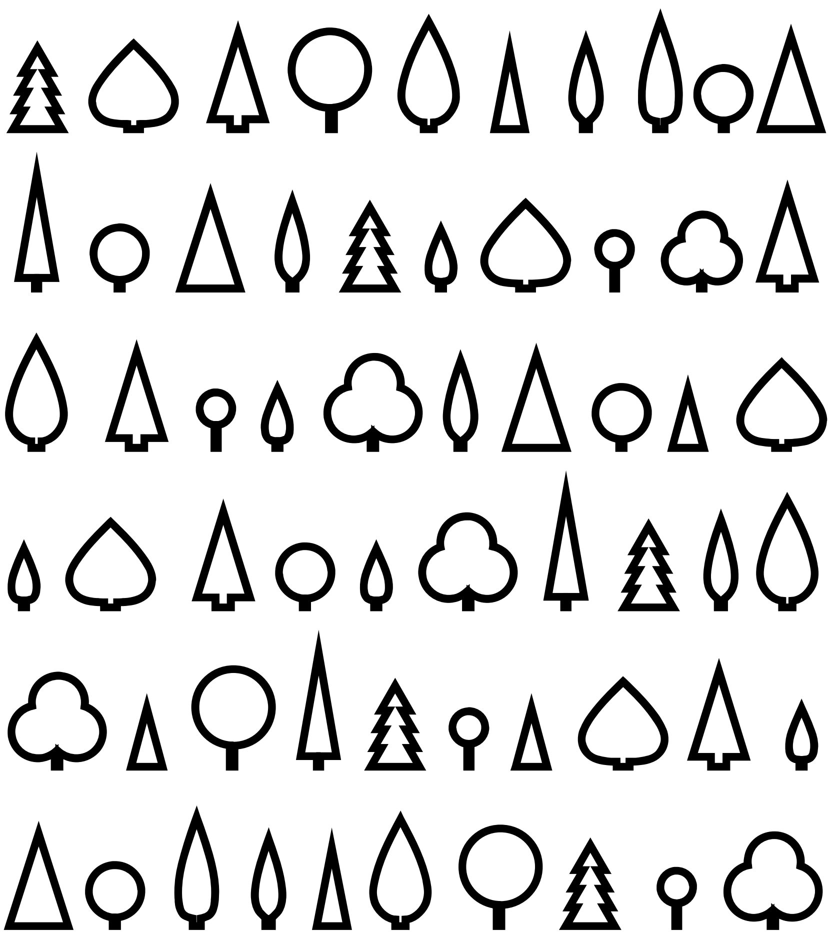
134 sq miles



THE AMOUNT OF ENERGY THE SUN PRODUCES OVER 1 SQUARE MILE OVER 1 YEAR IS EQUAL THE AMOUNT OF ENERGY IN 4 MILLION BARRELS OF OIL

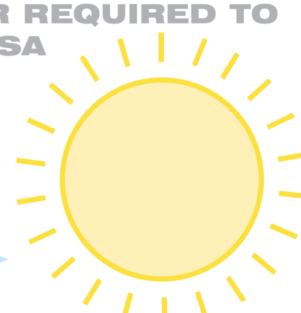
1 SQ MILE
OF SOLAR OVER 1 YEAR = **4 MIL** BARRELS OF OIL

60 MIL TREES / **100 SQ MILES** OF FOREST



IT WOULD TAKE 60 MILLION TREES 1 YEAR TO ABSORB THE AMOUNT OF CO2 EMMISIONS PRODUCED FROM 4 MILLION BARRELS OF OIL. THAT MANY TREES WOULD TAKE UP OVER 100 SQ MILES, THAT SAME AMOUNT OF SURFACE AREA NECCESARY TO POWER THE ENTIRE UNITED STATES. SAVE MILLIONS OF TREES AND GO SOLAR

100 SQ MILES
OF SOLAR REQUIRED TO POWER USA



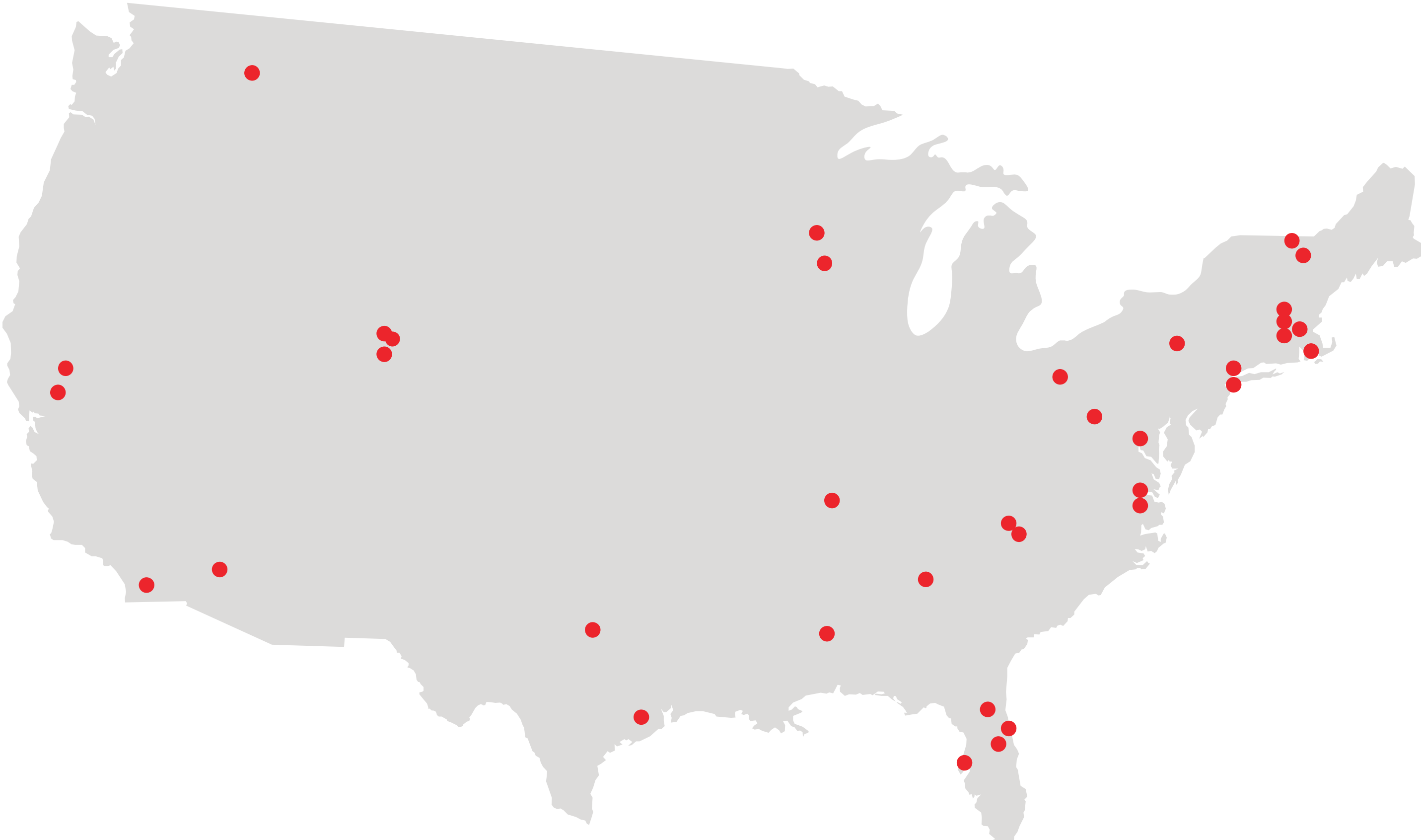
MONEY TALKS

The most common use of solar power is the production of electricity through photovoltaic panels organized in farms or placed on the roofs of buildings. Photovoltaic, or PV, panels convert light rays from the sun into electricity. Although there are other types of solar power systems, like those that convert solar heat gain into electricity, they are less efficient than PV panels. As technology evolves, these PV systems are becoming more and more efficient and therefore more affordable. Developments such as transparent PV glass creates more architectural opportunities for integration. The technology is there so why aren't we using it to power our buildings and our cities?

