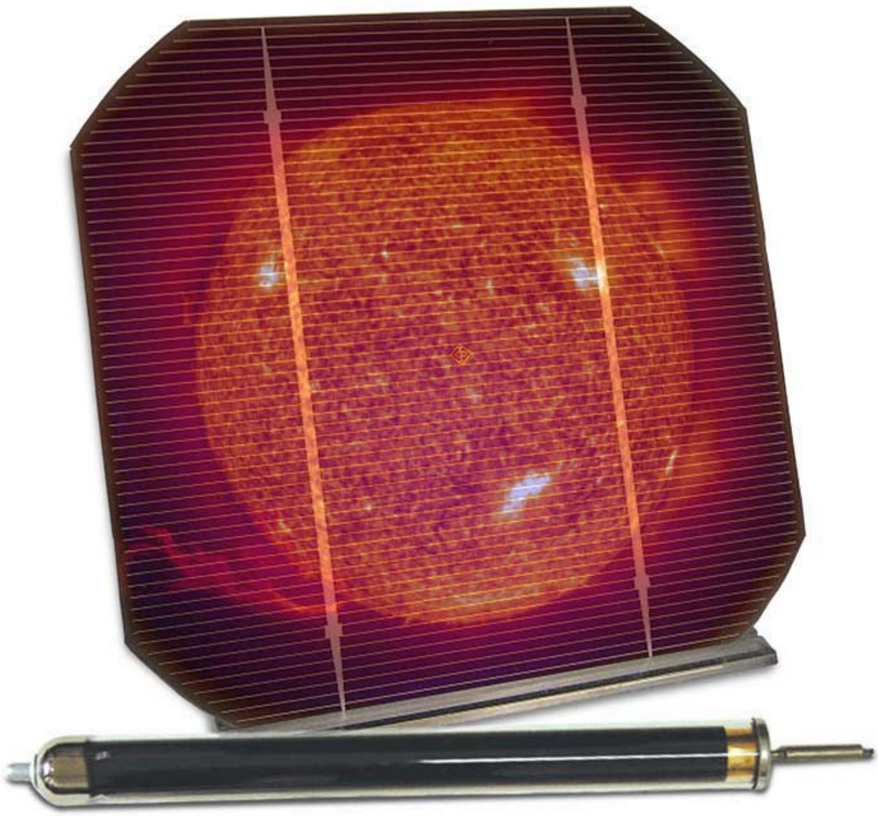
SOLAR ENERGY – POWER FOR A NEW AGE

An Analysis of the Integration of Photovoltaic and Thermal Solar Systems in Buildings



Holger de Groot

2008

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An Analysis of the Integration of Photovoltaic and Thermal Solar Systems in Buildings

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“[…] the crisis of ecological scarcity can be viewed as primarily a moral crisis in which the ugliness and destruction outside us in our environment simply mirrors the spiritual wasteland within; the sickness of the earth reflects the sickness in the soul of modern industrial man, whose life is given over to gain, to the disease of endless getting and spending that can never satisfy his deeper aspirations and must eventually end in cultural, spiritual and physical death."

W. Ophuls in Architectural Ecology and the Politics of Scarcity [1]

[1] Stephen Rainbow, *Critical Issues in New Zealand Society*. Auckland, New Zealand: Oxford University Press, 1993, p.21.

ABSTRACT

The aim of this research report is to examine and to indicate the need of a rethinking in architectural design and building construction in terms of the basic principles of solar radiation and to introduce solar technologies as design elements. It explores passive solar design issues as future-proof solutions to provide thermal efficiency in buildings and proves that active solar energy is a significant factor to reduce carbon emissions. This research paper is focused on thermal solar and photovoltaic (PV) technologies. The paper illustrates the different types of solar collectors, such as the flat plate collector and the vacuum tube collector, and shows that building-integrated photovoltaic (BiPV) technology is rapidly evolving and is becoming a significant part of building design.

As Randall Thomas argues, the 21st century will be the age of solar energy, such as the 20th century was the age of oil. [1] In context to this thought, this research report considers that the integration of thermal solar collectors and PV-modules in architectural design becomes an important factor to design future-proof buildings. It examines concepts to integrate these systems into a building envelope as well as into a new sustainable project. In this context, the report examines different examples of sustainable buildings in New Zealand. These prove through their energy consumption that sustainable design and the introduction of PV-systems and thermal solar collectors are offering considerable benefits in terms of the energy yield to the building and its occupants. However, the research report indicates that the goal is the full integration of PV-modules and thermal solar collectors into the architectural design and construction process and shows that active solar systems must be used as design elements and not only as a technological bonus.

Overall, this research report considers that some architects are starting to realise their responsibility. They become interested in sustainable design to ensure that new buildings are designed and built with new standards of sustainability to reduce the amount of carbon dioxide emissions and the consumption of energy. However, it especially shows that solar systems are still not realised as design elements in sustainable architecture by New Zealand's leading architects. Furthermore, the paper assumes that the built examples can be a significant possibility to move forward the development of building-integrated solar systems, which helps to reduce the consumption of energy and to achieve a significant carbon dioxide reduction in New Zealand's architecture.

[1] Randall, Thomas (ed). Max Fordham and Partners (ed). *Photovoltaics and Architecture*. London, New York: Spon Press, 2001.

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ABBREVIATIONS

a	Year
APES	Action Programme Energy Saving
a-Si	Amorphous Silicon Cell
BiPV	Building-integrated Photovoltaic
BMS	Building Management System
BRANZ	Building Research Association of New Zealand
°C	Celsius
CFC	Chlorofluorocarbon
CIS	Copper Indium Diselenide Cell
CO_2	Carbon Dioxide
CO4	Methane
DHW	Domestic Hot Water
EAC	Ecological Awareness Center
ECN	Energy Research Foundation
ECNZ	Electricity Corporation of New Zealand
EnEv	German Energy Saving Ordinance (Energieeinsparverordnung)
EST	Energy Saving Trust
GHG	Greenhouse Gas
GtC	Gigatonne of Carbon
H	Harvest Factor
h	Hours
HERO	Home Energy Rating Options
HFC	Hydrofluorocarbon
HSC	Health Sponsorship Council
HVAC	Heating, Ventilation and Air Conditioning
IPCC	Intergovernmental Panel on Climate Change
ISE	Institute for Solar Energy Systems
K	Kelvin
kW	Kilowatt
LCA	Life Cycle Assessment
LGBG	Laser Grooved Buried Grid

Low E	Low-Emissivity
N2O	Nitrous Oxide
NABERS	National Australian Buildings Environmental Rating System
NIWA	New Zealand National Institute of Water & Atmospheric Research
Nm	Nanometre
NZBC	New Zealand Building Code
NZGBC	New Zealand Green Building Council
m	Metre
m-Si	Mono-Crystalline Silicon Cell
Metservice	New Zealand's National Meteorological Service
O3	Tropospheric Ozone
OpTIC centre	Opto-electronics Technology and Incubation Centre
PFC	Perfluorocarbon
pc-Si	Poly-Crystalline Silicon Cell
PV	Photovoltaic
R-value	Thermal Conductivity
SBN	Swedish Construction Standard (Svensk Byggnorm)
SF_6	Sulphur Hexafluoride
SOLARCH	Solar Architecture Research
TLA	Territorial Local Authorities
UN	United Nations
UNCED	United Nations Environment Programme
UNEP	United Nations Conference on Environment and Development
UNFCCC	United Nations Framework Convention on Climate Change
U-value	Thermal Transmittance Value
UV	Ultraviolet Sunlight
UVI	Ultraviolet Index
VRV	Variable Refrigerant Volume
W	Watt
WCC	Wellington City Council
Wp	Watt peak
WSchVO	German Heat Protection Regulation (Wärmeschutzverordnung)

INTRODUCTION

A particular interest in renewable energy resources and technologies has inspired the research in the integration of solar thermal generators (collectors) and photovoltaic (PV) modules (solar modules) into architectural design.

In order to meet the problem of the global warming effect that is becoming the biggest challenge of the 21st century, it will be necessary to dramatically reduce the emissions of heat trapping gases. For example, in Europe, buildings are responsible for about 47 per cent of the total carbon dioxide (CO_2) emissions today. [1] In order to meet this problem it must be asked how sustainable technologies can be integrated into an architectural concept to reduce the CO_2 emissions of buildings. This new kind of architectural concept and design is an indicator in the development towards becoming a sustainable society.

This paper explores the integration of solar energy systems into New Zealand's architectural design, in order to reduce the CO_2 emissions of buildings. During the last years, the integration of solar technologies in buildings increased and led to a new kind of architecture in Europe. This research paper fills a gap of information between the integration of solar energy systems and a new architectural design in New Zealand.

The scope of this research paper is to consider how thermal solar collectors and photovoltaic modules can be involved aesthetically into an architectural concept. In this context, the research report considers the basics of thermal solar technologies and PV-systems which are already on the market. It also explores recent developments and new methods of integration into a new building design and considers the possibilities of collectors and PV elements.

Furthermore, the paper explores different concepts and applications and presents built examples to explain how solar systems have been installed already. The focus is to review existing design and construction methods to present how solar collectors and photovoltaic elements can be seamlessly integrated into the design of a new building. This possibility in terms of the design imposes a higher responsibility on everybody who is involved in the design and construction process of a new building - especially on the architect and the builder. It shows that these technologies are becoming increasingly significant in the

[1] Smith, Peter F. *Architecture in a Climate*, Oxford, Architectural Press, 2005, p.XIII.

architectural design process and are already a part in the contribution towards the transition to renewable sources. [2]

Research for this paper has been primarily literary, using books and journal articles which are held at the library of the University of Auckland. Secondary online media sources have also been successful, as have personal discussions with architects in New Zealand and Germany. Referencing is done by using the "Vancouver Method" (also known as the "Sequential Numbering Method"). The research paper itself is presented in three parts. Part one comprises relevant background material and a literature review; Part two explores active and passive solar design and analysis different photovoltaic and thermal solar technologies; Part three presents the results of this research paper and an overall conclusion.

Part one comprises two chapters: chapter one looks at the environmental conditions and explores architectural design in terms of the integration of renewable energies. Chapter two contains an introduction of sustainable architecture and encompasses a critical literature review.

Part two of the research paper has four chapters. Chapter three explores the principles of passive and active solar design, as well as the common problems and technical limitations in solar design. Chapter four explores thermal solar technology. It also looks at the technical features, limitations and built examples, as well as recent developments. The PV-technology is subject of chapter five. It indicates technical features, limitations and built examples, as well as recent developments. The last chapter in part two, chapter six, examines four case study projects to identify the current problems of building-integrated solar systems in New Zealand's sustainable architecture and explores the level of integrated active solar systems.

Part three contains chapter seven that considers the results and outcomes of this research report. It presents a proposal, which suggests that a new kind of architectural design will be the next step in New Zealand's sustainable development. This guarantees a wider usage of thermal solar and photovoltaic technologies in a high quality of integration. Overall, the architectural integration of these solar technologies becomes a significant part and moves towards the reduction of carbon emissions in building design.

[2] Prasad, Deo. (ed.) Snow, Mark. (ed.) *Designing with Solar Power – a source book for building integrated photovoltaics (BiPV)*, Lodon, Sterling, VA, Earthscan, 2005, p.9.

1. SOLAR ENERGY

Before this paper examines solar technologies, it explores natural sunlight and the basic principles of solar radiation in relation to the New Zealand climate. This chapter illustrates that the introduction of solar technology in buildings can reduce carbon emissions and explores the major rule of carbon as a key element to warm up the earth to support the genesis of life in form of the carbon cycle. It shows that since the human beings started to use fossil fuels and to destroy vegetation, this cycle is out of balance. In order to restore this balance, the United Nations adopted the Kyoto Protocol in December 1997, which is explained in this chapter. The objectives of the protocol are generally to stop the increase of greenhouse gas (GHG) emissions and to reduce global warming. Therefore, this chapter shows why New Zealand took up the challenge by accepting the ratification of the Kyoto Protocol in December 2002.

1.1. ENERGY FROM THE SUN

The sun and its energy are the starting point. They can be seen as the engine that drives the weather and the climate. During a year, the earth receives around 178,000 terawatt of energy from the sun. Simply put, this is 15,000 times more than the energy consumption of the whole world today. 50% of this energy is absorbed by the earth and 30% is reflected back into space by the atmosphere. The hydrological cycle is powered by the remaining 20% and only 0.6% of this amount is going into photosynthesis. [1] Photosynthesis is the basis of all life forms on Earth and created the reserves of fossil fuel. It is well-known that these reserves are not endless and the decrease of the availability of fossil fuel resources shows that fossil fuel security becomes questionable today. [2] Being faced with this coming problem, a complete change to renewable energy resources as a free, clean and silent energy supply should become unavoidable. This offers a great potential to reduce global warming and to stop the effects of climate change. [3]

1.1.1 SOLAR RADIATION

This renewable energy comes from the sun. The sun emits radiant energy as a result of nuclear fusions inside it. The radiant energy that is not absorbed or reflected by clouds,

[1] Peter F. Smith, *Architecture in a Climate of Change – A guide to sustainable design*. Oxford, UK: Architectural Press, 2005, p.xiv.
[2] Peter F. Smith, *Sustainability at the Cutting Edge – Emerging technologies for low energy buildings*. Oxford, UK: Architectural Press, 2007, p.xii.
[3] Prasad, Deo. (ed.) Snow, Mark. (ed.) *Designing with Solar Power – a source book for building integrated photovoltaics (BiPV)*, Lodon, Sterling, VA, Earthscan, 2005, p.9.

ozone and dust is called direct radiation and is noticed as daylight and heat. The amount of this kind of energy depends on location and altitude. It also depends on the position of the sun, which is related to the season, the time of the day and the geographic latitude. However, the global radiation is still a mixture of direct radiation and diffuse sky radiation. It includes all wavelengths of solar electromagnetic radiation that is not just the visible light. Only 50% of this light is actually visible radiation (wavelengths between 380 and 789 nm), the other 50% being infrared and ultraviolet radiation. This part is not visible to the human eye, however it is also important in terms of photovoltaics and thermal solar gain. [4]

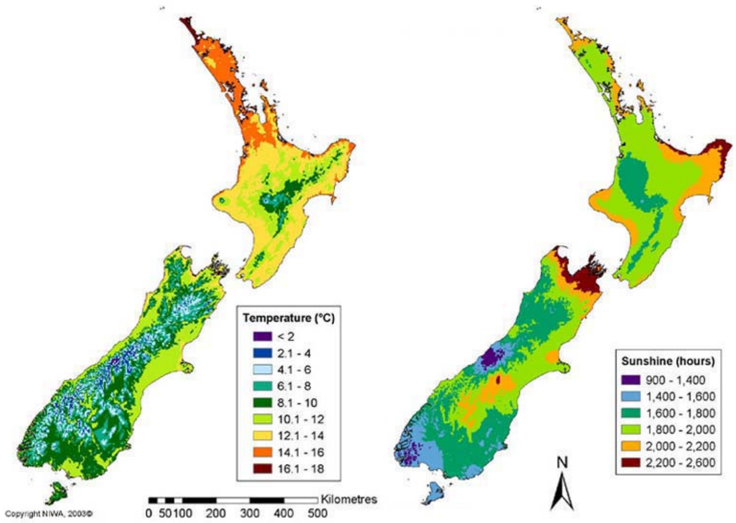

Plate 1.1
Annual Temperature and Sunshine Hours of New Zealand, 1971-2000

Light is a composition of elementary particles that are called photons. A photon is the carrier of electromagnetic radiation of all wavelengths that includes gamma rays, X-rays, ultraviolet light, visible light, infrared light and microwaves, as well as radio waves. [5] Depending on the conditions, the sunlight can reach a maximum of 1 kW (kilowatt) per square meter. As an example and according to the database from the New Zealand National Institute of Water & Atmospheric Research (NIWA), the Auckland region has about 2060 hours of sunshine per year. This is approximately 1530 kWh/a (kilowatt hours per year) of global radiation. Other cities, such as Palmerston North (1734 sunshine hours, 1280 kWh/a) and Wellington (2065 sunshine hours per year, 1420 kWh/a) are significantly lower. [6]