The economics of solar power go back to the issue of infrastructure. With so much invested in our current energy infrastructure, it will take incentivizing solar power, much like was done with coal in its early days, to make the necessary changes to our power grid for solar to become a widespread system. In the 1930's, Franklin Roosevelt signed into law the Rural Electrification Act which gave power to those without electricity and set in place the model for our current electricity grid. The first solar panel wasn't sold until the 1970's and the electricity grid didn't begin to change until the San Francisco based Pacific Gas and Electric (PG&E) Company came in in the late 90's with enough capital to kick start the solar movement. On the tail end of a water contamination scandal, PG&E needed the good publicity that solar power would bring. They brought net metering with solar power into 42 states, making the first step towards mainstream solar power. This large corporation provided the financial backing, but an architect was the inventor. Net metering consists of allows those with PV panels on their roof to save on their electricity bills by potentially producing and selling energy to the utility company. The way electricity use is quantified in the US is through meters that simply measure how much is used, by moving forwards when energy is taken from the grid and moving backwards when energy is put back. The entire reason net metering exists is because of one architect. It began in 1979 when a young architect Steven Strong put photovoltaic panels on two of his buildings in Massachusetts, which are apartment buildings with 270 units. He did not notify the local utility company but instructed his electricians to wire the panels to permit excess energy to go back into the grid. Thus, net metering was born. Even when net metering became mainstream in the 90's, solar power was still more expensive than coal or natural gas, until a leasing system was developed. The system allows the building owner to lease panels, paying less and less to the electric company overtime, though the payoff still takes years and the initial cost is higher.

Solar Co-ops and other money saving financial structures are available for those wanting to use solar power but storing solar power and selling it back into the grid is still not widely supported by our current infrastructure, reducing its efficiency. Our current grid limits access to solar power. In 2012 when hurricane Sandy devastated the east coast, many were left without power for weeks. Those with solar panels were unable to access the energy they produced because they were locked into the grid. A change in this outdated structure could mean true energy independence with investment in the right infrastructure. Greater flexibility means more opportunities. Today some of America's top companies like Google, Apple, and Walmart are looking to capitalize on those opportunities, investing in solar power, proving it has become not only an environmental decision, but an economic one. IKEA who furnishes millions of homes has also begun to power them. They have embarked on a mission to sell solar power to millions of homes and are making great strides to reach that goal. Solar power is the next frontier for many corporations looking towards sustaining their growth in a changing energy market.

If economy and technology are not the issues, what is stopping us from opting to power our homes and cities with solar power as the default instead of the exception? The issue is systemic, not individual. Investing money into infrastructure that supports solar energy instead of clinging to the dated grid we currently use is one solution. What role does architecture play in incentivizing this change?



SOLAR CO-OPS IN THE UNITED STATES

TOP INVESTORS IN SOLAR POWER

1 WALMART
2 KOHL'S
3 COSTCO
4 APPLE
5 IKEA
6 MACY'S
7 JOHNSON & JOHNSON
8 TARGET
9 MCGRAW HILL
10 STAPLES

The worlds largest solar project cost $2.44 billion, but by 2020 it is projected that the cost of each solar watt will be less than a dollar

HOW DID WE GET HERE : SOLAR GENESIS

A BREIF HISTORY OF THE EMERGENCE OF SOLAR POWER IN ARCHITECTURE

1930

President Franklin Roosevelt signs into law the rural electrification act, effectively providing power to the entire nation, setting the infrastructure for our current grid

1939

Non PV solar collectors placed on house at MIT. Prior to the 1970's, most homes with solar panels were built by universities or researchers.

1949

First home heated entirely by solar. the Peabody house is the result of the collaboration of three women: Amelia Peabody, a sculptor, Maria Telkes, an engineer, and Elanor Raymond, an architect. the building was built without any backup heating, relying entirely on solar power. this was a great accomplishment for the time, especially for three professional women in 1949

1954

First Photovoltaic cell invented

1959

First solar house put up for sale

1964

NASA launches first solar powered satelitte into space, powered by a 470 watt photvoltaic array

1969

The Odelio solar furnace in France is constructed. This structure contains an 8 story tall parabolic solar array. It functions as a solar reflector and a producer of electricity.

1971

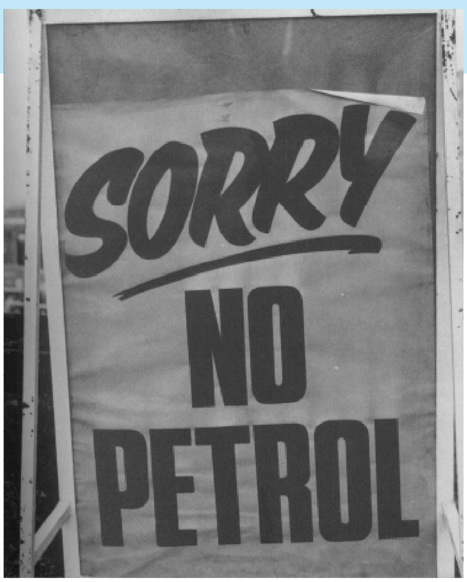
Steve Baer designs his “zomes” in New Mexico, using innovative strategies to create a Mars like solar powered dwelling in the desert

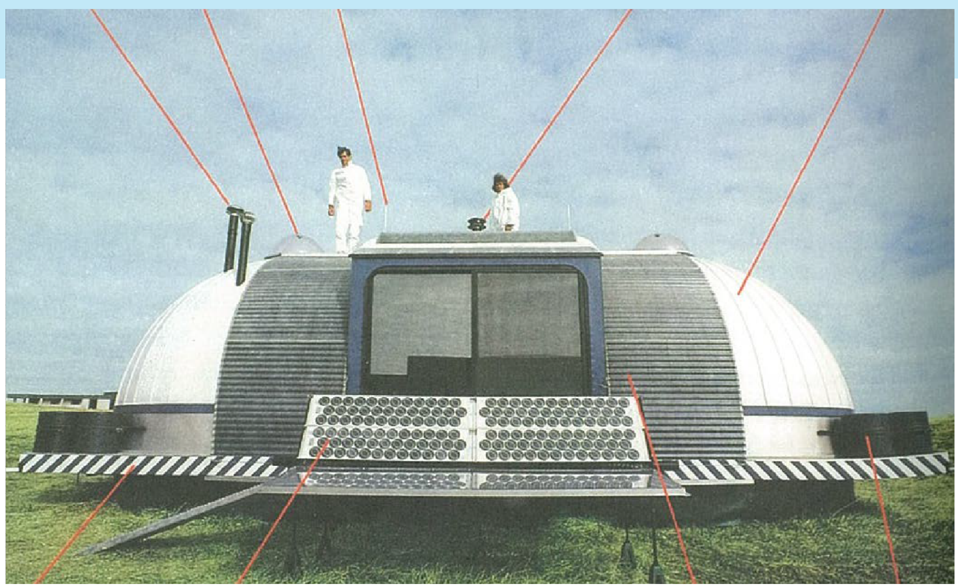
Net metering invented by “solar pioneer” Steven Strong. A young architect, strong places panels on the roof of an apartment building, wires them to put excess electricity back into the grid, and net metering as we know it today was born.

The second oil crisis hits. Spikes in solar power investment and research come typically in the wake of energy struggles

1973

1979





First oil crisis hits due to tensions in the Middle East and a susequent oil embargo on allies of Isreal

Michael and Ellen Jantzen design a solar mobile home influenced by aero-space design and the use of solar panels on satellites