However, New Zealand's climate zones vary from cool temperate climates in the south to warm subtropical climates in the north. That is caused by the mountain ranges that extend

[4] Ingrid Hermannsdörfer, Christine Rüb, *Solar Design: Photovoltaics for Old Buildings, Urban Space, Landscapes*. Berlin, Germany: Jovis Verlag, 2005, p.129.
[5] Ingrid Hermannsdörfer, Christine Rüb, 2005, p.129.
[6] New Zealand National Institute of Water & Atmospheric Research, *Climate Data and Activities*. Auckland, New Zealand, Retrieved April 23, 2008 from the World Wide Web: http://www.niwa.cri.nz/edu/resources/climate.

the length of New Zealand. These chains are barriers for the western winds and divide New Zealand into different climate regions. The average temperatures are around 10°C in the south and 16°C in the north. As an example for the Auckland region, the coldest month is usually July with an average air temperature of 10.8°C. The warmest are January and February, which have an average air temperature between 19.3°C and 19.8°C. However, more important is the number of sunshine hours per year in New Zealand that are typically 2000 hours annually. [7] The midday summer solar radiation index, the Ultraviolet Index (UVI) is often very high and can be extreme in northern New Zealand where the ozone layer is depleted as well as in mountainous areas. According to the New Zealand's National Meteorological Service (Metservice) database and NIWA, the maximum UVI between 10am - 4pm in January is usually around 11 UVI. [8]

1.2. THE CARBON CYCLE

The sun and its transmitted energy offer the possibility for a change to renewable energy resources. Furthermore, the introduction of solar technology into New Zealand's building design makes it possible to reduce carbon dioxide (CO_2) emissions of buildings and to reduce climate change. [9] However, CO_2 is one of the largest sources of inorganic carbon and plays a major role in form of compounds in the atmosphere to warm up the Earth and to support the genesis of life. Plants, animals, micro-organisms and humans are all made of carbon and, therefore, it is the basis element of life on Earth. [10]

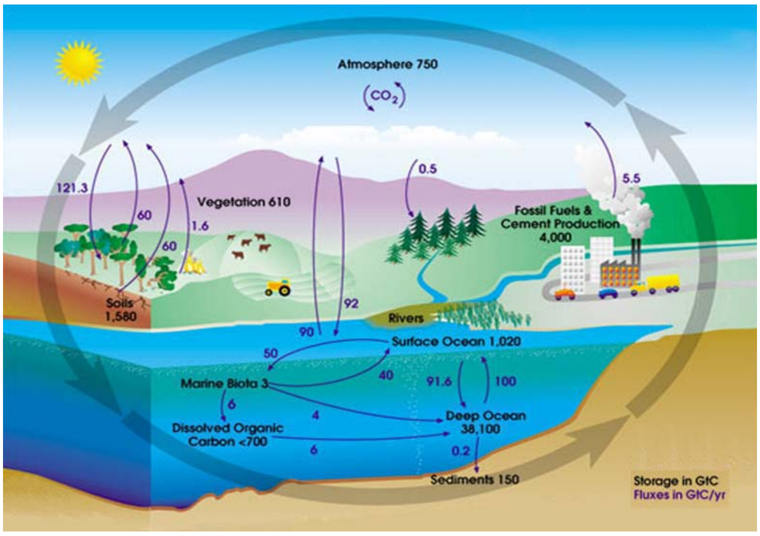

Plate 1.2
Diagram of the carbon cycle,
Human activities add about 5.5 billion tons of carbon dioxide per year to the atmosphere. The illustration shows total amounts of stored carbon in black and annual carbon fluxes in purple in gigatonne of carbon (GtC).

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[7] New Zealand National Institute of Water & Atmospheric Research, Retrieved April 23, 2008 from the World Wide Web: http://www.niwa.cri.nz/edu/resources/climate/overview.
[8] Health Sponsorship Council (HSC), *Ultraviolet Index (UVI)*. Wellington, New Zealand, Retrieved June 04, 2008 from the World Wide Web: http://www.sunsmart.org.nz/uv-radiation--index/ultraviolet-index-(uvi).aspx.
[9] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, p.9.
[10] Peter F. Smith, 2005, p.1.

CO_2 is locked into each form of life. For example, plants draw free CO_2 out of their environment to convert it into their structure through photosynthesis, a process of carbon fixation in biomass. Some of this biomass is eaten by animals and some of this carbon is again exhaled by animals as free CO_2. Furthermore, some CO_2 is dissolved in the oceans and dead plants or animals, which matter may become oil or coal that can be burned with the release of CO_2. If bacteria consume the biomass of dead plants or animals, the carbon is gradually released into the atmosphere again. Overall, this cycle of carbon fixation and release is known as the carbon cycle, which is simply the physical relation of carbon and the life cycle. [11]

Without the human factor, the carbon cycle is balanced and the release of CO_2 into the atmosphere is similar to its absorption by plants. Since mankind started to use fossil fuels as energy source and to destroy vegetation for economic and agricultural interests, the carbon cycle is out of balance. Furthermore, scientific reports declare that the amount of CO_2 in the atmosphere will be tripled by 2100 at the present rate. Even if a significant reduction of carbon dioxide emissions into the atmosphere is realised the atmospheric concentrations will be doubled by this date. [12]

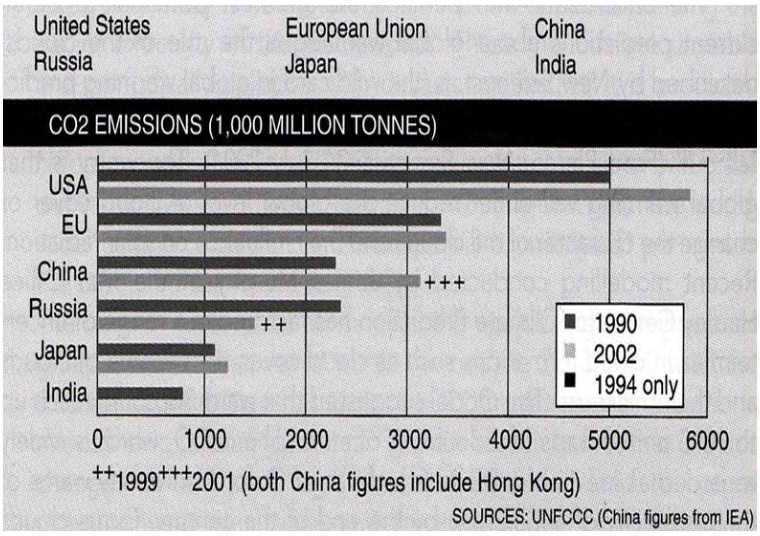

Plate 1.3
Emissions by Principal Nations,
CO_2 *emissions in 1,000 million tonnes, 2001*

According to the NIWA database, New Zealand's CO_2 emissions in 2001 were around 21.7 million tonnes annually. This can be split into 2.5 million tonnes of CO_2 from the South Island and 19.2 million tonnes of CO_2 from the North Island. However, the emissions in 2001 are calculated for each Territorial Local Authority (*refer to image 1.4*). [13]

[11] Peter F. Smith, 2005, p.1.
[12] Peter F. Smith, 2005, p.2.
[13] New Zealand National Institute of Water & Atmospheric Research, 2008 from the World Wide Web: http://www.niwa.cri.nz/ncces/projects/ghge/industrial.

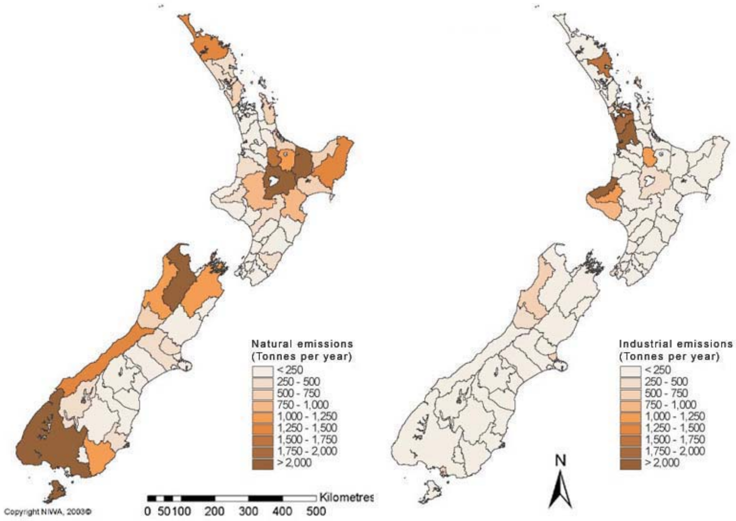

Plate 1.4
New Zealand's Emissions,
The amount of natural and industrial emissions in New Zealand in 1,000 tonnes, 2001

It may seem that during the last century, New Zealand's society lost touch with nature in terms of global warming. However, the 2007 report on "international climate change effects, vulnerability and adaptation" by the Intergovernmental Panel on Climate Change (IPCC) shows that climate change is already happening. The report identifies a warming of 0.3°C to 0.7°C in the New Zealand region since 1950 and predicts a temperature rise of between 0.2°C and 1.3°C by 2080. Furthermore, it documents more frequent heat waves, fewer frosts, less rainfall in the north-east of New Zealand and more in the south-west, as well as a rise in sea level of about 70 mm. [14]

Plate 1.5
Floods in Otorohanga 2004,
A disastrous flood has struck Otorohanga in 2004

However, a report in the *Times* on 18 October 1995 already stated that global warming is a confirmed fact and not merely a controversial theory. The opportunities for a reversal of this trend are given to New Zealand's society nationally and to the political expedience

[14] Eddie van Udden, "Climate Change and the Build Environment" in *A deeper shade of Green: Sustainable Urban Development, Building and Architecture in New Zealand*. Auckland, New Zealand: Balasoglou Books, 2008, p.42.

internationally. Therefore, international businesses and government communities have started to hold a series of urgent conferences aimed at finding global remedies and starting to admit the vast extent of environmental destruction. The scope of the conferences is to move forward the reduction of global warming to stop climate change. Global warming is a result of the greenhouse effect which normally supports the genesis of life. In fact, without a shield of greenhouse gases in the troposphere, the earth would be 33°C cooler and uninhabitable for human beings. [15]

1.2.1 THE GREENHOUSE EFFECT

The Earth surface reflects infrared radiation coming from the sun back into the atmosphere. The cooler upper atmosphere, the troposphere, is the lowest portion of Earth's atmosphere and extends to between 10 and 15 kilometres. This troposphere contains greenhouse gases that reflect infrared radiation back to the earth and provide an additional warming of the Earth surface. This effect is called the "greenhouse effect" and it reduces the loss of heat into space. Important greenhouse gases are water vapour, carbon dioxide (CO_2), methane (CO4), nitrous oxide (N2O), tropospheric ozone (O3) and chlorofluorocarbons (CFCs). The amount of greenhouse gases in the atmosphere, such as CO_2, CO4 and N2O is the key factor to reduce or to increase the greenhouse effect. [16]

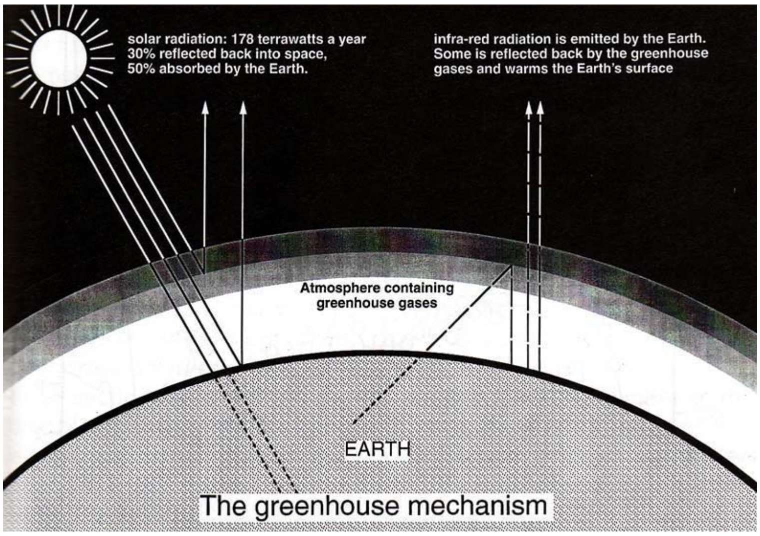

Plate 1.6
The Greenhouse Effect,
Infrared radiation is emitted by the earth. Some is reflected back by the greenhouse gases and warms the earth's surface

Certain human activities have changed the natural atmospheric levels of greenhouse gases. The concentration of CO_2 in the atmosphere is 26% higher than before the industrial revolution due to use of fossil fuels and deforestation. Another reason is the rising population around the world that is getting a major problem and has doubled the CO4 emissions. Furthermore, CO4 emissions have a global warming potential of 25 over a period of hundred

[15] James Wines (eds.), *Green architecture*. Köln, London: Taschen, 2000, p.35.
[16] Peter F. Smith, 2005, p.2.

years. That means that the impact on temperature is 25 times higher than CO_2 emission. The emissions of N2O increased to 8%. Its global warming potential is 310 times higher than the potential of CO_2 over a period of hundred years. [17]

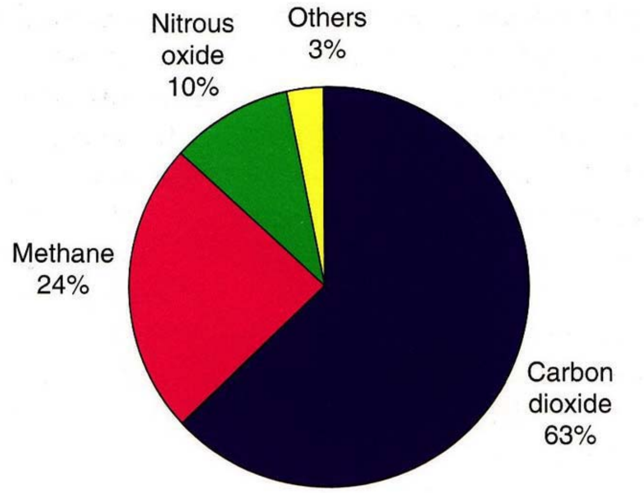

Plate 1.7
Global Warming Potentials, Potentials for selected gases from the Third Assessment Report by the intergovernmental panel on climate change (IPCC),

New Zealand's greenhouse gas emissions are quite low which is related to New Zealand's overall energy supply management. Nearly 65% of it comes from renewable sources such as hydro and wind power. Hydro power is currently the biggest part of it, but wind power started to increase and is already about 3% of the total energy generation. However, there are still 35% of New Zealand's overall energy supply which are produced by burning coal, gas and oil at power stations that produces greenhouse gases. [18]

In order to obtain facts and amounts of emissions, the NIWA records the total greenhouse gas emissions for all territorial local authorities (TLA) in New Zealand. A report from 2001 allocates New Zealand's greenhouse emissions per year. It illustrates that about 21.7 million tonnes of CO_2, 50 thousand tonnes of CH4, 463 tonnes of N2O, 65 tonnes of hydrofluorocarbon (HFC), 9 tonnes of perfluorocarbon (PFC) and nearly 1 tonnes of sulphur hexafluoride (SF_6) were released into the atmosphere. Of course, buildings are particularly implied into this process, but unfortunately there is no specific information available yet which reports the specific amount of building emissions in New Zealand. [19]

[17] Peter F. Smith, 2005, p.3.
[18] New Zealand's Department of Building and Housing, *Your guide to a smarter home*. Wellington, New Zealand: Department of Building and Housing, 2007, p.20.
[19] New Zealand National Institute of Water & Atmospheric Research, 2008 from the World Wide Web: http://www.niwa.cri.nz/ncces/projects/ghge/industrial.

1.2.2 THE KYOTO PROTOCOL

As already stated, the United Nations (UN) have started to hold a series of urgent conferences aimed at finding global remedies. During the 1990s, the international community realised that the climate change was a confirmed fact and not merely a controversial theory. What followed was a global response to take up the challenge to limit the greenhouse emissions. It was adopted at the United Nations Conference on Environment and Development (UNCED), in 1992. This conference is also known as the Earth Summit and forms the basis to the Kyoto Protocol in conjunction with the United Nations Framework Convention on Climate Change (UNFCCC) and the Agenda 21 programme. [20]

The UNFCCC agreement is the first international agreement. Its scope is to stop the global rise of greenhouse gas emissions and to stabilise these at a level to reduce the negative impacts expected from future global warming. The Agenda 21 is a programme that is related to sustainable development and was intended to involve action at international, national and regional as well as local levels. In this context, the New Zealand Ministry for the Environment produced a national guide according to this programme such as a guide that can be used for national and local projects. [21] The Kyoto Protocol is a second international agreement that was negotiated in accordance with the UNFCCC and decided by the United Nations Framework Convention on Climate Change Conference of Parties in Kyoto, Japan on 11 December 1997. [22]

The goal of the Kyoto Protocol is to reduce the emissions of greenhouse gases in order to slow down and, finally, to stop climate change. The obligation of the ratification of the Protocol is to reduce GHG emissions to 1990 levels on average over the period 2008 – 2012, the "first commitment period". If a government does not reach the goal by 2012, it has to take the responsibility for any emissions above 1990 levels and needs to offset these GHG emissions. In this case, the Protocol gives the possibility to use other emissions units that were acquired under the clean development mechanism to buy additional emission units on the international market or to use sink credits from Kyoto forests. Sink credits are systems, which are natural or man-made and absorb GHG. Therefore, one sink credit is allocated for every tonne of CO_2. [23]

[20] James Wines (eds.), 2000, p.35.
[21] Brenda and Robert Vale, *The New Autonomous House.* London, UK: Thames & Hudson, 2000, p.12.
[22] New Zealand's Ministry for the Environment, "Kyoto Protocol: Ensuring our Future - Climate Change Consultation Paper" in *New Zealand Climate Change Programme*. Wellington, New Zealand: Ministry for the Environment, 2001, p.9.
[23] New Zealand's Ministry for the Environment, 2001, p.9.

The protocol is signed and ratified by 165 countries and it sets targets for each developed country to reduce their GHG emissions. For example, Europe has to reduce their collective emissions of GHG by 8%, compared to New Zealand that needs to stabilise its GHG emissions after it signed the Kyoto Protocol on 22 May 1998 and accepted the ratification on 19 December 2002. [24] However, the change in New Zealand's GHG emissions that included land use, land-use change and forestry (LULUCF), is about 21%, which means that New Zealand may not reach the goal to stabilise its GHG emissions until 2012. Furthermore, New Zealand's GHG emissions are expected to increase by another 30% under the current policies over the next 25 years. [25]

1.3. NEW ZEALAND'S GREEN STAR NZ RATING AND THE HERO SCHEME

Extensive industry and public consultation followed, after New Zealand ratified the Kyoto Protocol in December 2002 that moved forward the development of a rating system for buildings. Therefore, the New Zealand Green Building Council (NZGBC) introduced the first comprehensive environmental rating system in April 2007: the Green Star NZ for Offices (Design). This rating system assessed the expected environmental performance of offices in terms of their design and demand for green office space. Furthermore, its object is to reduce the environmental impacts of buildings and to establish a common language of sustainable design. [26]

Therefore, this rating reviews a building project in eight environmental impact categories and its unique innovation. Within each of these eight categories, points are awarded to rate it, and to present if the building has met the objectives of Green Star NZ. Afterwards, these points are weighted and an overall score is the result that equates to a rating of between 1 and 6 stars (*refer to image 1.8*). For example, 4 stars equate to "best practice", 5 stars to "New Zealand excellence" and 6 stars to "world leadership". [27] This paper agrees that the Green Star NZ rating supports the development of a sustainable society, but it also requires new models of financing, such as financial subsidies from the government, as well as a review of existing building laws and the New Zealand Building Code (NZBC) to establish sustainable design in New Zealand's Architecture. [28]

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[24] New Zealand's Ministry for the Environment, 2001, p.10.
[25] Johann Bernhardt, *A deeper shade of Green: Sustainable Urban Development, Building and Architecture in New Zealand*. Auckland, New Zealand: Balasoglou Books, 2008, p.9.
[26] Johann Bernhardt, 2008, p.128.
[27] New Zealand Green Building Council. *Green Star NZ*. Auckland, New Zealand, Retrieved April 24, 2008 from the World Wide Web: http://www.nzgbc.org.nz.
[28] New Zealand's Ministry for the Environment. 2001, pp.3-9.

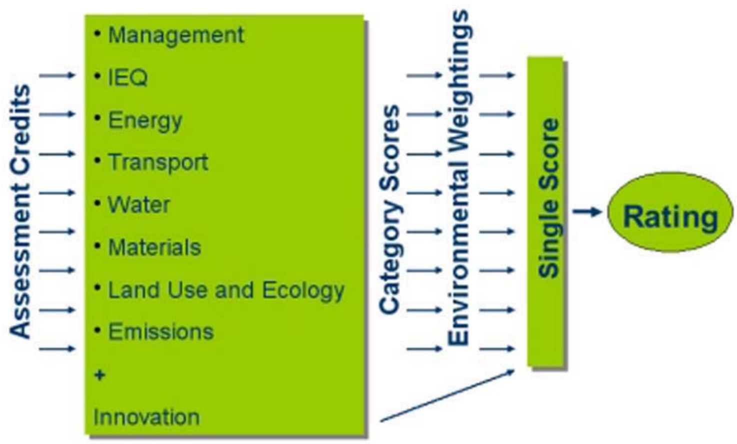

Plate 1.8
Green Star NZ for Offices (Design), Shows the eight environmental categories and its weighting

Another New Zealand rating system that exists since 1992 is the BRANZ-developed Home Energy Rating Options (HERO) Scheme. This rating system was developed as an energy efficiency rating system for houses for the Electricity Corporation of New Zealand (ECNZ). HERO makes it possible to rate the energy efficiency of existing houses and gives information to the occupants and house owners to improve their energy performance. This system rates the energy efficiency of a household as an open-ended system of stars awarded for performance. For example, 1 star describes the energy performance of an older uninsulated house with an original hot water system, compared to a 7 or a higher star rating that describes the energy performance of a passive solar design with energy efficient appliances that includes thermal solar systems. [29]

Overall, this chapter shows that a great potential of renewable energy is available, providing the possibility of a change to a clean and silent energy supply in New Zealand as well as world wide. International agreements such as the Kyoto Protocol and the New Zealand's new Green Star NZ rating system are only a few examples that move forward the development towards a sustainable society - but it is also necessary to establish new technologies in New Zealand's architecture. Therefore, this research paper explores the integration of solar technologies in New Zealand's building design and gives a definition of sustainable architecture.

[29] Roman Jaques, "Branz: Guide to energy awareness", *Architecture New Zealand*, September/October, 1993, p.87.

2. LITERATURE ON SUSTAINABLE ARCHITECTURE

It is not surprising that there are a lot of books, articles and other sources available that consider sustainable architecture as well as solar design. In order to achieve a high quality of information and to explore the subject of this research report, a definition of sustainable architecture and the scope of this paper are needed right at the beginning of the research process. Therefore, this chapter defines the boundaries and gives a critical review on existing literature which was used during the research for this report.

2.1. DEFINITION OF SUSTAINABLE ARCHITECTURE

The paper identifies an increased usage of terms, such as “environmentally conscious design”, “ecological design”, “sustainable architecture” and “green architecture” during previous years. The term “sustainable architecture” describes the integration of environmentally aware design and technology into an architectural context. Its scope is to minimise the environmental impact of buildings through the application of an efficient usage of materials and energy resources. In terms of environmental damages, the use of conventional energy resources in buildings is a major problem, but can be reduced through the integration of renewable energy technologies such as photovoltaic cells and thermal solar collectors in building design. The goal of sustainable architecture is to maximise energy efficiency through the entire life cycle of buildings to reduce their needs of energy and to reduce the CO_2 emissions. [1]

Some architects already started to use life cycle assessment (LCA) to assess the environmental impact of a specific material or building construction method. Studying environmental impacts through the use of LCA is the option to identify the major points to energy consumption and negative environmental impacts. Major environmental improvements can be realised e.g. through the introduction of passive solar design, a high quality of building insulation, the usage of renewable building materials and the application of active solar design elements such as photovoltaic (PV) modules and thermal solar systems. The introduction of active solar devices does not automatically imply a lower environmental impact when the life cycle of these systems is taken into account, but it reduces the energy needs of buildings and increases their ability to capture or generate their own energy. [2]

[1] Brenda and Robert Vale. *The New Autonomous House*. London: Thames & Hudson, 2000, p.18.
[2] Arjen Meijer, *Improvement of the life cycle assessment methodology for dwellings*, pp.81-82.

However, energy efficiency is the most important single goal of sustainable architecture. Active solar devices, such as PV-modules generate sustainable electricity and thermal solar collectors provide energy to heat buildings in a sustainable manner. A combination of these systems can reduce the use of conventional energy resources in buildings and generates excess energy for use in other structures. Therefore, the research of this report is focused on PV and thermal solar technologies and explores the possibilities to integrate these technologies into the architectural design.

2.2. LITERATURE REVIEW

After the definition and boundaries of this research report are stated, it requires a serious selection of literature sources, which are on the one hand general and on the other hand specific. General survey texts do not offer specific facts on thermal solar and photovoltaic technologies, but this body of literature contains key-references. These references are important to understand the basis of solar architecture and provide background information to contextualise the research in subsequent chapters. In this context, this literature review considers the main, as well as the specific literature sources of solar architecture and solar technologies. Therefore, the review is divided into two parts: Part one considers the general survey texts of sustainable architecture and the second part explores the specific sources that examine photovoltaic and thermal solar technologies.

2.2.1 GENERAL SURVEY TEXTS OF SUSTAINABLE ARCHITECTURE

In order to provide background information for this research report, this section identifies the secondary key sources such as literature by Peter F. Smith. He is one of the writers who are important in context to the topic of this research report. Smith is professor in sustainable energy at Nottingham University in the UK and also the chairman of the Housing Committee of the Energy Savings Trust. In *Sustainability at the Cutting Edge – Emerging technologies for low energy buildings* (2007), he explores pros and cons of several renewable energies, including wind, wave, solar and the pressing need for them. [3] Overall, he describes how buildings can be made to significantly reduce their reliance on fossil based energy through the use of solar and geothermal resources. However, he does not take the architectural design into account. Therefore, thermal solar systems are only described as a technological bonus which needs to be implied into the building design to reduce the consumption of conventional energy.

[3] Peter F Smith. *Architecture in a Climate of Change – A guide to sustainable design*. Oxford, UK: Architectural Press, 2005.

In the latest edition of *Architecture in a Climate of Change – A guide to sustainable design* (2005), Peter F. Smith presents information on wind generation, domestic water conservation, thermal solar systems and PV-technology as well as international case studies. The book leads the reader to consider new approaches to building making minimum demand on fossil based energy. He argues that the fastest reductions of CO_2 could come from reducing demand in the built environment, which is e.g. responsible for almost 50% of UK emissions. Smith brings up the point that buildings need to be transformed into net producers of clean energy. [4] As mentioned in relation to his publication in 2007, he does not consider the building design in this edition either. The scope is the integration of solar systems into building construction to exploit solar energy. However, it provides a high potential of technical information, but does not underline the scope of this research paper to identify solar systems as design elements which can be part of the architectural design.

In 1975, Brenda and Robert Vale published their monograph *The Autonomous House* that offers down-to-earth suggestions for sustainable building. Brenda and Robert Vale were both at the University of Auckland as professor of architectural technology and senior research fellow respectively, before moving to Victoria University of Wellington, New Zealand. Their first publication about the autonomous house is a technical guide for developing housing solutions that are energy-self-sufficient, environmentally friendly and comparatively easy to maintain. Their developed solution is a building that does not pollute the earth or waste resources. Therefore, *The Autonomous House* is widely recognized as an essential reading in the field of sustainable architecture. [5] However, while the publication can be seen as a significant move forward in the development of sustainable architecture, the report declares that the content of information of this source is related to the date of the publication in terms of technology advancements. Therefore, it is used as an important literature resource to provide background knowledge in terms of the development of sustainable architecture.

More important is the edition of *The New Autonomous House* that was published twenty-five years later - after the Vales built the autonomous house in Southwell, Nottinghamshire in England in the early 1990s. The book provides a thought provoking and practical solution to the environmental problems based on the principles of sustainable resources and shows the possibility to live in an inexpensive house. This project is an example of a house that is kind to the environment and reduces the consumption of energy. [6] The research paper identifies Robert and Brenda Vale as pioneer researchers and leading experts in the field of

[4] Peter F Smith. *Sustainability at the Cutting Edge – Emerging technologies for low energy buildings*. Oxford, UK: Architectural Press, 2007.
[5] Brenda and Robert Vale. *The Autonomous House*. London: Thames & Hudson, 1975.
[6] Brenda and Robert Vale. 2000.

sustainable housing, as they have been practicing in the field of sustainability for over 25 years now. Therefore, their publications provide a high quality of basic background knowledge explaining the principles of solar design and sustainable architecture.

2.2.2 SPECIFIC SURVEY TEXTS OF SOLAR TECHNOLOGIES

At the turn of the 21st century and in relation to the global developments, more books are published which specifically address and explore solar design. The book *Photovoltaics and Architecture (2001)* by Randall Thomas and Max Fordham and Partners, is one of these publications which give consideration to these issues. Thomas is visiting professor in architectural science at Kingston University in the UK and senior partner at Max Fordham & Partners. The book, published in April 2001, sets out the basic principles of PV design and its implications in a UK context. [7] Therefore, it is used to close the gap of information in terms of the basic principles of PV. However, it needs to be clear that the technical features of PV and thermal solar systems need to be introduced by other sources which are not dated in terms of technical advancements. However, Thomas argues that the 21st century will be the age of solar energy, such as the 20th century was the age of oil. [8] This statement points out that there is a need to develop a high quality of sustainable architecture that includes the integration of PV and thermal solar systems.