1977

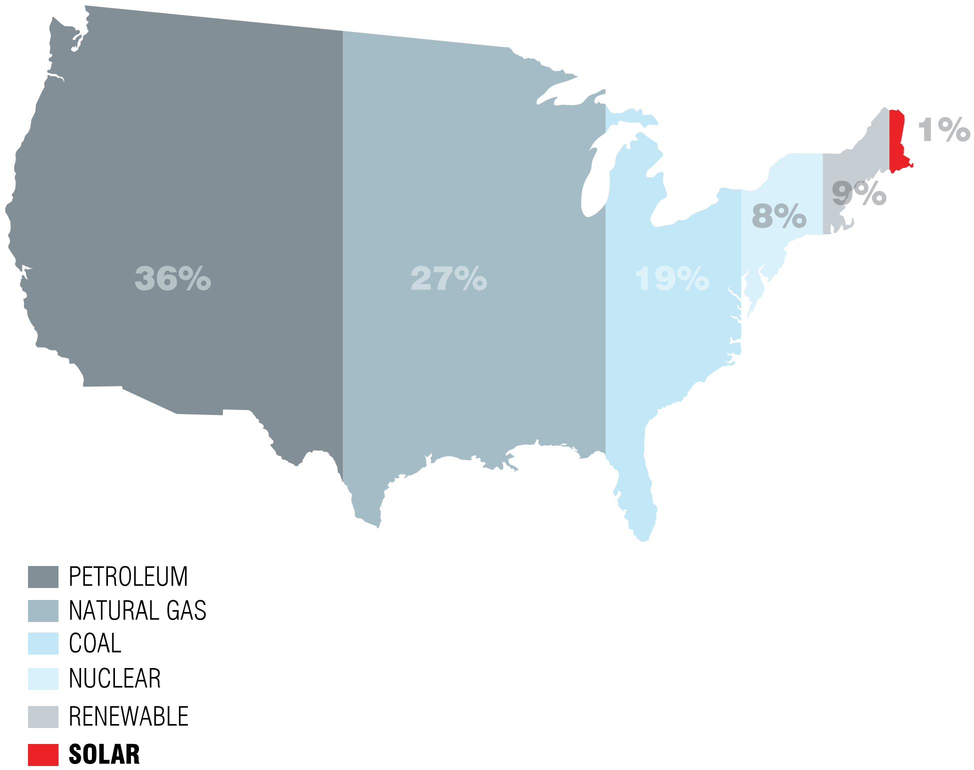
The DIY solar craze hits

CURRENT STATE OF SOLAR

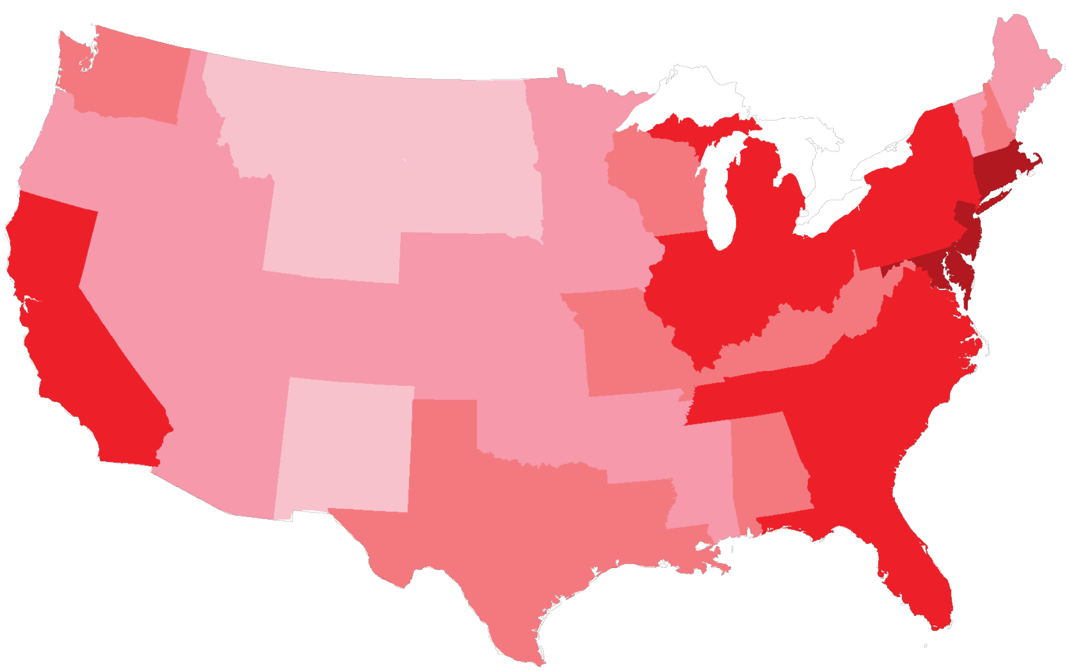
Many countries have already adopted renewable energy solutions for their cities. Germany has achieved a combined output between wind, solar, and other renewable forms of energy to produce up to 73% of their consumed energy. Energy prices for Germans and neighboring nations have plummeted because of the establishment of a more sustainable market, not dependent on foreign sources of fossil fuels that will eventually run dry. Their decentralized and diversified energy plan which includes solar, allows them to export energy to other European countries. In 2012, Germany accounted for one third of all solar capacity installed on the planet, indicating the impact one relatively small nation (surface area wise) can have. Previously a nation heavily reliant on fossil fuels, this change was sparked by the 1970's oil crisis as well as the Chernobyl disaster. It began as a grassroots effort with support from the local and federal governments, allowing communities to form their own renewable power plants. The communities had incentives to save energy that the companies concerned about profit did not. These plants brought, however, more jobs and profit to the communities than before. It was bottom up and top down cooperation. These plants have since grown to serve customers all over Germany. They initially were designed as a solar farm with a few wind turbines. Now they combine solar, wind, hydro, and combined heat and power (CHP) plants that use natural gas to supplement. Germany represents the best model of successful diversification. Solar power isn't the answer, but it certainly plays a major role.

The United States is one of the world's most energy intensive nations. Renewable energy only accounts for 14% of electricity produced in the United States. Our interest in solar power is growing, but not nearly as quickly as it should to be in competition globally. Oil, Coal, and Natural gas are our biggest energy sources, but each comes with its own hefty environmental drawback. Solar power will never replace these, up until the point that we run out of them, but it can certainly grow to match their contribution. If it cannot replace coal, can it at least reduce it to the point that mountaintop removal is no longer necessary? The question is worth asking. It is unwise to rely so heavily on fuel that is limited in supply without exploring opportunities for energy diversification. In most of the US, solar has reached an equal cost when compared to coal. However, the prior investment into the coal infrastructure makes it often the most convenient choice.

Politics also play a role; people in a coal state want to support their economy and so the lobby to keep coal from having to conform to standards that might cost the company money which might cost someone a job. That same lobby that fights against solar power subsidies was built on coal subsidies when coal was coming up as a major power player. Our free-ish market will correct that attitude eventually. Economic sustainability requires gradual change, with the old model slowly dying, making way for the better, newer model to emerge. Solar power in growing faster than coal would like, but its growth will benefit the consumer and the planet overall. Resistance to change is nothing new, which is why a new generation of architects must arise.

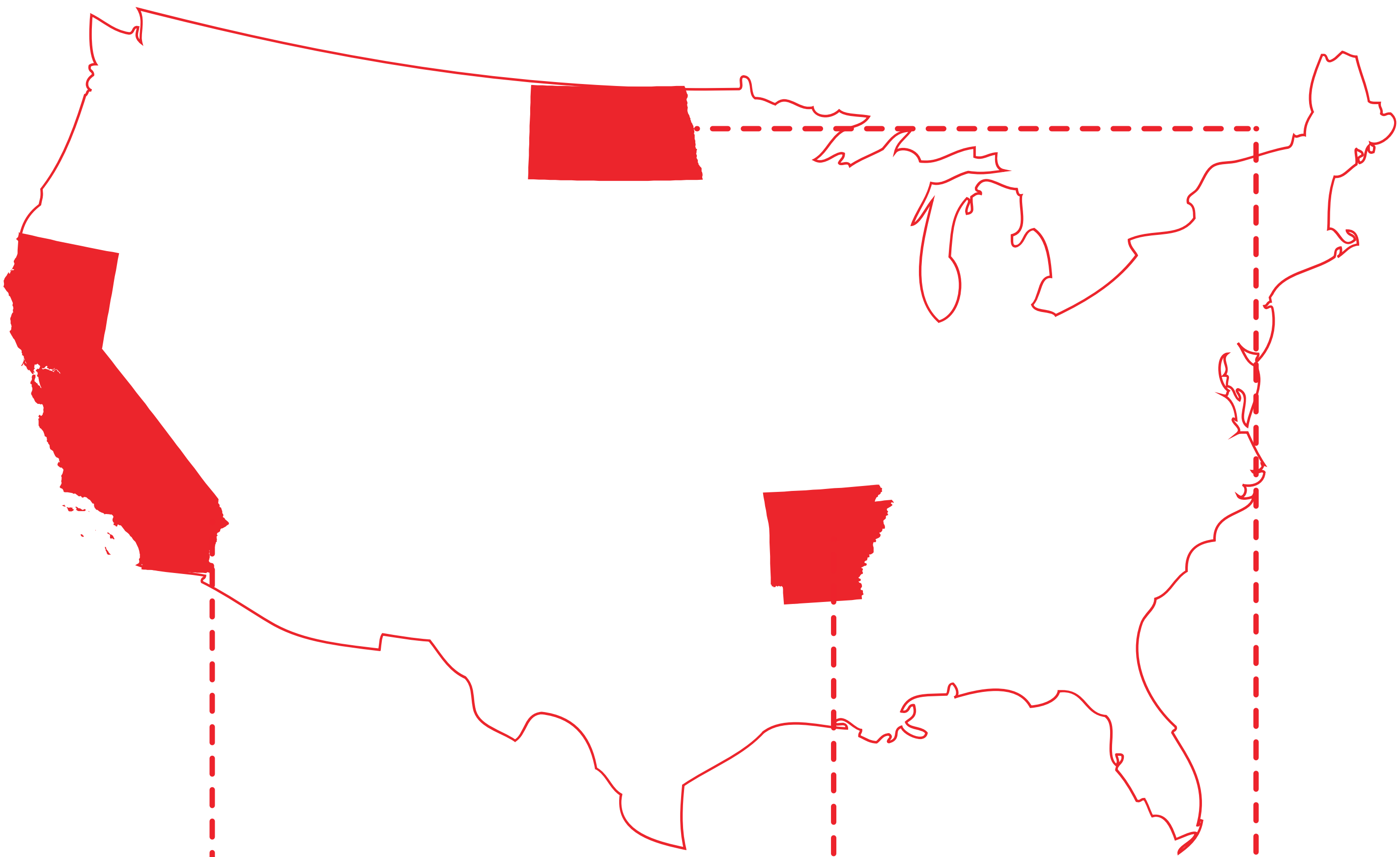


USA ENERGY USE



USA SOLAR PRODUCTION

The cost of solar in each state is effected less by solar potential and more by the cost of electricity, and incentives given by the state to increase the payback rate.