After the basic knowledge of PV and thermal solar systems is given by other literature resources, the following publications introduce the technical features of photovoltaic cell and thermal solar technologies, which are not too dated in terms of technical advancements. The subject of the book *A Source Book for Building integrated Photovoltaics – BiPV (2005)* by Deo Prasad, Professor and director of the Solar Architecture Research (SOLARCH) Group, and Mark Snow, senior researcher at the SOLARCH Group at University of New South Wales in Sydney, Australia, is PV technology. Their key-object is to move forward the architectural and technical quality of PV systems in the built environment. Prasad and Snow explore and remove non-technical barriers for the introduction of photovoltaic systems as an energy-significant option and introduce the holistic design process, as well as integration concepts. [9] This is important in relation to the scope of this research report to introduce active solar systems as design elements in New Zealand architecture.

[7] Randall Thomas (ed). Max Fordham and Partners (ed). *Photovoltaics and Architecture*. London, New York: Spon Press, 2001.
[8] Randall Thomas (ed). Max Fordham and Partners (ed). *Photovoltaics and Architecture*. London, New York: Spon Press, 2001.
[9] Deo Prasad (ed). Mark Snow (ed). *Designing with Solar Power: A Source Book for Building integrated Photovoltaics (BiPV)*. London, Sterling, VA: Earthscan, 2005.

In order to introduce new PV-technologies, such as PV-cells that are transparent and flexible, this research paper introduces the publication of Ingrid Hermannsdörfer, graduate in engineering, and the architect Christine Rüb. They published the book *Solar Design: Photovoltaics for Old Buildings*, in 2005. They indicate the fact that the use of solar energy in new building constructions has been grown rapidly. Hermannsdörfer and Rüb present solar design features and case studies of 30 realised projects and explore how photovoltaic systems can be consciously installed as structural design elements. They demonstrate these systems as increasingly compact and flexible elements in terms of architectural design. [10] Overall, this book is a presentation of the current practises and developments of the application of solar energy in contemporary architecture and important to the paper to identify new technical advancements.

Taking into account the information of all literature resources that were used during the research, it shows that it is necessary to combine passive and active architectural design to achieve a high efficiency of PV and thermal solar systems in buildings. Therefore, the next chapter explores passive and active solar design and indicates the need of a rethinking in architectural design. Afterwards, it examines the technical features and possibilities of the integration of PV and thermal solar systems in building design.

[10] Ingrid Hermannsdörfer. Christine Rüb. *Solar Design: Photovoltaics for Old Buildings, Urban Space, Landscapes*. Berlin, Germany: Jovis Verlag, 2005.

3. PASSIVE AND ACTIVE SOLAR DESIGN

This chapter examines and indicates the need of a new kind of architectural design. It explores passive solar design issues as future-proof solutions to provide thermal efficiency in building design and considers the passive house design from Europe. The subject of this chapter is to prove that passive solar energy is a significant factor in solar design to reduce the consumption of conventional energy.

The chapter considers active solar design as an additional option. It shows that active solar systems can be combined with passive design solution to achieve higher energy efficiency. Overall, this chapter illustrates the common problems in solar design and what must be done in a different matter to provide a higher efficiency.

3.1. A NEED OF RETHINKING IN ARCHITECTURAL DESIGN

The climate change is becoming the biggest challenge of the 21st century and it will be necessary to dramatically reduce the emissions of CO_2 into the atmosphere. Buildings are particularly involved in this process, e.g. across the European Union they are responsible for about 47% of the total CO_2 emissions. A rethinking in building design and construction must be the prime factor to reduce the amount of emissions and the effect of the climate change. Architects and engineers have the responsibility to persuade their clients of sustainable design and construction. They need to ensure that new buildings are realised with the highest standards towards sustainability to reduce the amount of CO_2 emissions. [1]

Another point is the overall energy consumption of industrial countries. Almost half of this amount of energy is used by buildings to provide heat, ventilation, light and supply of power. This energy is still produced mainly from non-renewable fossil fuels which release harmful emissions to the environment. In terms of climate change and the limited availability of fossil energy sources, the efficient usage and a rationalisation have become a primary aim, politically and socially. Renewable energies, such as solar power and a responsible approach to the environment are the solution to achieve a higher efficiency. Therefore, solar systems must become a standard element in a new architectural design. Rather, these elements must be recognised and treated as design elements that make an important contribution to architectural design. In order to reach this goal, a thorough rethinking in

[1] Peter F. Smith, *Architecture in a Climate of Change – A guide to sustainable design*. Oxford, UK: Architectural Press, 2005, p.xiii.

architectural design is necessary by the architects, engineers and builders in order to establish solar systems as design elements in sustainable architecture. [2]

In 1995, 30 leading European architects signed the European Charter for Solar Energy in Architecture and Urban Planning to underline a rethinking in architectural design. Their idea was to support the introduction of solar energy to the public to achieve an acceptance of solar buildings as a new kind of architecture. Today, solar energy systems are not anymore exclusively technological systems, which can produce heat and electricity, but is necessary to combine these systems with passive and active building technologies to minimise the consumption of conventional energy and to exploit natural assets. This combination of existing and recent technologies can help to cut the emissions of CO_2 by half, if it is used in new buildings, as well as in existing ones. [3]

3.2. PASSIVE SOLAR DESIGN

The effect of passive solar gain needs to be considered in relation to the complete solar design and not just only in terms of the positioning of windows and skylights. Specific attention must be paid to the site and location of the building in terms of climate, solar orientation and the placement of glazing-and-shading elements. Furthermore, the building design should be compact in its shape to reduce the external surface area in order to reduce heat loss. The main façade of a building and its windows must be oriented towards to the equator (to south in the northern hemisphere and to north in the southern hemisphere) to maximise passive solar gain. The effect on heat gain of windows can be significant and should be low-emissivity (Low E) double glazing to reduce the U-factor by suppressing radiative heat flow. In this context, different types of Low-E coatings were developed to allow for high, moderate or low solar gain. The frame of the glazing should be a timber frame in order to eliminate thermal bridges. [4]

Overheating is still a major problem, but it can be minimised with external shading elements. These elements should be installed above windows to provide shading and to keep the thermal solar gain under control. Another point is the building structure that can be lightweight material, but some internal thermal mass such as concrete walls and tiled surfaces is necessary to store the thermal heat gain and level out the peaks and troughs of temperature inside the house. However, passive solar design does not include solutions

[2] Ingrid Hermannsdörfer, Christine Rüb, *Solar Design: Photovoltaics for Old Buildings, Urban Space, Landscapes*. Berlin, Germany: Jovis Verlag, 2005, p.7.
[3] Peter F. Smith, 2005, p.104.
[4] Peter F. Smith, 2005, pp.105-106.

such as active ventilation, evaporative cooling or the analysis of the life cycle assessment (LCA). Still, it is a solution to provide high thermal efficiency in sustainable design. [5]

The first Eco-house by Wellington City Council (WCC) can be seen as a good example of passive design in New Zealand. The interior thermal comfort of the house is related to the sun's daily and annual cycles in order to reduce the requirement for an active heating and cooling system. In this context, each room is placed in relation to its function and to the benefit of thermal solar gain. Furthermore, the passive ventilation system is taking advantage of the natural flow of heat inside the house. Roof windows that are installed at the highest point of the house and windows at the ground level use the stack effect to provide fresh air and to cool down the house within a short period of time. [6]

Plate 3.1
Wellington's first Eco-House,
The first Eco-house owned by the City Council of Wellington, viewed from the Regent Street, Wellington, New Zealand, 1995

3.2.1 THE PASSIVE HOUSE

A passive house design (German: Passivhaus) refers to the rigorous passive house standards for energy use in buildings in the northern hemisphere. It must be noted that there are no passive houses in the southern hemisphere to date, but these standards can be applied as well. However, passive house design is an integrated design process in association with architectural design. A passive house is an ultra-low energy building which requires only a little amount of energy for heating. The construction of a passive house is about energy saving and a comfortable interior climate that can be maintained without

[5] Peter F. Smith, 2005, pp.105-106.
[6] John Storey, "A paradigm of the possible", *Architecture New Zealand*, vol. October/September, 1995, pp.26-30.

additional active heating and cooling systems. Furthermore, the house heats and cools itself, therefore it is called "passive house". [7]

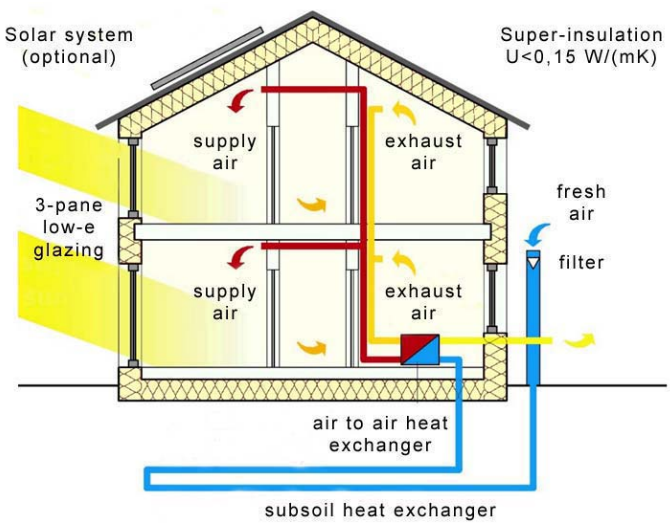

Plate 3.2
Passive House Section,
Passive House building system that suits the Central European climate

In order to reduce the transfer of heat through walls, roof and floor, all components are highly insulated to achieve a U-value that does not exceed 0.15 W/(m²K). In this context, special attention has to be paid to thermal bridges. Heat always flows the easiest path from the heated inside to the outside. This path with the least resistance is created when materials with a low thermal conductivity (R-value) come in contact and allow heat to flow. There are three different kinds of thermal bridges that are known as “repeating“, “non-repeating” and “geometrical” thermal bridges. A repeating thermal bridge is present if it follows a regular pattern, such as wall tiles that are penetrating a cavity wall. If a thermal bridge is made e.g. by a single lintel that is bridging a cavity wall it is known as a non-repeating thermal bridge. A geometrical thermal bridge can be identified e.g. at the junction of two planes such as at the corner of a wall. However, the heat losses of thermal bridges are significantly reduced in a passive house design and thus become negligible. [8]

Air tightness of a building is another point that is important to minimise the level of heat loss by the air which goes through the building envelope of the house. A blower door test is useful to identify air leakage, which must be less than 0.6 times of the house’s volume per hour (n50 ≤ 0.6 / hour). The rate of air change can be optimized and carefully controlled by an efficient heat recovery ventilation system. It recovers heat from exhaust air using an air-to-air heat exchanger that can provide a heat recovery rate of 80%. Another solution is passive

[7] Wolfgang Feist, *Passive House Institute: Research and development of high-efficiency energy systems*. Darmstadt, Germany, Retrieved April 26, 2008 from the World Wide Web: http://www.passiv.de.

[8] Wolfgang Feist, *12th International Conference on Passive Houses 2008*. Darmstadt, Germany, Retrieved June 04, 2008 from the World Wide Web: http://www.passivhaustagung.de/Passive_House_E/passive_house_avoiding_thermal_brigdes.html.

preheating or precooling of fresh air through underground ducts that exchange heat with the soil. [9]

Another significant factor in the passive house design is the use of passive solar energy. In this case, windows should have a good solar heat-gain coefficient around 50%, which has a Low E coating. Therefore, the glazing needs to be doubled or even tripled and filled with argon or krypton gas to provide U-values that do not exceeding 0.80 W/(m²K) including the frame. [10]

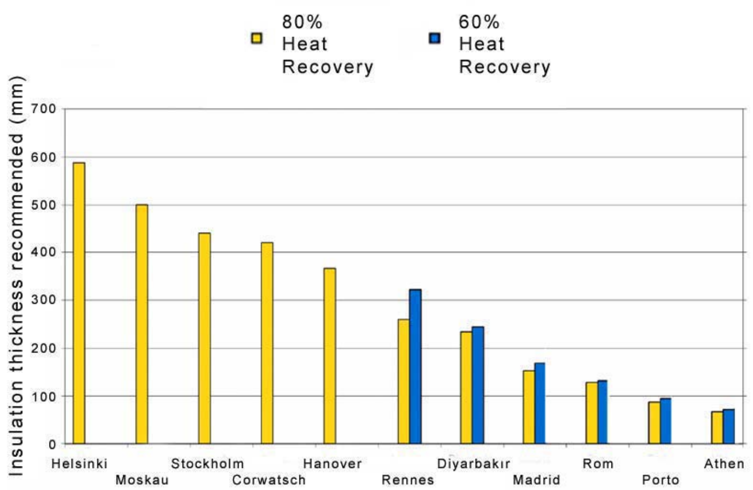

Plate 3.3
Insulation Levels,
Passive house insulation levels in different climate zones of Europe

According to the publication by Wolfgang Feist of the Passive House Institute, the energy consumption of a passive house may not exceed 120 kWh/(m²a) for heat, hot water and household electricity which reflects the combined primary energy consumption of a European passive house. Furthermore, the integration of solar collectors and heat pumps can provide energy for the domestic hot water (DHW) supply.

Of course, these additional applications require energy as well, but they are very efficient and in combination with a PV module, the solar collectors and heat pumps become a true zero fossil energy option that is carbon neutral. [11] Also, low energy household appliances such as refrigerators, stoves, lamps, etc. are important to minimise the waste of energy. Overall, the consumed energy by a passive house should be less than 25% of the energy consumed by a new residential building that complies with the German Energy Saving Ordinance (EnEV) (*refer to image 3.4*). [12]

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[9] Peter F. Smith, 2005, pp.104-105.
[10] Peter F. Smith, 2005, pp.104-105.
[11] Peter F. Smith, *Sustainability at the Cutting Edge – Emerging technologies for low energy buildings.* Oxford, UK: Architectural Press, 2007, p.15.
[12] Wolfgang Feist, 2008 from the World Wide Web: http://www.passiv.de.

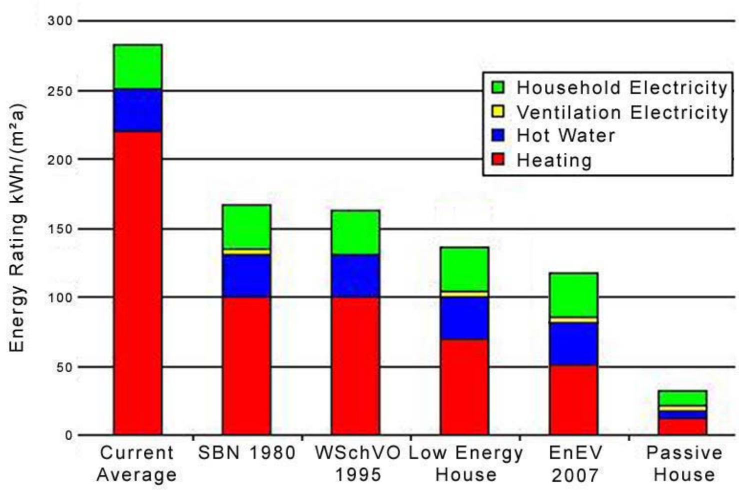

Plate 3.4
Energy Ratings of Homes,
Energy Ratings of Homes in Europe, Including the Swedish Construction Standard (SBN), the German Heat Protection Regulation (WSchVO) and Energy Saving Ordinance (EnEV)

3.3. ACTIVE SOLAR DESIGN

Compared to a building that is based on passive solar design, an active solar design uses additional devises such as heat pumps or PV modules. These devices use external energy and, are therefore classified as active solar technologies, which are used e.g. to convert solar energy into usable thermal energy and electricity or cause air-movement for ventilation and cooling. They are different in their operation as well as in their appearance and the requirement of additional energy to operate which leads to additional operating and maintenance costs. Passive solar systems do not require additional energy and provide only low maintenance costs. Therefore, passive solar technologies should be given full consideration, but can be combined with active solar systems. [13]

An active solar technology e.g. is a thermal solar system, also known as a collector. The collector transforms solar radiation into thermal heat energy and (except for those which are based on the thermosiphon method) it uses additional electrical or mechanical equipment such as a pump to circulate the water or another heat transfer liquid. Inside the building it is used for heating or to provide DHW to the occupants. Another active solar technology is a photovoltaic generator, also known as a solar module. A generator transforms the solar radiation directly into electric energy and can be used straight afterwards. However, these two solar systems are the main active solar systems, which are introduced in active solar design, but there are also other systems, which can reduce the consumption of conventional energy. One of these systems e.g. is a heat-cycle pump that recovers heat from exhaust air and minimises heat loss by a ventilation system. That leads to a high energy efficiency and reduces the waste of energy. [14]

[13] Ingrid Hermannsdörfer, Christine Rüb, 2005, p.129.
[14] Ingrid Hermannsdörfer, Christine Rüb, 2005, p.129.