BEST

CALIFORNIA

NET COST: $10,192

MONTHLY SAVINGS: $143

TOTAL SAVINGS: $34,260

PAYBACK PERIOD: 9 years

BEST CASE STATES:

New York, Louisiana, Florida

MID

ARKANSAS

NET COST: $18,595

MONTHLY SAVINGS: $59

TOTAL SAVINGS: $14,076

PAYBACK PERIOD: 13 years

WORST

NORTH DAKOTA

NET COST: $23,015

MONTHLY SAVINGS: $36

TOTAL SAVINGS: $8,699

PAYBACK PERIOD: 19 years

WORST CASE STATES:

Kansas, South Dakota, West Virginia

SOLAR HARDWARE

SILICON PV PANEL

Standard photovoltaic panel made of silicon cells

15% conversion rate

Suitible for home useage

Inefficiency would require large scale solar farms

To power the earth would require 662,406 km2

THIN FILM PANEL

Cheaper and easier to use than silicon cells

19.2% conversion rate

Suitible for home useage

Perfect for lining rooftops or window glazing

To power the earth would require 517,504 km2

CONCENTRATED PV PANEL

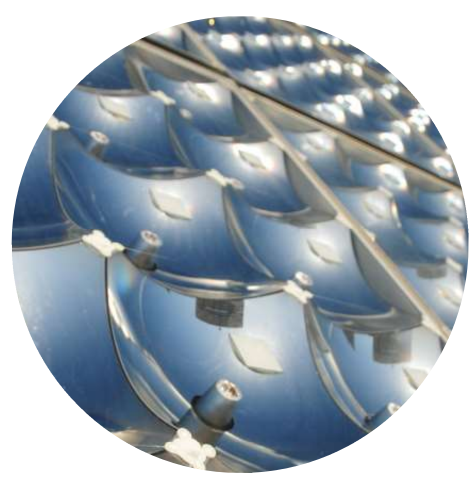
Uses optics to focus sunlight on PV cells

31.8% conversion rate

Too large for home useage

Requires induistrial sized farms in sunny locations

To power the earth would require 312,455 km2



PV GLASS

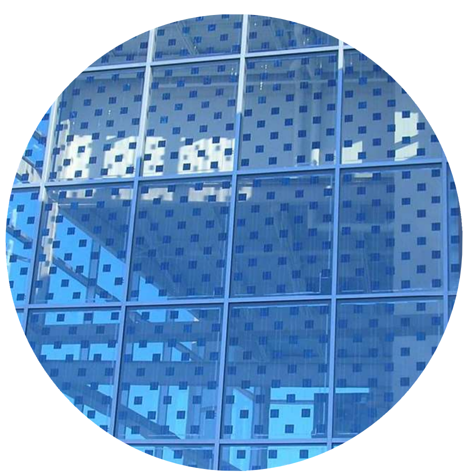
Transparent to translucent glass that incorporates transparent semiconductor photovoltaic cells between 2 sheets of glass

12 - 15% conversion rate

Suitiable for large scale buildings with large amounts of glazing, often used on fins

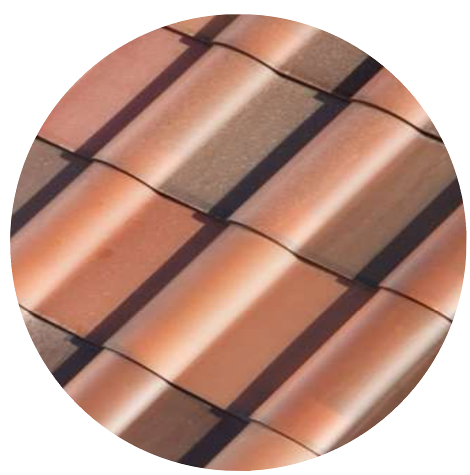
Available in variety of colors and transparency

A proposal from Steven Holl architects seeks to use colored PV glass trhoughout the entire facade of a building.



SOLAR SHINGLES

Not new to the market, but new advancements allow for them to appear to be normal shingles. Tesla is a major player in the solar shinlge game and are set to rellease their various versions onto the market soon



THE SOLAR ARCHITECT

How our homes are run is absolutely an issue for anyone who lives in one, but certainly for the architects who decide how we live in them. Frank Lloyd Wright is touted as the "Great American" architect, designing economical and exquisite homes across America. He dictated where its occupants would sit, how they would move, and occasionally what they would wear. Why would architects today think it beyond their level of responsibility to dictate how the occupants warm their homes and cool their fridge. It is not a new notion. In the AIA code of ethics that licensed architects are obligated to strive for sustainable building practices when possible. However, this single line in a legal document that architects read once and promptly forget, does not effectively promote sustainable practices. Conversely, when notable architects get into the solar game, solar power awareness increases as does its potential for application in architecture.

Within the architecture world, there is a stigma surrounding the integration of solar power into architecture. It is perceived as a noble thought, but an afterthought that negatively impacts the appearance of the building. This is an inherently false attitude, as many notable and architects have fully integrated photovoltaics into their designs successfully. The success is driven by the initial assumption that PV panels will be integrated from the very beginning of the design. Photovoltaics are rising in popularity as they decrease in cost. Steven Holl, a known "starchitect" has recently announced that his firm will be building the headquarters for Doctor's Without Borders in Geneva, clad entirely with colorful and beautiful photovoltaic glass. The seamless integration of photovoltaics is what architects everywhere should see as the new normal for solar power. However, Holl was certainly not the first to elevate photovoltaics.

Renzo Piano in collaboration with his structural engineer Guy Nordenson introduced photovoltaic cells onto the roof of the addition to the Kimbell Art Museum in Fort Worth, TX. Placed next to Kahn's masterpiece, the Piano addition rivals the original in its elegance and smart use of lighting, which is owed in part to the photovoltaic cells. The cells are located atop small louvers in the roof which would typically only reflect but here the cells absorb southern light which can be harmful to the artwork, but good for energy gain. The louvers are angled in such a way that allows northern sun in and lights the galleries almost exclusively through natural light, saving on energy. The discrete system would never be directly seen be museum patrons, but its effects are certainly noticed.

These examples by world renowned architects prove that integration of solar power can create elements that serve more than one purpose, both highly useful and aesthetically successful. To truly understand the capabilities of solar power in architecture, a diverse range of precedents must be analyzed.