3.4. COMMON PROBLEMS IN SOLAR DESIGN

In order to achieve the best results during the design and construction process it is necessary that the designer and the architect are up to date. They must work with the newest available technologies and systems that are essential and efficient as well as easy to use and to maintain, but also not too over-complex for the client. Typically, the client and the service manager have only information that is accessible to a non-specialist. If an over-complex system comes into operation, most times the service manager is not up to the requirements of the technology. The result is a poor maintenance and the system starts to deteriorate fairly rapidly or is totally abandoned at the end. [15]

Another recent development in sustainable architecture is building automatism. It provides a high level of comfort and safety and is addressed to control the problem of the human factor in building operation to reduce the demand of energy. People usually do not have time and patience to keep fine tuning their building environment. They like to have things under control and to switch things on, but they normally do not switch them off again. An automatic off can be the answer and should become the norm. [16]

Furthermore, standards and building codes such as the New Zealand Building Code (NZBC), are important and need to be realised by the architects and engineers. If it comes to the adoption of new technologies and systems into building design that are not already included, it is necessary to review these rules. On the other hand, a blind faith in a new technology is totally inappropriate, because there are always upsides and downsides. However, it becomes a common problem in architecture that architects, designers and engineers do not give the same weight of attention to risks as to a new vision. [17]

Overall, this chapter calls for a change in conventional building design and construction to reduce the CO_2 emissions by buildings. Architects and engineers have to take up their responsibility to persuade their clients of sustainable design now. The chapter shows that the application of solar systems in building design is only one possibility, but an important contribution to move forward is the rethinking in architectural design. Therefore, PV and thermal solar systems are important to convert solar energy into usable thermal heat and electricity to reduce the demand of energy.

[15] Peter F. Smith, 2005, p.196.
[16] Peter F. Smith, 2005, pp.199-200.
[17] Peter F. Smith, 2005, p.198.

4. THERMAL SOLAR TECHNOLOGY IN ARCHITECTURAL DESIGN

This chapter explores thermal solar technology and illustrates different types of solar collectors such as the flat plate and the vacuum tube collector which are already available on the market. Furthermore, it examines the differences of passive and active thermal solar systems and takes a closer look on the principles of an active direct and active indirect system. The chapter explains factors and indicators that are useful to identify the most successful thermal solar system for each project and shows how important these are in terms of the integration into the building envelope. It examines concepts to integrate collectors into a building as well as into a new architectural project and contains recent developments, which prove that thermal solar technology is becoming a significant part of building design.

4.1. THERMAL SOLAR COLLECTOR SYSTEMS

Solar radiation is a renewable energy resource that offers the largest potential of free energy. For example, if only 1% of all deserts around the world are covered with solar systems, it would produce the energy demand, which was required for the year 2000. In terms of domestic hot water (DHW) supply, the potential of thermal solar collectors is normally about 1 m² per person, but the amount of thermal energy that a solar collector can reach during the day, depends on many factors. The geographical location and the house orientation are important in terms of the thermal solar gain which affects the thermal environment and results in a minimum of house heating demand. The key factor is a balance between the captured and stored thermal energy in the water and the energy that is necessary for a pleasant temperature inside the house. If this balance is not given it will not be possible to achieve an efficient thermal solar system. [1]

4.1.1 FLAT PLATE COLLECTOR

The two basic systems of thermal solar collectors are the flat plate collectors and the vacuum tube collectors. The flat plate collector is the least complex and most common type of solar collector for use in solar water heating systems and in solar space heating. A flat plate collector heats the circulating fluid to a temperature considerably less than that of the boiling point of water which makes it particularly suitable to supply gas boilers or immersion heaters with pre-heated water. Therefore, the flat plate collector is best suited to applications where the demand temperature is 30°C to 70°C and for applications that require heat during winter.

[1] Mirek Piechowski, "Solar house heating and night sky cooling – how to make it work", *Architect Victoria, Winter*, 2006, p.22.

The collector can be mounted in a variety of ways, depending on the type of building, application, and type of flat plate collector (*refer to chapter 4.4*). [2]

Plate 4.1
Flat Plate Collector,
2 EURO C20 collectors with a gross surface of 2.6 m² each, can be mounted vertically or horizontally, on-roof, in-roof or free standing, ~95% sorption, ~5% emission, Wagner & Co, Cölbe, Germany

The system consists of an absorber, a transparent cover, a frame that included the insulation underneath the absorber and a heat transfer medium that flows through the flow tubes. This absorber is usually tilted black chrome plates that are coated to maximise the heat collecting efficiency. The cover of glass (glazing) or plastic prevents the system from wind and breezes that carries the collected heat away. It also protects the absorber from adverse weather conditions in combination with the frame that is usually made from aluminium alloy or galvanized steel. The heat transfer mediums are copper pipes, known as flow tubes behind the absorber. These pipes are usually painted with black colour and bonded to the material of the flat plate collector to maximise the heat absorption. Inside the pipes is a heat absorbing medium, such as water or air. [3]

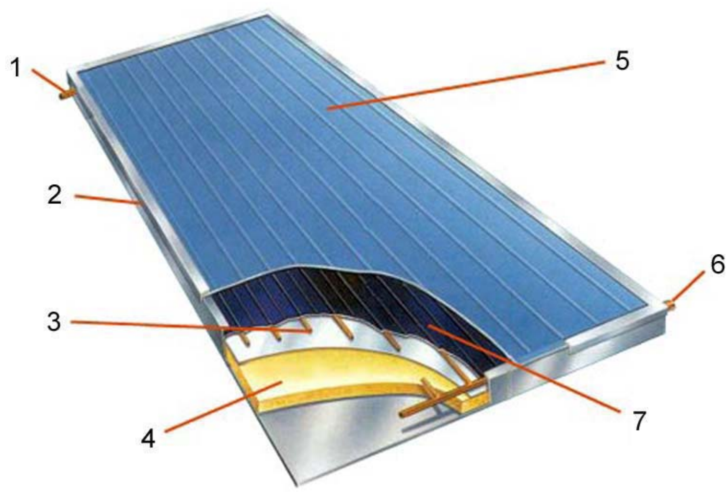

Plate 4.2
Flat Plate Collector Components,
1: Inlet connection
2: Frame
3: Flow tubes
4: Insulation
5: Cover
6: Outlet connection
7: Absorber

[2] Peter F. Smith, *Sustainability at the Cutting Edge – Emerging technologies for low energy buildings.* Oxford, UK: Architectural Press, 2007, p.15.
[3] Peter F. Smith, 2007, p.116.

The absorber efficiency of the flat plate collector system is normally around 91% to 96% with an emission efficiency of 5% to 10%. Furthermore, this collector is the most common type and offers a high range of mounting possibilities. [4]

4.1.2 VACUUM TUBE COLLECTOR

A vacuum tube collector costs more than flat plate collector, but achieves higher temperatures and efficiencies. The circular shape of the evacuated tube makes it possible to exploit solar radiation for most of the day and offers the advantage that it works efficiently with high absorber temperatures and low radiation. This reduces heat loss and provides an absorber efficiency of the system that is normally about ~92% with an emission efficiency of ~8%. Therefore, a vacuum tube collector can heat water up to 60°C (in good conditions significantly higher) and provides a good energy performance even at low light angles. The flat plate collector is normally in a fixed position and allows the sun only to be perpendicular to the collector at noon. This characteristic of the vacuum tube collector in combination with the fact that the vacuum minimises heat losses, makes it particularly suitable to cooler climates. [5]

Plate 4.3
Vacuum Tube Collectors,
4 VERO VC 20 collectors allow for good utilization of roof space with a weight of 20kg, Wagner & Co, Bingen, Germany

The system of the vacuum tube collector is built as an evacuated tube that is enclosed within an insulated steel casing and based on a special fluid that begins to vaporize even at low temperatures. The steam rises in the individual heat pipes and warms up the carrier fluid in the main pipe. Afterwards, the condensed liquid flows back into the base of the heat pipe to be heated again. Therefore, the absorber strip is located in a pressure proof glass tube and the heat transfer fluid flows through the absorber. Therefore, the vacuum tube collector has

[4] Peter F. Smith, 2007, p.116.
[5] Peter F. Smith, 2007, p.16.

to be mounted with a tilt or vertical so that the process of vaporizing and condensing can proceed. [6]

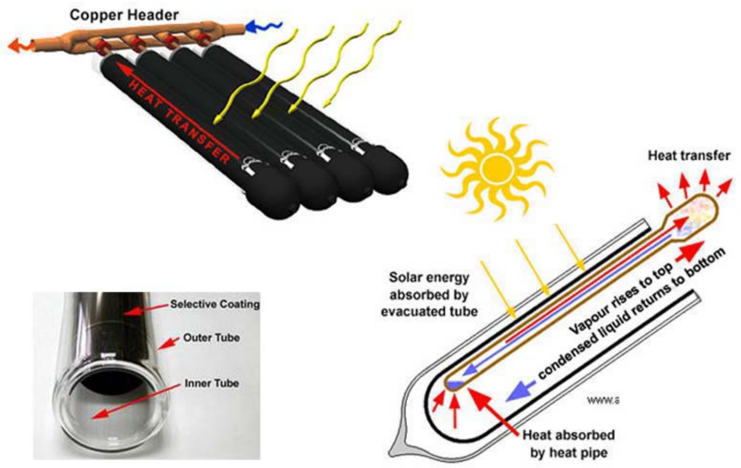

Plate 4.4
Function and Components of a Vacuum Tube Collector,

4.1.3 DOMESTIC HOT WATER STORAGE TANK

In order to use the full potential of a thermal solar system it has to be connected to a hot water storage tank. This tank stores the excess warmth during the day to supplement DHW and night heating. [7] The tank should provide a minimum of 80 and preferably 100 litres storage per square metre of the collector area. A typical size for a family of four is 300 litres, 75 litres per person each day (*refer to chapter 4.4.3*). This paper introduces the ECO basic solar storage unit as an example of an economically and technologically proven storage solution for a thermal solar system. This storage tank is steel made and has 2 welded in heat exchangers for solar and space heating circulation. [8]

Plate 4.5
Domestic Hot Water Storage Tank, ECO basic solar storage made from enamelled steel

[6] Peter F. Smith, 2007, p.16.
[7] Peter F. Smith, 2007, p.16.
[8] Wagner & Co, *Solar Technology*, Cölbe, Germany, Retrieved June 08, 2008 from the World Wide Web: http://www.wagner-solar.com/wagnerEN/SW/04/P2.php?navid=15.

4.2. ACTIVE AND PASSIVE THERMAL SOLAR SYSTEMS

A collector can also be applied into a thermosiphon based system that uses gravity and thermal buoyancy to drive water through the solar collector to be heated directly by the sun. This allows the water to move through the system without electric components, such as electric pumps (*refer to image 4.7*). Therefore, the passive system is generally more reliable and easier to maintain than active systems and known as a passive thermal solar system. If this system is installed in cooler climate zones, it is possible to combine it with a heat transfer fluid in an indirect system, also known as a closed loop system (*refer to chapter 4.3*). [9] However, the system is prone to sluggish performance and offers a poor control of overheating. Furthermore, the use of the thermal buoyancy also requires the installation of the hot water storage tank above the collector, which in return requires a high quality of planning to optimise the energy performance. [10]

Plate 4.6
Thermosiphon based System, Vacuum tube collector with a direct connection to a horizontal storage tank with a weight of 109kg and a tank volume of 192 litre, 90%~94% absorption, ~7,5% emission, temperature 55°C, Shanghai Solar Panels Co. Ltd, Shanghai, China

Unlike the passive thermal solar systems, the active system uses pumps to provide circulation of the water and make it possible to place the tank freely instead of above the collector. The pumps are controlled by a temperature controller to control overheating and to provide thermal energy from the collector at an optimal rate. The sensors of the controller are placed at the collector and on the hot water storage tank to activate the system when the water in the collectors is hotter than in the tank. Therefore, the introduction of electric components optimises the energy performance, but also leads to a higher complexity. Furthermore, the pumps cause higher costs and require conventional electricity, which can be alleviated through the combination with a PV system. [11]

[9] Peter F. Smith, 2007, p.16.
[10] National Green Specification 2006, *Solar Technology*, UK, Retrieved June 08, 2008 from the World Wide Web: http://www.greenspec.co.uk/html/energy/solarcollectors.html.
[11] Peter F. Smith, 2007, p.16.

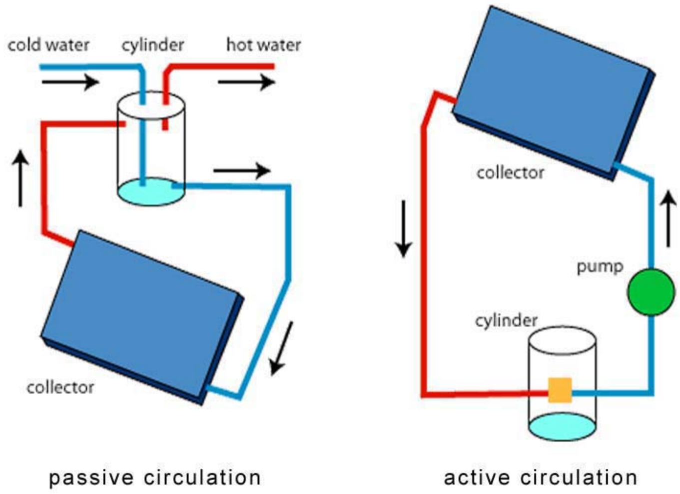

Plate 4.7
Passive and Active Circulation,
Passive circulation is based on the gravity and the thermal buoyancy to drive the water, active circulation uses a pump to provide mechanically circulation of the water

4.3. DIRECT AND INDIRECT THERMAL SOLAR SYSTEMS

Thermal solar systems are based on one of two basic principles, which are different in terms of heat exchange. The first one is the active direct system, also known as an open loop system, and the second the indirect system, also called a closed loop system. The active direct system is similar to the passive thermal solar system, but it uses a pump to drive the water through the solar collector and it is not possible to use water with antifreeze supplement. A thermometer and controller register when the solar collector is warm enough to heat up the water. The controller starts the pump and the water moves into the thermal solar collector to be heated by the sun. Then the DHW can be stored in a hot water tank or is used straight by the occupants. This type of system is usually combined with a gas or electricity system in order to keep the water warm during periods of cold days. Another problem is that this system circulates pure, potable water through an outdoor collector and needs an additional safeguard system to protect the collector from frost damage. [12]

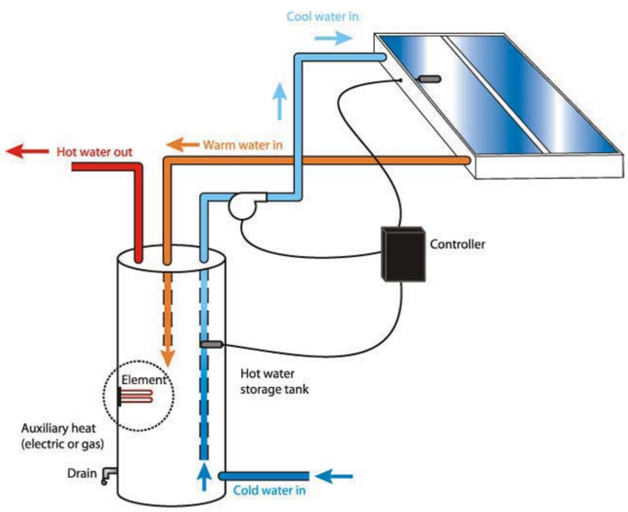

Plate 4.8
Active Direct System,
The pump as an additional devise drives the water directly into the tank and back into the collector

[12] Peter F. Smith, 2007, p.16.