A SOLAR ARCHITECTURE

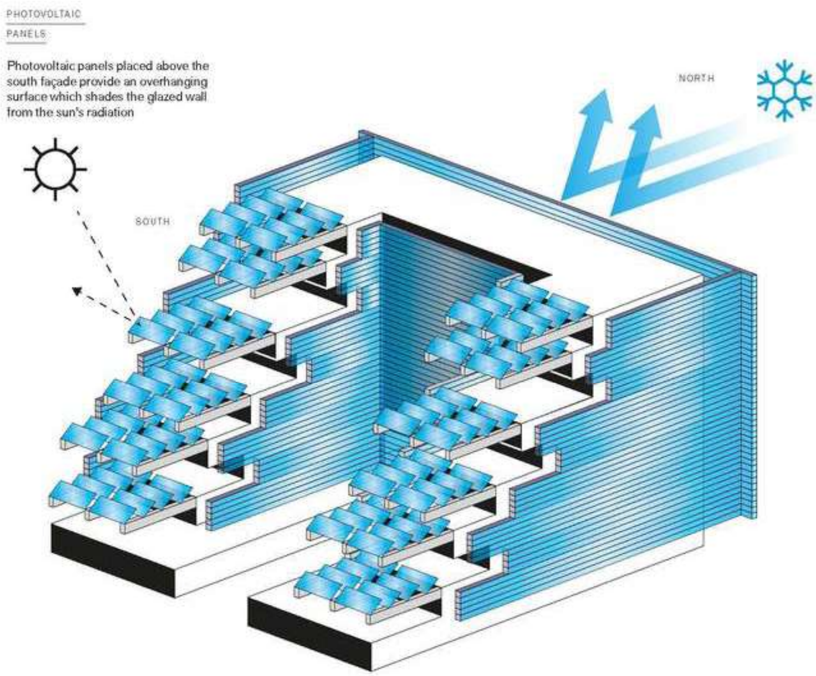
SINO ITALIAN ECOLOGICAL + ENERGY EFFICIENT BUILDING

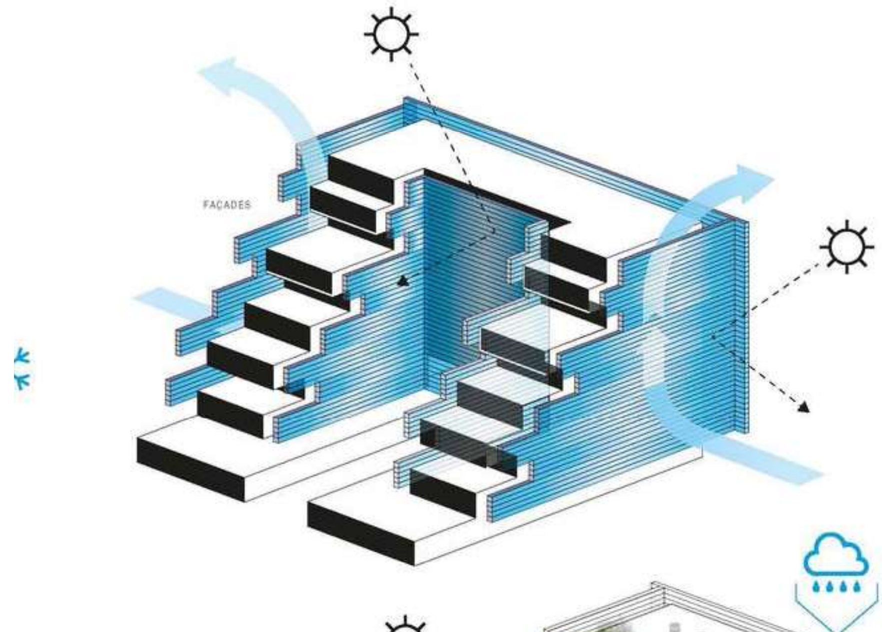
Mario Cucinella Architects
Beijing, China / 2006

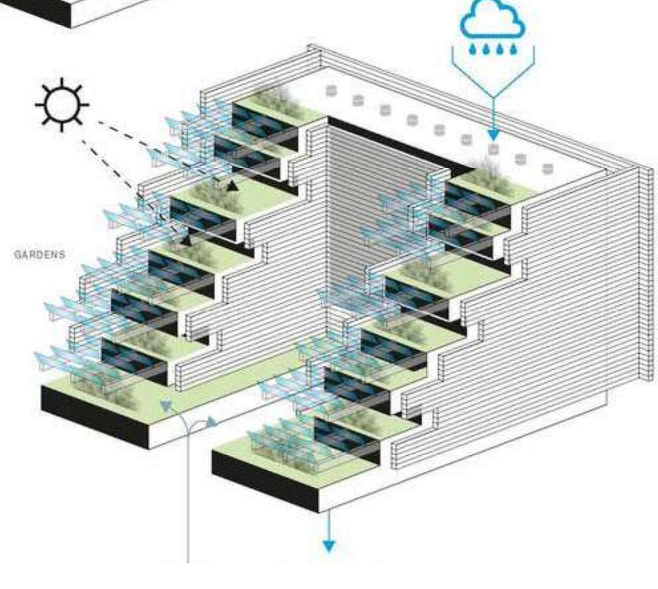
A collaboration between the Italian and Chinese governments, this center was designed to facilitate research and enviromental protection efforts. Energy conservation is key in the daily operation of the building and a priority for the program housed within it. It is meant to be an example for the potential of architectcture to play a role in reducing CO2 emmissions in China. The building utilizes both passive and active strategies to create a hospitible internal environment.

The building uses typical passive strategies to reduce unwanted heat gain and loss. The north facade is closed off to protect from cold winds while the southern face is open and heavily glazed to allow for daylight and appropriate heat gain. the east and west both have double glazing systems with horizontal louvers for shading. The building wraps around a courtyard which contains moving glass louvers with a reflective coating to deflect unwanted solar gain from entering the building. This building uses advanced passive systems on its facades but where this project sets itself apart is in the combination of the pasive and active systems. On the upper levels along the south, horizontal shading elements keep the interior cool and shade terraced gardens while discretely housing 1000 + square meters of solar panels. The energy produced from these panels powers the heating and cooling needed for the interior when the passive systems are not enough.

In addition to the solar panels, the architects opted fro a highly efficient heating and cooling system which uses recaptured heat and absorption chillers. The system is controlled through sensors to minimize use of the system in unused rooms. These systems reduce the building's potential carbon footprint by 58% when compared to using typical systems.


PHOTOVOLTAIC
PANELS
Photovoltaic panels placed above the south façade provide an overhanging surface which shades the glazed wall from the sun's radiation
NORTH
SOUTH


FAÇADES


GARDENS

SOLARSEIDLUNG AM SCHLIERBERG

Rolf Disch Architects
Freiburg, Germany / 2007

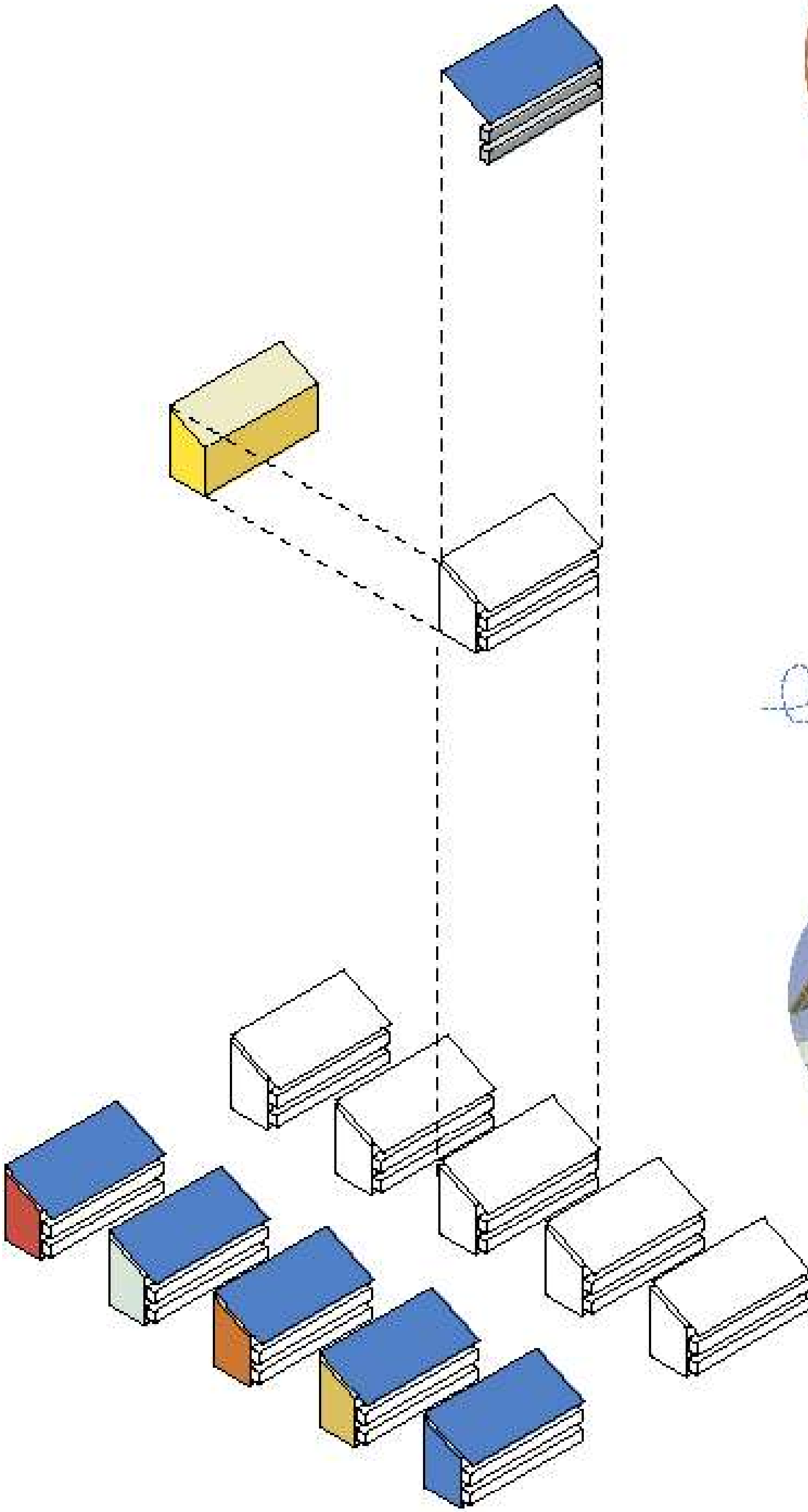
This housing project makes use of a simple but custom roofing system that integrates the solar panels beyond a typical solar roof system. The solar panels sit upon a frame that extends beyond the edge of the roof that simultaneously shades the balconies from direct solar gain and absorbs that energy to produce power for the building. Lifting the panels up to allow air flow underneath also increases their efficiency. The system also incorporates drainage for the roof. The framing system continues down the wall of the building to support the balcony system for the residential units. These buildings also incorporate the colors of the panels into the scheme to create a more cohesive design that prevents the panels from looking like an afterthought.