An indirect system is a combination with a heat transfer fluid or water that is mixed with an antifreeze supplement. This system, known as a closed loop system, is different in terms of the heat transmission. A pump drives the antifreeze solution through a loop into the thermal solar collector that heats up the antifreeze solution by the sun. Afterwards, it leaves the collector and is pumped into a heat-transfer unit. This unit transfers the heat from the antifreeze solution to the domestic water which is stored in a hot water tank or is used straight by the occupants. The antifreeze solution then returns into the solar collector again. Indirect systems, or closed loop system, are used in region with climates that have extended periods of below zero temperatures (*refer to image 4.5*). [13]

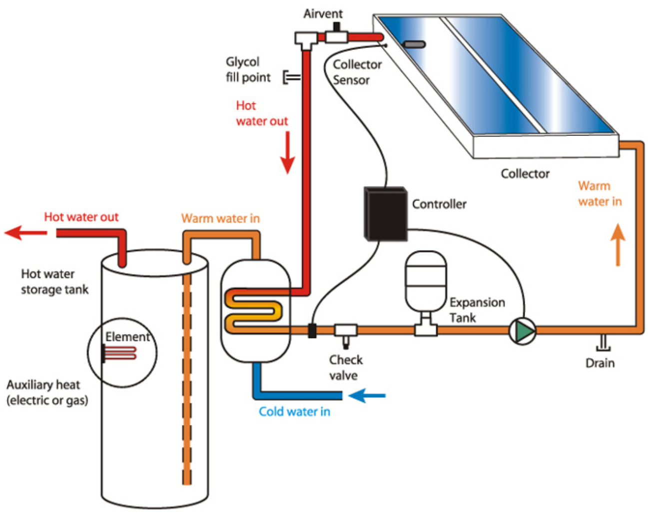

Plate 4.9
Active Indirect System,
The pump as an additional device drives the water into the heat-transfer unit that transfers the heat from the antifreeze solution to the domestic water.

4.4. DESIGN CONCEPTS

Creative and innovative ideas are necessary to create an aesthetic architectural concept that enables a sensitive introduction of thermal solar collectors into a new building design. The financial support and the technical feasibility have to be taken into account as well. In this case, the architect and the engineer must consider the integration of thermal solar collectors and systems from the early stage. The relation between the cost development and the standardisation, as well as the specialisation of products, is also important. Overall, it must be decided individually in each case, which product and which system suits the current project. [14]

4.4.1 ORIENTATION AND TILT

In order to receive the maximum annual amount of solar radiation, the thermal solar collector must be facing towards the equator (south in the northern hemisphere and north in the

[13] Peter F. Smith, 2007, p.16.
[14] Ingrid Hermannsdörfer, Christine Rüb, *Solar Design: Photovoltaics for Old Buildings, Urban Space, Landscapes*. Berlin, Germany: Jovis Verlag, 2005, pp.33-35.

southern hemisphere) with a specific tilt from the horizon that is related to the latitude of the building site. For example, London at latitude of 51° 30′28″N generates a maximum annual amount of 1045 Wh/m² per year with a south orientation and at a tilt of about 31°, which is the latitude of the building site minus 20°. In New Zealand (southern hemisphere) the collector should face true north with an angle from the horizon 5° to 10° greater than the angle of the latitude. For example, Auckland at a latitude of 36° 51′S exploits the maximum annual amount with an orientation due true north and at a tilt of about 41° to 46°. It is also possible to make deviations from the latitude angle of ±20%. This leads to a wide range of possible orientations and tilts, but the total output per year is still around 95% of the maximum. [15]

Roof angles in New Zealand are normally between 20°and 30° and thermal solar collectors should be mounted flush with the roof to lower costs, rather than to use supports to achieve a greater angle. The performance in winter might be slightly reduced, but the benefits outweigh the costs. Furthermore, roof areas are not only well suited for the installation of thermal solar systems. In fact, they are also eligible for the installation of photovoltaic systems and this applies to pitched roofs and flat roofs as well (*refer to chapter 5*). [16]

Another point is that the technical requirements of some thermal solar systems could become a problem. For example, passive systems, like the vacuum tube collector system based on the thermal buoyancy, need to be mounted with an angle. This fact in mind, it makes the passive systems not useable as a horizontal installation, e.g. mounted on a flat roof. It has also to be considered that the horizontal and the vertical installation are less efficient than an installation on inclined surfaces, because it never allows the sun to be perpendicular to the collector, which reduces the annual amount of solar radiation. Furthermore, these situations call for an additional basic structure to provide an angle to the thermal solar collectors. [17]

4.4.2 BUILDING-INTEGRATED THERMAL SOLAR SYSTEMS

A broad range of thermal solar collectors are available on the market that can be roof-attached or roof-integrated systems. Against photovoltaic systems that provide normally lower additional weight to the roof structure, it could be necessary to provide structural alterations when vacuum tube collector with a storage tank above would be installed. Furthermore, the choice of a thermal solar system, either a flat plate collector system or a

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[15] Randall (ed) Thomas, Max (ed) Fordham, *Photovoltaics and Architecture*. London, New York: Spon Press, 2001, pp.11-12.
[16] Randall (ed) Thomas, Max (ed) Fordham, 2001, pp.11-12.
[17] Ingrid Hermannsdörfer, Christine Rüb, 2005, p.21.

vacuum tube system, as well as its size of the collector system is based on the local climate and location, and the usage of the specific building (*refer to chapter 4.4.3*). Overall, the design and the structural integration of thermal solar collectors in an architectural design have to take three different aspects into account: energy engineering, architectural design and the building itself. [18]

An innovative solution of building-integrated thermal solar collectors was demonstrated at Sweden's first international housing exhibition, the Bo01 in Malmö, Sweden. The new city district is called “City of Tomorrow” and is a part of the experimental campus. The buildings are designed to minimize energy demands for heating and electrical equipment. Therefore, a large proportion of the heating needs is extracted from sea water and groundwater and is complimented with vacuum tube collectors. These vacuum tube collectors are vertically mounted and are an essential part of the DHW supply. Flat plate collectors are cheaper, but vacuum tube collectors provide a higher efficiency with an absorber temperature that is significantly higher than what a flat plate system can reach. This makes this system particularly suitable to cooler climates such as Sweden. Furthermore, the mounting angle of a vacuum tube collector is not critical and, thus, makes it ideal for vertical wall installations. [19]

Plate 4.10
City of Tomorrow,
Vacuum tube collectors that are wall mounted at a building that is part of the experimental campus, ~82.5 % absorption, weight: 68Kg, dimensions: 2126 x 1996 x 122, Malmö, Sweden, 2001

The Viessmann Vitosol 300 thermal solar collector is an essential part of this thermal solar system. It can utilize diffused solar radiation and is suitable for domestic hot water applications as well as a backup for central heating purposes. 30 vacuum tubes form one collector panel with a total surface area of up to 3m². Therefore, this thermal system is

[18] Ingrid Hermannsdörfer, Christine Rüb, 2005, pp.29-31.
[19] Antonoff, Jayson. “Can Pioneer Square-Stadium District be energy self-sufficient?”, *Daily Journal of Commerce*, October, 2005.

realised with 21 collectors that form a surface area of approximately 63 m². [20] However, the thermal solar collectors are added to the architectural image and the research report comes to the conclusion that the contextual integration is excellent. The system creates a visual edge to the building and lead to a positive influence on the architectural design that does not overpower the building form.

The Upland Hills Ecological Awareness Center (EAC) in Oxford, United States is another example of a building-integrated thermal solar system. During the research process it came up that it was difficult to find specific resources that provide facts and information about the data of this building. [21] However, the flat plate collectors determine the architectural image and are used as an integral part of the building envelope. Therefore, they are playing an important role in the total architectural image of the building. Generally, specific attention has to be given to the site in terms of the solar orientation, but it seems that the system is shaded by existing trees on site. Therefore, the research paper identifies that the location of the thermal solar system is imperfect, but the building design can be seen as good example of a building-integrated thermal solar system.

Plate 4.11
Upland Hills EAC,
The Upland Hills EAC is another example of building-integrated flat plate collectors that is part of the architectural design, Oxford, US, 2004

The integration of thermosiphon based systems that have a direct connection to a horizontal storage tank into an architectural design might be difficult. Therefore, the architectural quality has to be of a high standard to be qualified as "well-integrated". Furthermore, the technical performance of the thermal solar system and the building quality itself have to be met. In this case, it has to be clear that a poorly integrated thermal solar system on a well-designed

[20] Viessmann Manufacturing, *Vacuum Tube Collector: Vitosol 300*. Waterloo, Ontario, Canada, Retrieved June 08, 2008 from the World Wide Web: http://www.viessmann.us/web/canada/ ca_publish.nsf/ Content/Vitosol300_ca_english.
[21] Upland Hills Ecological Awareness Center (EAC), Building-integrated Thermal Solar System. Oxford, Michigan, US, Retrieved June 08, 2008 from the World Wide Web: http://www.uheac.org.

building might be disturbing, but a poorly integrated thermal solar system on a poorly designed building is worse. [22] For example, the Earthsong Eco-Neighbourhood in Waitakere City contains 32 self-contained dwellings that are compact, passive solar buildings with thermosiphon based thermal solar systems on their roofs. These collectors are not building-integrated, but they feed into the architectural design that includes productive landscaping, native bush, orchard areas and water management. [23]

Plate 4.12
Earthsong Eco-Neighbourhood, Compact, passive solar buildings with thermosiphon based thermal solar systems on their roofs, Waitakere City, New Zealand, 2007

Another innovative project is the “plusenergy house”, the Heliotrop in Freiburg i.B., Germany. A “plusenergy house” produces more energy from renewable energy sources (on average over a year) than it imports from external sources. This is achieved in this project by using a combination of active devices such as PV modules, vacuum tube collectors and a rainwater catch system, solar design and a high quality of insulation. The construction stands on a ring gear with a swinging element that offers the possibility to turn the face of the house with its glass-façade to the sun - or to turn it out of the sun during the time of high temperatures. Furthermore, different types of experimental thermal heating systems that have been the subject of research are installed to test them first in this building.

One of these systems is a newly developed radiant ceiling heating of copper segments that is developed as a quick low-temperature heating system and can be used as a cooling device in summer as well. Another one is a solar tank that is used to control the ventilation with heat recovery and an earth-to-air heat exchanger. It works as an air conditioner in the summer in order to save energy and to improve the living comfort. Furthermore, the solar

[22] Prasad, Deo. (ed.) Snow, Mark. (ed.) *Designing with Solar Power – a source book for building integrated photovoltaics (BiPV)*, Lodon, Sterling, VA, Earthscan, 2005, p.29.
[23] Johann Bernhardt, *A deeper shade of Green: Sustainable Urban Development, Building and Architecture in New Zealand*. Auckland, New Zealand: Balasoglou Books, 2008, pp.181-182.

tank system synergises with the radiant ceiling heating to warm up the room quickly or to cool it down in the summer. [24]

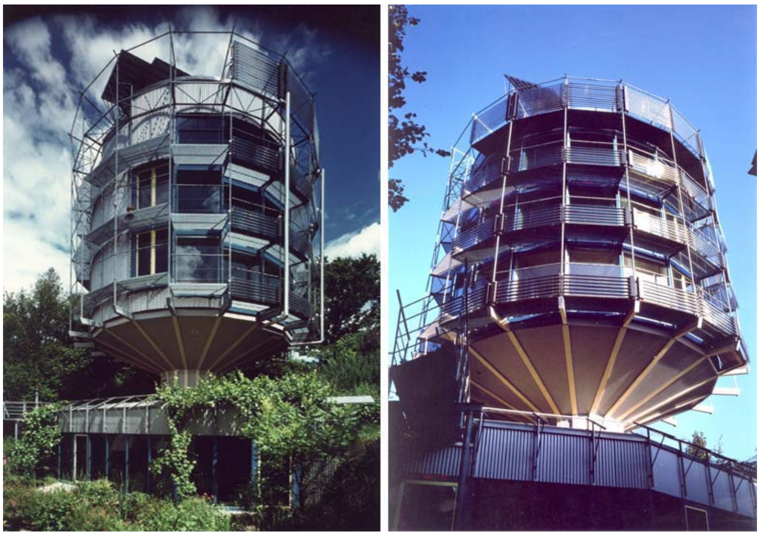

Plate 4.13
Heliotrop,
The rotating solar house, called the Heliotrop is an energy-producing plusenergie house, Freiburg i.B., Germany, 1994

The vacuum tube collectors deliver the remaining thermal heat and energy requirement for the DHW supply. Furthermore, the vacuum tubes are integrated as integral parts of the balustrades outside the building - an excellent solution of integration into an architectural design. [25] The application of the thermal solar collectors into the building design in combination with the PV modules and the other concepts such as the solar design and a rainwater catch system lead to a new kind of architecture. Furthermore, this project presents new design options and concepts, but architecturally it is distinguishable from traditional residential buildings and has to be seen as a unique building. Therefore, it is not usable as a solution that could be built in bigger quantities.