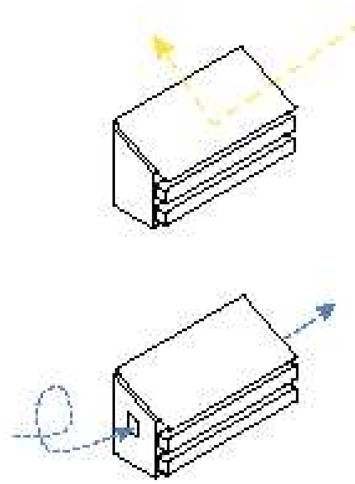
Passive Solar Strategies:
Direct solar gain / daylighting / operable windows /
cross ventilation / east west orientation

Active solar strategies:
Photovoltaic panels / solar hot water thermal system

High performance strategies:
high performance building enevelope, triple glazing, heat recovery from facade integraated ventilation components, high performance ventilation system, energy efficient appliances and lightting systems, neighboorhood woodchip heat and power plant

Total annual building consumption:
3.2 - 6.3 kBtu/ sq ft
Size of PV system: 455 kW





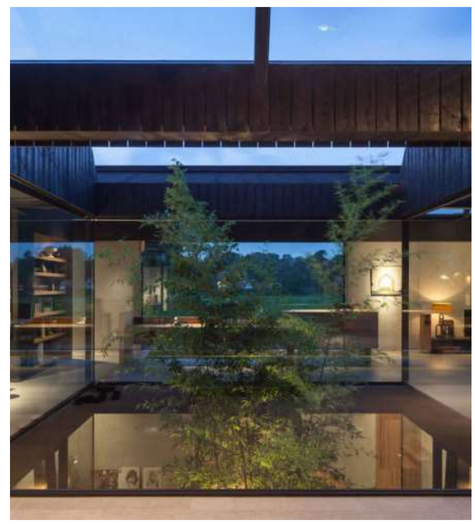
Paul de Ruiter Architects
Schoorl, Netherlands / 2016

Passive Solar Strategies:
Direct solar gain / daylighting / operable windows /
east west orientation

Active solar strategies:
Photovoltaic panels

Villa Schoorl is located in the North Holland Dunes. The landscape served as the main inspiriation for the design. The villa took into consideration not only its landscape, but ecologically consious materials and building strategies as well. Villa Schoorl is surrounded by typical homes with pitched rooves , farhouses, windong roads and mills. The form is a play on the typical homes of the area, but with a clearly different set of contemporary values. Most of the villa is actually buried to keep its impact on the scenery to a minimum. In keeping with that unobtrusive attitude, the solar panels palaced on the roof are placed so as to be barely noticed. The overall strategy for placing the panels is not unusual. The panels are placed on the southern slope at the angle most effcient for its lattitude. What makes this building's solar integration exceptional is the detailing that makes all the difference. Instead of solar panels slapped onto a roof, they are set into a recessed spcae designed specifically for their dimensions so that the simply becom the surface of the roof. In order to maximze the power produced and minimize the visual effect, the architect broke the roof up into three identicalsections which conceal eachothers panels. Instead of seeing one long slope covered in panels, you see one small slope, and even then it is not obvious that the panels are anything but the roof itself.

The power produced serves to heat the home as well as provide electricity for appliances and lighting. The home also incorporates passive strategies trhough shading elements. The west facade has vertical folding elements to mitigate unwanted sunlight. On the southern side og the home, a covered terrace is created with the overhang of the shed roof that also holds the solar panels. The brilliance of Villa Schoorl is that it implements the same system as most homes that add solar panels years after initial construction, but careful detailing elevates the simple system. That attention is what prevents the panels from detracting from the architecture.

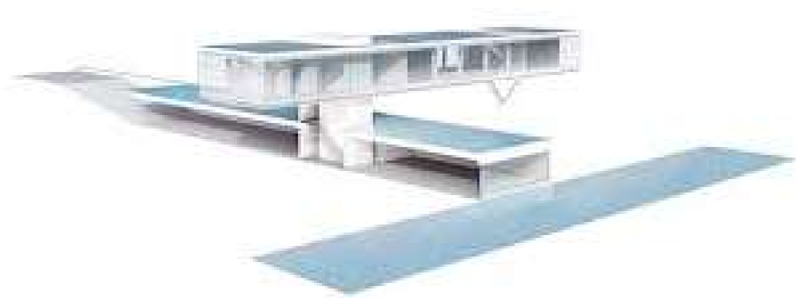


Paul de Ruiter Architects
Kamperland, Netherlands / 2009

Passive Solar Strategies:
Direct solar gain / daylighting / operable windows /
east west orientation
Insulated glass

Active solar strategies:

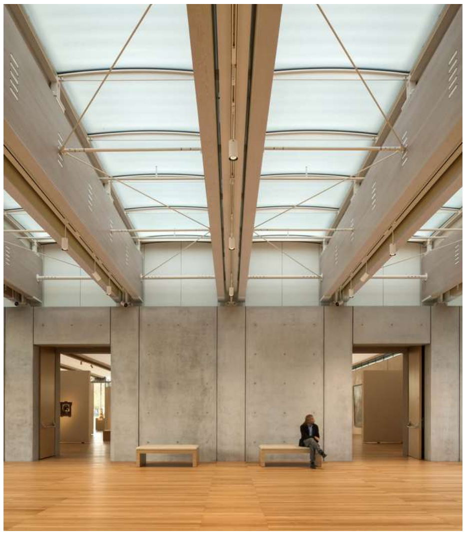
Light activated moving screens
Photovoltaic panels
Wind energy on site



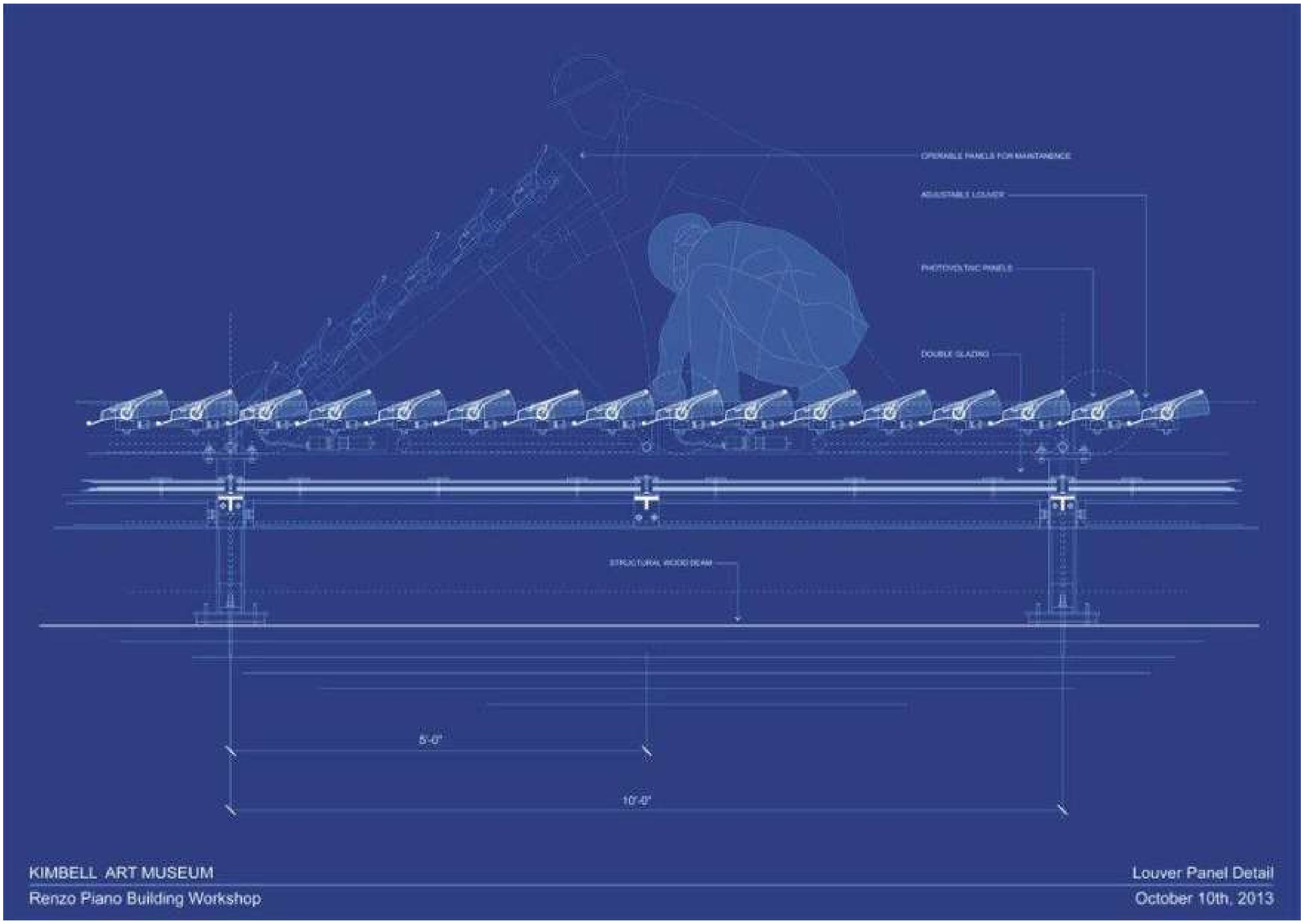
Villa Kogelhof is a perfect example of solar power playing a small but essential role ion a larger system. While normally you would see these many elements at the scale of a city, here energy production is diversified even at the scale of a home. The home is built on an estate managed by the government as a part of a program to connect ecological zones. It is in a protected habitat for plants and wild life and part of the requirements of building on the site is to return it to its original forested state. In keeping with the mission of the land its is built on, the architects designed the home to be self-sufficient, producing its own energy while creating views onto the natural landscape it seeks to preserve. The façade is made entirely of glass to facilitate views, but it also contains an important function. It is considered a “climate façade” comprised of an outer layer of floor to ceiling insulated glass and an inner layer of sun reflecting fabric that can be raised and lowered depending on the movement of the sun. This allows for a Miesian façade without the major energy loss typically associated with that type of system. The photovoltaic panels placed on the flat roof are not visible due to the height of the parapet and they produce a large chunk of the building’s electricity. The rest is supplemented by a windmill built on site. This project uses a typical PV panel system in combination with wind energy and passive systems to create an off the grid masterpiece.

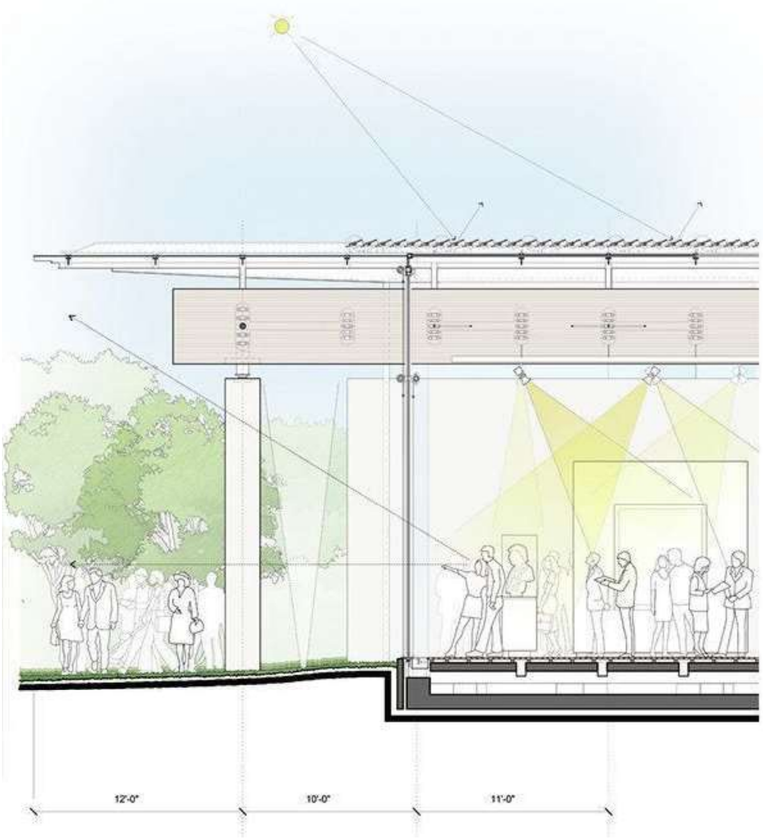
KIMBELL ART MUSEUM ADDITION

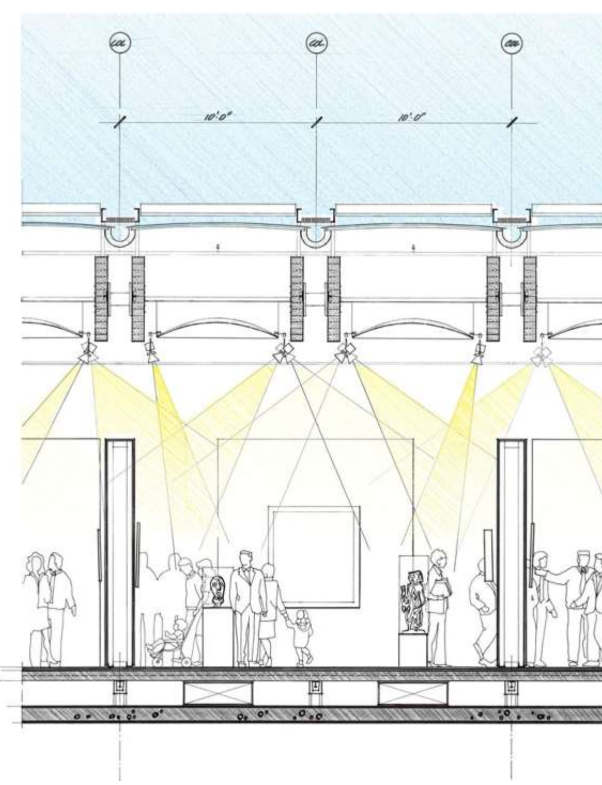
Renzo Piano Building Workshop
Fort Worth, TX / 2013



Anyone to even attend architecture school has no doubt heard of the Kimbell Art museum, architect Louis Kahn's masterpiece. It was completed in 1972 and is still regarded as a masterclass in structural simplicity and daylighting a museum environment. The building has no doubt contributed to the success of the museum and as the collection has grown, they were in need of more space. That need gifted us Renzo Piano's contemporary Kimbell. The new building references Kahn's in many ways, the most impactful being the zenithal light. Piano uses a sophisticated roof system that silmutaneously filters light into the gallery and collects energy through photovoltaic cells. The beauty if this system is that without seeing an aerial view or detail section, a visitor to the museum would be entirly ignorant to the fact that this museum has solar panels on the roof. The discrete system uses aluminum louers to prevent harsh southern light form damaging the art, while allowing northern light to filter through a translucent scrim below that hides the acrobatics of the the roof system. The southern light that is deflected is actually absorbed through photovoltaic cells on top of the louvers. A highly engineered roof structure that also brings in light echoes ideas of the original museum, but updated with solar power technology. The PV cells produce energy which goes towards powering the lighting in the galleries.

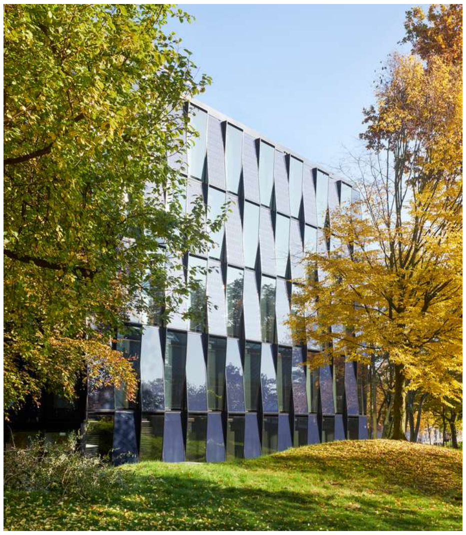

5'-0"
10'-0"
KIMBELL ART MUSEUM
Renzo Piano Building Workshop
Louver Panel Detail
October 10th, 2013


12'-0"
10'-0"
11'-0"


10'-0"
10'-0"

THE BLAUHAUS

Kadawittfeldarchitektur
Mönchengladbach, Germany / 2015

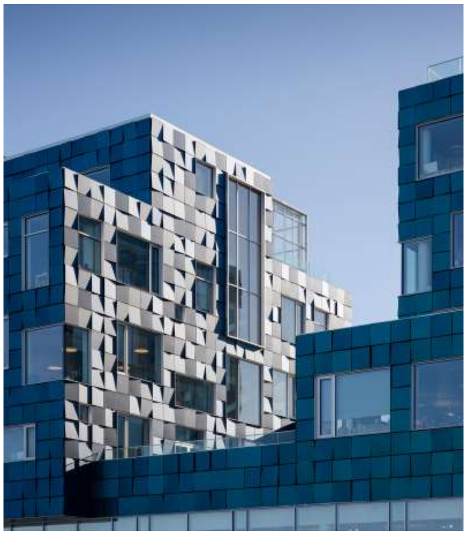


The new building on the campus of Hochschule Niederrhein in Monchengladbach is a collaboration between the energy and water company and the university to create an energy efficient center on campus. It is meant to highlight the latest technology in solar energy through its sculptural façade, imbedded with photovoltaic cells. The façade is made of panels with opposing incline made of a blue tinted glass and PV cells. The angles of tilt were designed specifically for the building's orientation and location to properly absorb and deflect solar radiation where desired. The system is so fine-tuned that it has been classified as a zero emissions building. The pv panels exist within a rigid frame but can be rotated depending on the shifting solar angle to maximize energy production. The building functions as a symbol of energy efficient design, as well as housing room for the energy center and the "Innovvatorium," an energy laboratory for students and faculty. As in the Copenhagen International School, the level of integration goes beyond the physical and becomes a part of the educational process as well. It pormotes solar power integration in architecture an encourages students to see what is possible through collaboration and innovation.