4.4.3 CALCULATION OF A THERMAL SOLAR ABSORBER AREA

The design of a thermal solar system is a complex process. It is required to manage a range of related factors before it is possible to create an energy efficient building. The site, the building orientation and the financial resources are only a few aspects in terms of the integration of a thermal solar system. [26] Furthermore, it is important to know the size of the thermal solar system that is necessary to provide DHW to the occupants before even designing the building. Therefore, this research paper introduces a system of factors that can be used to calculate the size of an absorber area of a thermal solar system. This system transforms all related values, such as sunshine hours, collector orientation, DHW consumption, the number of the occupants and the hot water demand into factors in order to

[24] Disch, Rolf. *Solar Architecture Office: Heliotrop Project*, Freiburg i.B., Germany, Retrieved Mai 08, 2008 from the World Wide Web: http://www.rolfdisch.de
[25] Disch, Rolf. 2008 from the World Wide Web: http://www.rolfdisch.de
[26] Brenda and Robert Vale, *The New Autonomous House*, p.67.

calculate the absorber area. Therefore, the research paper uses the Auckland region as an example to be able to identify the climate zone and to explain the calculation of the area that would be necessary to provide DHW for 4 occupants (parents with 2 children).

climate zone	sunshine hours	factor
1	1900 - 2000	0,8
2	1800 - 1900	0,9
3	1700 - 1800	1,0
4	1600 - 1700	1,1
5	1500 - 1600	1,2

Plate 4.14
Annual Value of Sunshine Hours,
Auckland has a value of approximately 2060 sunshine hours per year, 2060 ≙ factor 0.8

The Auckland region has a value of approximately 2060 sunshine hours per year. According to the climate zone, this leads to a sunshine factor of 0.8 (*refer to image 4.14*). The collector should face true north with an angle from the horizon of 5° to 10° greater than the angle of the latitude. Auckland with a latitude of 36° 51′S has the maximum annual amount of solar radiation in a range between 41° to 46° of tilt. Standard roof angles are normally between 20°and 30° in New Zealand and the collector should be mounted flush with the roof to provide lower costs rather than to using supports to achieve a greater angle in this case. [27] Taking this into account, the thermal solar collector should face true north with an angle of approximately 25°, which leads to a factor of 1.1 (*refer to image 4.15*).

roof tilt	collector orientation		
	N	NO/NW	O/W
15°	1,2	1,2	1,3
25°	1,1	1,2	1,4
35°	1,0	1,2	1,5
45°	1,0	1,1	1,5
55°	1,1	1,2	1,6
65°	1,2	1,3	1,7
75°	1,3	1,4	1,8

Plate 4.15
Collector Orientation on the Roof,
Roof angles in New Zealand are normally between 20° and 30°, towards north has the highest radiation, north 25° ≙ factor 1.1

Furthermore, it is necessary to indicate the DHW consumption of the occupants. In this example, the hot water consumption by the occupants is assumed to be around 75 litres per person, which is considered to be normal. This leads to a consumption factor of 1.0 (*refer to image 4.16*).

low		normal		high
0,6	0,8	1,0	1,2	1,5

Plate 4.16
Hot Water Consumption, normal ≙ factor 1.0

Taking the sunshine hours (factor 0.8), the collector orientation (factor 1.1), the DHW consumption (factor 1.0) and the number of the occupants (factor 4) into account, it comes to

[27] Randall (ed) Thomas, Max (ed) Fordham, *Photovoltaics and Architecture*. London, New York: Spon Press, 2001, pp.11-12.

the result that 3.50 m² of solar absorber area are necessary (*refer to image 4.16*). This amount of absorber area can be used to create a building design that satisfies the needs of the occupants and provides enough DHW to the household.

factor sunshine hours		factor roof orientation		factor hot water demand		occupants		absorber area (square metre)
0,8	x	1,1	x	1,0	x	4	=	3,52

Plate 4.17
Solar Collector Absorber Area, demand ≙ 3.5 m²

It is also necessary to know how much DHW has to be stored in the house. Generally, a hot water storage tank should provide a minimum of 80, preferably 100 litres of storage per square metre of the absorber area. Assuming that 4 occupants live in the household with a normal consumption of DHW, it comes to the result that a 300 litre hot water storage tank would be necessary (*refer to image 4.18*).

occupants		factor hot water demand		hot water demand		hot water storage tank
4	x	1,0	x	e.g.75 Ltr.	=	300 Ltr.

Plate 4.18
Hot Water Storage Tank, assumed 300 litre

The last major decisions that have to be made are about the two basic principles of thermal solar systems, the direct or indirect system and the position of the hot water storage tank. In order to make the right choice, it is useful to know that the Auckland region has approximately 10 days of frost with a temperature of -2.5°C every year. Therefore, the thermal solar system can be designed as an indirect system that contains a heat transfer fluid or water that is mixed with an antifreeze supplement. However, taken the number of days into account where this solution would be necessary, it seems useful to design the system as a direct system in combination with a safeguard system to protect the collector from freezing during this short period. Furthermore, it has to be asked where the storage tank has to be located. In order to be in the position to locate this facility downstairs inside the house, the research paper assumes that it would be useful to introduce an active system. [28]

[28] New Zealand National Institute of Water & Atmospheric Research, *Climate Data and Activities. Auckland*, New Zealand, Retrieved April 23, 2008 from the World Wide Web: http://www.niwa.cri.nz/edu/resources/climate.

4.5. RECENT DEVELOPMENTS

An active vacuum tube collector system requires power to run the pump that circulates the water which. This requires power, which produces emissions. In order to become a true zero fossil energy option, the active collector system has to be a combination of a thermal solar collector and a PV module. [29] For this purpose, the first hybrid vacuum tube thermal solar collector, the AMK OPC15 Edition EU21 is developed by AMK Solac-Systems AG and the German engineer's office EU21. Their thermal solar collector is designed to produce thermal energy with vacuum tubes and electrical energy with a high-quality current-generating copper indium diselenide (CIS) laminate (*refer to chapter 5.2.2*).

Plate 4.19
Vacuum Tube Collector
** Absorber area: 2.50 m²*
** Weight: 48 kg*
** Capacity value: 752 kWh/(m²a)*

Copper Indium Diselenide Cell
** Capacity: 16.0 W*
** Voltage: 17.0 V*
** Electric current: 0.92 A*
** Dimensions: 1200 x 150 x 17.75*

Overall, the combination of thermal solar systems and PV-technology makes it possible to integrate an active solar system that functions without any external energy, making it effectively carbon neutral. Furthermore, this thermal solar collector is suitable for places where no electrical supply is present. Finally, this innovative idea leads to zero operating costs and a minimum environmental impact. [30]

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[29] Peter F. Smith, 2007, p.15.
[30] AMK Solac-Systems AG. *Hybrid Vacuum Tube Collector: AMK OPC15 Edition EU21*, Sevelen, Switzerland, Retrieved Mai 08, 2008 from the World Wide Web: http://www.amk-solac.com/index.php?Itemid=41&id=24&option=com_content&task=view

5. PHOTOVOLTAIC TECHNOLOGY IN ARCHITECTURAL DESIGN

This chapter explores photovoltaic (PV) technology and takes a closer look at the operating principles. It explains factors and measurements, such as the energy payback times and efficiencies of different types of PV cells. The chapter shows how important these indicators are in terms of the application of solar cells and modules in different types of building typologies.

The chapter examines concepts to integrate PV-modules into the envelope of an existing building or a new architectural project. It explores building-integrated photovoltaic (BiPV) technology that is rapidly evolving and shows that this technology is becoming a significant part of building design.

Recent developments are introduced in the last part of this chapter to illuminate what might be possible tomorrow. These examples of developments are important in two ways as they demonstrate a positive development in sustainable technologies and designs and also indicate the need of a rethinking in energy usage.

5.1. PHOTOVOLTAIC TECHNOLOGY

The word "photovoltaic" is a combination of two words: phos, which is the Greek word for light, and volt, which is the unit of electric voltage. The first photovoltaic cells have been used in space ships and satellites at the end of the 1950s. Since then, there have been many further developments. Today, the most common standard module is made from high-grade silicon that is based on crystalline silicon cells (c-Si), also known as solar grade silicon. [1]

This common solar cell is treated with positively and negatively charged semiconductors, called phosphorous and boron. The actual transformation of solar energy into usable electrical power takes place at the atomic level. For example, if a photon hits a solar cell, it detaches the negatively charged electrons from their atoms through the impact and excites the electrons within the cell. This effect is called "doping" and it initiates the flow of electrons from the negative semiconductor (phosphorous) to the positive semiconductor (boron) that is finally known as the PV effect, this is what generates electricity. [2]

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[1] Ingrid Hermannsdörfer, Christine Rüb, *Solar Design: Photovoltaics for Old Buildings, Urban Space, Landscapes*. Berlin, Germany: Jovis Verlag, 2005, p.133.

[2] Prasad, Deo. (ed.) Snow, Mark. (ed.) *Designing with Solar Power – a source book for building integrated photovoltaics (BiPV)*, Lodon, Sterling, VA, Earthscan, 2005, p.23.

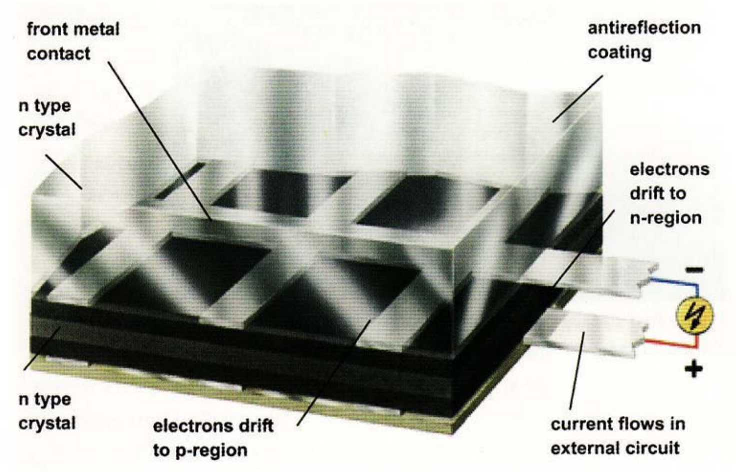

Plate 5.1
Solar Cell Operating Principles
A common solar cell made from high-grade silicon and treated with positively and negatively charged semiconductors

5.2. CELLS, MODULES AND ARRAYS

The basic solar cell produces only a small amount of power. In order to increase the efficiency, PV cells are electrically connected as modules and usually in series, also known as arrays, to produce more power. Theoretically, this modularity offers the possibility to design a PV system that can meet any electrical requirement. However, the size of the system is related to the size of the building structure. The module is mostly sealed with glass to protect the solar cells inside the module from environmental influences. These influences can be e.g. mechanical wear, weather conditions and corrosion. A standard module is normally produced with a frame to protect the edges from breakage and to provide a higher quality of sealing, but it also causes higher costs. In order to achieve a higher flexibility in terms of building design, it is advisable to use frameless modules. [3]

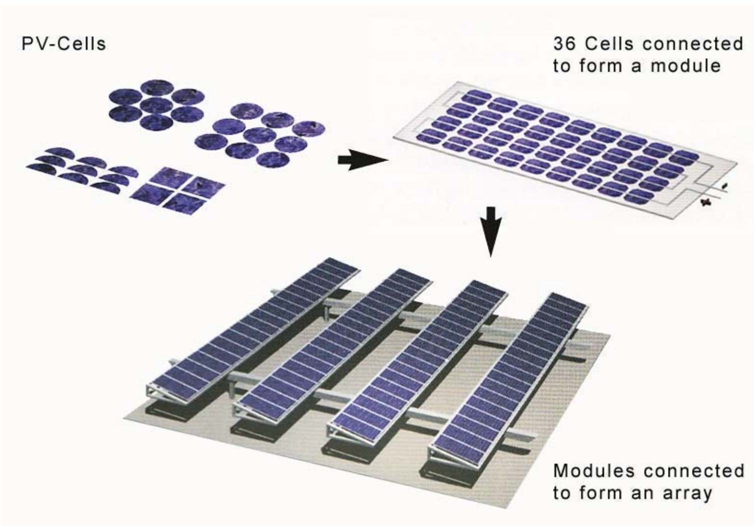

Plate 5.2
PV-Cells, Modules and Arrays

[3] Ingrid Hermannsdörfer, Christine Rüb, 2005, p.133.

5.2.1 MONO, POLY AND AMORPHOUS SILICON CELLS

The most important part of a solar cell is the semiconductor layer. Solar cells are manufactured from a wide range of different semiconductor materials, but the most important material is silicon, used in various forms. According to their crystalline structure, PV-cells can be separated into three different major categories: the mono-crystalline cell, the poly-crystalline cell and the amorphous silicon cell, also known as thin-film cell. (*refer to images 5.3 to 5.8*). The mono-crystalline silicon cell (m-Si) is made of pure mono-crystalline silicon that leads to higher costs for the production compared to other technologies. It has a high efficiency that is normally between 12% and 15%. [4] The second is formed by the poly-crystalline thin-film cells with copper indium diselenide (CIS) and thin-film silicon (*refer to images 5.9 and 5.10*). The last category is the single-crystalline thin-film cell that is made with gallium arsenide, also known as copper indium gallium diselenide (CIGS) cells (*refer to images 5.11 and 5.12*). [5]

The Energy Research Foundation (ECN), based in the Netherlands, shows how mono-crystalline silicon cells can be used to explore a new architectural concept. The architectural design of the conservatory glazing contains 570 PV modules on a total area of approximately 400 m², generating 43 kWp of power. Aluminium glazing profiles are placed to hold the 575 x 1175 mm PV-modules that contains 32 PV-cells, horizontally and vertically. The integrated PV cells are BP Solar mono-crystalline laser grooved buried grid (LGBG) cells that have a size of 125 x 125 mm with an efficiency of 16,5 %. Furthermore, the cells are spaced with a distance of 1 and 2 centimetres to allow light transmittance of 30% to the interior conservatory space, avoiding overheating, but allowing natural lighting. [6]

Plate 5.3 / 5.4
Mono-Crystalline Silicon Cell (m-Si)
Used to explore a new architectural concept at the ECN

[4] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, p.23.
[5] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, p.23.
[6] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, pp.112-117.

The poly-crystalline silicon cell (pc-Si), also known as multi-crystalline cell, is generally less efficient than the mono-crystalline silicon cell, but is considerably less expensive to produce. The manufacturing can be done in a variety of ways, but based on using ingots of multi-crystalline silicon. The average efficiency of a poly-crystalline silicon cell is between 11% and 14%. [7] The range of colours for crystalline as well as for thin-film cells is limited by physical reasons. Usually, poly-crystalline cells are blue, but in order to achieve other colour schemes it is possible to modify the antireflection layer. The negative effect is that the modification also lowers the efficiency of the cell. [8]

The ECN building can also be used as an example to show how poly-crystalline silicon cells can be added to the architectural design in form of a PV lamella façade. This façade contains 546 PV-modules produced by Shell Solar. The lamellas are made of folded aluminium sheet, enamelled for a higher durability, and mounted on vertical IPE 120 steel profiles that are interconnected with horizontal IPE 120 profiles. The rears of the metal lamellas have holes for ventilation of the PV-modules which have a size of 478 x 1006 mm. Each PV-module generates 48 Wp (*Watt peak - refer to chapter 5.3.1)*, adding up to 25.21 kWp of power for the complete PV-array. [9]

Plate 5.5 / 5.6
Poly-Crystalline Silicon Cell (pc-Si)
Added to the architectural design of the ECN as a shading device

An amorphous silicon cell (a-Si), also known as a thin-film cell, is rigid and flexible. This characteristic makes it ideal for curved surfaces and fold-away modules, but it also reduces the efficiency down to 6 % and 8 %. In terms of manufacturing, the amorphous silicon cell technology provides the possibility to reduce the amount of light absorbing material that is required to produce a solar cell. The results are lower costs in terms of material on one hand,

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[7] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, p.23.
[8] Ingrid Hermannsdörfer, Christine Rüb, 2005, p.41.
[9] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, pp.105-111.

but also a reduction of the energy conversion efficiency on the other hand. [10] In order to minimise the effect of the reduction, the integration of a multi-layer thin-film cell would be a solution. This multi-layer exploits the spectral range of light in a higher degree and has an efficiency that lies above the current standard of a crystalline silicon cell technology. [11]

The amorphous silicon cells are also a major part of the architectural design of the solar house project of the TU Darmstadt for the Solar Decathlon 2008 in Washington D.C., United States. The solar house is completely surrounded by timber shutters that support the energy supply of the building. The louvers of the east, south and west facades are equipped with Schott amorphous silicon cells. Therefore, the integrated PV system determines the architectural image and is used as an integral part of the building envelope. In order to increase the efficiency, the louvers move with the ideal sun angle. Overall, this project won the Solar Decathlon 2008 and the paper assumes that it can be seen as an excellent example of building-integrated PV technology. [12]

Plate 5.7 / 5.8
Amorphous Silicon Cell (a-Si)
Added to the architectural image of the Solar House Project

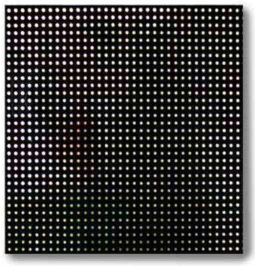
5.2.2 SEMI-TRANSPARENT CELLS

Thin-film photovoltaic cells are also available as semi-transparent cells. These cells offer new application possibilities in terms of the architectural integration. Semi-transparent cells are used to generate power like the standard modules, but are multifunctional in their application. Therefore, they are known as multifunctional objects which combine power generation, lighting and other functions. Furthermore, they can be used as design elements and integrated as a replacement of standard glazing, e.g. conservatory glazing. [13]

[10] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, p.24.
[11] Ingrid Hermannsdörfer, Christine Rüb, 2005, p.133.
[12] University of Technology Darmstadt, *Solar House Proj*ect, Darmstadt, Germany, Retrieved June 10, 2008 from the World Wide Web: http://www.solardecathlon.de/index.php/our-house/the-shell/.
[13] Ingrid Hermannsdörfer, Christine Rüb, 2005, p.39.