COPENHAGEN INTERNATIONAL SCHOOL

C.F. Møller
Copenhagen, Denmark / 2017

11



The new building for the Copenhagen International School has acheived many goals beyond serving the basic classroom needs.It aims to connect the existing campus to the urban surroundings while creating an inviting aura. Its location on the water creates a waterfront public space that can engage the students as well as the people of Copenhagen through events and activities.
The building itself is divided into four towers, each catering to specific age groups. For example, the youngest group has larger rooms with more functions to facilitate more free play. The towers also serve as visual markers, helping students and parents find their way to the correct place. The towers are connected through a base that houses their common program: the lobby, cafeteria, gym, and auditorium. These common spaces are open for school and community events. The playground is located on the roof of the base, also accessible to all four towers so children at different stages can all intermingle while containing the younger kids for safety.

The school's façade is covered in 12,000 solar panels. Each of the panels is angles to create "a sequin -like effect." The panels produce over half of the energy supply for the school. The solar cells cover 65,100 square feet of the façade. This makes the Copenhagen school the largest "building integrated solar power plants" in Denmark. It produces so much energy it is no longer classified as a building with solar panels, but as a solar power plant. The estimated production is over 200 MVh per year. The solar cells not only produce power for the school, but they play a significant role in the classroom. The students monitor energy production and use the data from the panels in their math and physics classes. The solar system is not only integrated physically, but socially as well

Active solar strategies:

Photovoltaic panels

High performance strategies:

Total annual building consumption:

Size of PV system: 65,100 sq ft

THE FURTHER EDUCATION CENTER AT MONT CENIS

Hegger Hegger Schlieff
Herne, Germany/ 1999

This building has two main layers. The outer layer is the climate layer made of single glazing and photovoltaic cells on the roof. It has 9,180 m2 of solar modules that produce a total output of 1 MWp, one of the largest BIPV systems in the world. The energy produced is fed into the grid as well as providing for the needs of the project itself. The cells are modulated in such a way that they shade and allow light in to a specific degree so that additional shading is not necessary. The architect argued for the inclusion of photovoltaics when discussing the shading options. When the client realized how much energy could be produced, they were on board. The outer shell creates a Mediterranean like climate. Its structure is a heavy timber framing system, filled with glass to allow for plenty of natural light and the greenhouse effect that creates the microclimate. The outer shell is constructed of recycled material, adding to its ecofriendly agenda. The interior "layer" is actually a series of individual buildings, but built without protection from the environment, as the outer layer does that job. The circulation for the buildings exists between the buildings and the climate shell. Under the shell, there are education centers, municipal facilities, and public space.

Active solar strategies:

Photovoltaic panels

Photovoltaic glass

Technische Universitat Darmstadt, Germany/ 2015

This project was designed for the Solar Decathlon in Washington, DC. The US Department of Energy sponsors the competition which calls for universities from around the world to design dwellings powered by the sun. This project was one of 20 in a “solar village” from a team based in Darmstadt, Germany. This home incorporates solar technology in the façade and on the roof as well. The outer envelope is shuttered with photovoltaic cells on each louver. The louvers rotate to allow in light and adjust automatically for the angle of the sun. The photovoltaic shutters wrap the east, south, and west faces. Designed with simulation software, the louvers operate at maximum efficiency, proving the value of digital technology in the solar age. While the shutters produce a lot of energy, the majority comes from the roof. The roof integrates PV by sandwiching semi transparent PV cells between two layers of glass to create skylights that produce energy and provide daylighting. There are also high efficiency monocrystalline silicon PV modules on the solid part of the roof. Unlike typical solar roofs, this house does not slope. The intent was to prove that solar doesn’t necessarily have to change the architectural form. By introducing the cells to a flat roof, only 8% efficiency is lost from that of a southern sloping roof. There are 3 types of PV systems as well as a solar hot water collector integrated into the design. Aside from the PV elements, the house is designed to function as a passive solar house. The shutters serve to control daylight and heat gain as well as creating a thermal buffer between the inner layer of the home that the envelope. The shutters in combination with sliding glass wall of the interior provide for passive ventilation as well.

Passive Solar Strategies:

direct solar gain
daylighting
sunshading
ventialtion

Active solar strategies:

Photovoltaic panels
Photovoltaic glass
solar hot water thermal system

Total annual building consumption:
15 kWh/m2

THE SOLAR SUCCESS

Solar power is nothing new. So why hasn't architecture caught up? Considering the current concern for climate change and building healthy environments responsibly, it just might. A new awareness of our environment and an ever-shrinking financial gap between solar and other energy sources is leading the second solar revolution. The monetary barriers are fading, the technological barriers are gone, and it has been proven that solar power can be beautifully and seamlessly integrated into an architectural design. So what is left? The stigma of a clunky solar roof is no more. Architects of the highest caliber are pushing the limits of what solar material can do for their building and for the environment. So what creates a successful solar powered architecture? When considered from the genesis of the project, full integration is possible. This attention is necessary from the architect to convince clients that this is a worthy investment. Numerous successful strategies have been described and they all have one thing in common, they don't use just one strategy. True integration combined architectural principles of proportion and scale with passive solar strategies and finally the active system: photovoltaics. Best practices include considering all the principles passed down from the passive masters of Frank Lloyd Wright and Buckminster Fuller and yet knowing that the active systems will play a role. Whether the intent is to hide the panels in plain sight, conceal them, or glorify them, each strategy can produce a beautiful building when it is fully committed to. Designing beyond the panels mounted on top of a sloped roof cannot only increase the effectiveness of the design but can enhance the overall architecture. Architecture that runs from the realities of our changing environment will fade away in time. Embracing the current state can only provide for longevity of the architecture, and the planet the building occupies. Designing for solar is also designing for humans. Studies have shown that creating healthy beautiful environments only increases productivity and overall wellbeing. An increase in solar means a decrease in coal, petroleum, natural gas, and even nuclear. All sources of power that ultimately corrupt and pollute our environments. Solar may not be THE solution to the world's growing energy problem, but it is a solution. Through diversification and integration, solar can play a major role in how we run or world, and that can be embedded directly into our buildings in a beautiful way.

Sources

ArchDaily . Accessed April, 18. https://www.archdaily.com/879152/copenhagen-international-school-nordhavn-cf-moller

ArchDaily . Accessed April, 18. https://www.archdaily.com/880371/sino-italian-ecological-and-energy-efficient-building-mario-cucinella-architects

Borasi, Giovanna, Mirko Zardini, Adam Bobbette, and Harriet Russell. *Sorry, out of Gas: Architecture's Response to the 1973 Oil Crisis.* Montréal: Canadian Centre for Architecture, 2007.

Guidelines for Making Solar Claims. May, 18. https://www.epa.gov/sites/production/files/2017-09/documents/gpp-guidelines-for-making-solar-claims.pdf

Guzowski, Mary. *Towards Zero-energy Architecture: New Solar Design*. London: Laurence King, 2012.

Hegger Hegger Schliff Architeckten. Accessed April 11, 2018. https://www.hhs.ag/projekte-kultur-further-education-center-mont-cenis.en.html.

Johns, Howard. *Energy revolution: Your Guide to Repowering the Energy System*. Hampshire: Permanent Publications, 2015.

McGrath, Jenny*. Germany's Blauhaus doesn't hide its solar panels, it flaunts them.* Digital Trends. https://www.digitaltrends.com/home/zero-emission-blauhaus-solar-panel/

Moe, Kiel. *Convergence: An Architectural Agenda For Energy*. London: Routledge, Taylor & Francis Group., 2013.

Paul De Ruiter Architects. Accessed May 12, 2018. https://www.paulderuiter.nl/en/.

Renzo Piano Building Workshop. Accessed February/March, 18. http://www.rpbw.com/project/kimbell-art-museum-expansion.

Solar Nation. Accessed April, 18. http://www.solar-nation.org/can-i-earn-money-with-my-solar-power-System

Guidelines for Making Solar Claims. May, 18. https://www.epa.gov/sites/production/files/2017-09/documents/gpp-guidelines-for-making-solar-claims.pdf