As an example, this research paper introduces the new semi-transparent Sunways solar cell. This semi-transparent cell is based on mono- and multicrystalline silicon and achieves efficiencies of up to 13.8 % with 10 % transmittance. Furthermore, it is possible to vary degree of transparency infinitely. [14] The semi-transparent Sunways solar cells are also an integral part of the architectural design that is conceived for the solar house project of the TU Darmstadt. The students integrated the semi-transparent cells into the glass roof of the loggia in order to generate power and to provide shade and natural light inside the house. By arranging the perforated cells with little gaps between each of them, it is also possible to manage the grade of light transmission and energy gain. [15]

Plate 5.9 / 5.10
Semi-transparent Cell
Added to the architectural image of the Solar House Project



5.2.3 COPPER INDIUM DISELENIDE CELLS

A recent development is the copper indium diselenide (CuInSe2 or CIS) cell. It is based on a poly-crystalline thin-film cell, which provides efficiency between 8% and 14%. Under standard test conditions, it can reach even the efficiency of the best poly-crystalline-silicon cell. Furthermore, the CIS cell absorbs 99% of the radiation in the first micrometer of the material, leading to an extremely high absorptivity. In order to improve the voltage and the efficiency of the CIS cell, small amounts of gallium can be added to the lower absorbing CIS layer. This particular variation is known as a copper indium gallium diselenide (CIGS) cell. A problem is the production of the CIGS cells that is still too complicated. [16]

However, Shell Solar has developed a copper indium diselenide module, the ST36 CIS-Module that is integrated in the architectural design of the new Opto-electronics Technology

[14] Sunways AG, *Photovoltaic Technology*, Konstanz, Germany, Retrieved June 10, 2008 from the World Wide Web: http://www.sunways.de/en/products/solarcells/solarcelltrans.php.
[15] University of Technology Darmstadt, 2008 from the World Wide Web: http://www.solardecathlon.de/index.php/our-house/the-shell/.
[16] Ingrid Hermannsdörfer, Christine Rüb, 2005, p.133.

and Incubation Centre (OpTIC centre) in St Asaph, North Wales. In order to create a curved "solar wall", the design integrates 2400 ST36 CIS modules that provide a capacity of 85 kWp. Since its installation 2004, it is still Europe's largest single CIS solar-powered building installation. [17]

Plate 5.11 / 5.12
Copper Indium Diselenide Cell (CIS)
Added to the architectural image of the OpTIC centre in St Asaph

5.3. SYSTEMS AND MEASUREMENTS

A PV-system can be built as an island system (also known as a stand alone system) and as a grid-connected system. An island system works independently from the public utilities' grid. Therefore, and to guarantee a constant supply of power, it requires a storage system, such as batteries, to compensate variations in power supply. The grid-connected system, as the name already assumes, is connected to the public utilities' grid to feed the power into the grid or to take it back to compensate variations of power supply. In order to control this in- and output of power and to reimburse the costs, the system uses a surveillance system, a distribution system and a current counter. [18]

The grid-connected system guarantees a constant supply of power without any additional storage systems and the profitability of a PV system is greater, the higher the comparative cost of grid supply is. However, the choice between an island system and a grid-connected system is also related to the climate, the location, the use of the building and, of course, the availability of a public utilities' grid. Furthermore, it is necessary to consider the costs and savings of other building components, such as roof tiles, when the system is building-integrated, as well as important data of the PV system, such as the energy yield. [19]

[17] AVANCIS GmbH, *Opto-electronics Technology and Incubation Centre*, Torgau, Germany, Retrieved June 10, 2008 from the World Wide Web: http://www.avancis.de/references/optic-centre.html.
[18] Ingrid Hermannsdörfer, Christine Rüb, 2005, p.139.
[19] Ingrid Hermannsdörfer, Christine Rüb, 2005, p.139.

5.3.1 WATT PEAK AND THE REAL EFFICIENCY

The delivered power of a PV-module under perfect conditions is measured in "Watt peak" (Wp) in order to indicate the highest possible productivity. Perfect condition means the direct and perpendicular solar irradiation with a maximum of 1 kW/m² (*refer to chapter 1.1.1*). The real efficiency of a photovoltaic cell depends on the geographic location, on the irradiation duration and the incident angle of the solar radiation which is related to the season. The energy that is exploited by the photovoltaic cell is determined as an annual yield in kWh/m². For example, a photovoltaic module that has a size of one square metre and a vertical irradiation by the sun of one hour, delivers an electric power of 0.1 kW, which corresponds to be a real efficiency of 10 %. [20]

cell technology	real efficiency	laboratory efficiency
mono-crystalline silicon	12% - 15%	24.7%
poly-crystalline silicon	11% -14%	19.8%
amorphous silicon	6% - 8%	12.7%
copper indium diselenide	8% - 12%	18.8%

Table 5.1 - Cell Efficiencies [21]

5.3.2 ENERGY PAYBACK TIME AND THE HARVEST FACTOR

Another important factor is the energy payback time. It describes the time that a PV cell needs to exploit solar energy to return the amount of energy which was consumed for its production. The production of a PV cell would be useless if the energy payback time was higher than the lifetime of the cell. In this case, the term "energy" can be seen in relation to costs. For example, the amorphous silicon cell has energy payback time of 2.8 years. Related to the energy payback time is the harvest factor (H). This factor describes the number of times that a PV cell exploits the energy that is used for its production during its life time. For example, with a life time of 30 years and a performance guarantee of 20 to 25 years by the manufacturers, the mono-crystalline cell has a harvest factor of 5 to 8, the poly-crystalline cell between 7 and 14, and the amorphous silicon cell even between 9 and 21. [22]

cell technology	energy payback time	harvest factor
mono-crystalline silicon	7.3 years	5 - 8
poly-crystalline silicon	4.6 years	7 - 14
amorphous silicon	2.8 years	9 - 21
copper indium diselenide	1.9 years	-

Table 5.2 - Mean Energy Payback Times [23]

[20] Ingrid Hermannsdörfer, Christine Rüb, 2005, p.135.
[21] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, p.24.
[22] Ingrid Hermannsdörfer, Christine Rüb, 2005, p.139.
[23] Ingrid Hermannsdörfer, Christine Rüb, 2005, p.139.

5.4. DESIGN CONCEPTS

So far, this research paper has examined different PV technologies, but the integration of a PV-system into the architectural design makes the holistic approach even more important. Therefore, the market offers a wide choice of proprietary PV composite systems. These are i.e. curtain wall systems for vertical and inclined façades, rain screen cladding systems, fixed and motorised solar shading systems, integrated roof cladding, sheeting and tiling systems, pitched and flat roof mounted systems or roof light systems. [24] However, each project is unique in its task and it is necessary to see the building-integrated PV system as an element of the building design and construction. The integration of a PV system is not simply the replacement of building materials and components. Furthermore, the installation can be used to generate power, to provide shade and to allow daylight inside the house. For example, a PV system can be integrated as part of a building element, such as canopies and exterior shading systems. However, the architect needs to examine the details of a PV system to understand how to integrate the system effectively and elegantly. [25]

5.4.1 EFFICIENT PARTS OF THE BUILDING ENVELOPE

In order to create a design concept for the building envelope, an analysis of the building shape is required. This analysis identifies the most efficient parts for the installation of PV modules. Roof areas are well suited for PV module installations in the first place. Furthermore, flat roofs with a large surface area provide the possibility to optimise the orientation and the inclination of the PV modules according to the technological requirements. PV systems that are located on reasonably high buildings are mostly not visible from below, allows the usage of standard products without any aesthetical degradation. [26]

Pitched roofs can also be used, if they are facing the right direction. PV systems can be attached to the roof, as well as be integrated into the roof skin. The additional weight of these elements does usually not influence the roof structure and additional alterations are not necessary. The flexible thin-film technology makes it possible to embed photovoltaic cells into curved modules as well. Also the installation of PV systems on domed roofs is a possibility through the application of flexible solar cells and the cut-to-size system. Another option is the integration of smaller surfaces such as chimneys or dormers. Especially the surface of dormer is more important than others, if its roof area faces only in one direction. [27]

[24] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, p.16.
[25] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, p.22.
[26] Ingrid Hermannsdörfer, Christine Rüb, 2005, p.21.
[27] Ingrid Hermannsdörfer, Christine Rüb, 2005, p.21.

Apart from roof areas, façades are also suited to integrate PV modules into the building envelope. It needs to be taken into account that vertical installations of PV modules normally provide a lower efficiency than installations on inclined surfaces. However, if the PV modules are installed on a north-facing façade they may be more efficient than modules on a roof element which is shaded or that does not face towards +/- 45° (northeast or northwest). Apart from the building envelope, there are other building elements, e.g. window shutters, loggias and canopies, which are also useful to integrate PV modules in the building design. In this context, semi-transparent modules are particularly suitable, because they can be integrated into windows and e.g. provide solar shading as an additional function. [28]

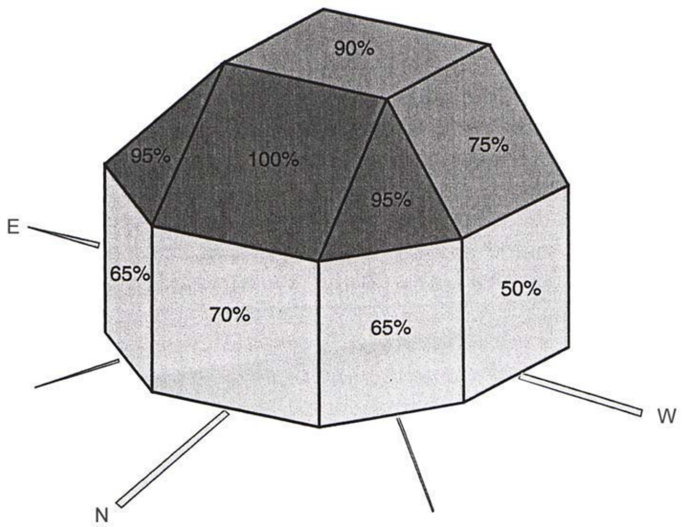


Plate 5.13
Efficiency of Angle and Orientation, PV efficiency according to the angle and orientation of the building envelope

5.4.2 BUILDING-INTEGRATED PHOTOVOLTAIC

Apart from active and passive solar design and the analysis that is required to identify the most efficient parts of the building envelope, a high-quality PV system is also about the integration of the system into the building envelope. In this case, the market offers a large range of different systems and both standard and custom-made products. Standardisation provides lower costs to the client on one hand, but specialisation leads to new architectural expressions in terms of technology. The goal is to figure out which products and related standards meet the specific design conceivability and if these fit into the financial resources of the client. [29] However, the integration of PV systems is not simply about the replacement of materials and components through a photovoltaic module. In order to achieve a high quality of integration into the building envelope, an interaction between the BiPV design and the PV system is required as well. [30] A possibility is to replace a conventional external building material, e.g. tiles on a roof or cladding with a façade, but the goal is a full

[28] Ingrid Hermannsdörfer, Christine Rüb, 2005, p.23.
[29] Ingrid Hermannsdörfer, Christine Rüb, 2005, p.33.
[30] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, p.26.

integration of the PV systems into the building design. Therefore, the integration of PV systems into an architectural design can be divided into five categories. [31]

category	the integration can be
1	applied seamlessly
2	added to an architectural design
3	added to an architectural image
4	used to determine an architectural image
5	used to explore a new architectural concept

Table 5.3 - Building-integrated Photovoltaic (BiPV) [32]

The former imperial artillery barracks in Osnabrück in Germany (part of the campus of the University of Osnabrück) is a good example in terms of the first category. The architects designed a PV system that was seamlessly installed on the south-facing roof to preserve the authentic overall impression of the building. The major problem was the existing roof structure that was not able to support significant additional loads. Therefore, the architects preserved the delicate roof supports and the historical appearance of the building by integrating a light weight construction made of galvanised aluminium. The nano-crystalline thin-film cells that are laminated on the top harmonise with the complete building and do not disturb the existing design. [33]

Plate 5.14
Former Imperial Artillery Barracks, Osnabrück, Germany, 2003

The project is a result of the regional Action Programme Energy Saving (APES), initiated in 1998. The architectural design contains 176 nano-crystalline thin-film modules provided by ThyssenKrupp Solartec. Each PV module contains 22 nano-crystalline thin-film cells that provide a capacity of 128 Wp. The size of each module is 474 x 5800 mm with a weight of

[31] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, p.22.
[32] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, p.26.
[33] Ingrid Hermannsdörfer, Christine Rüb, 2005, pp.56-57.

8.46 Kg/m². The total area of the PC-system is 460 m², generating 22.53 kWp of power which leads to an energy yield of 18,000 kWh/a.[34]

Plate 5.15
Nano-Crystalline Thin-film Modules,
Provider: ThyssenKrupp Solartec,
Energy Output: 22.53 kWp,
Energy yield: 18 000 kWh/a,
Total area: 460 m²

The second category describes a system that is added to the building design. The design may be missing a function, such as an eave to provide shading, which can be solved with a practical solar canopy in combination with the PV system.[35] In this context, the paper introduces the “Le Donjon” (English: the castle) office building that is located between a residential neighbourhood of the 1930s and a train line. Therefore, the town planning regulations and building codes strictly required integration into the environmental context and it was not possible to design a very futuristic high-tech building with a huge south oriented PV roof or a glass façade that could fit into the neighbourhood. The new building is very basic and includes renewable features, such as the PV canopy roof above the façade wall.[36]

Plate 5.16
Le Donjon Office Building,
The building design includes a PV-canopy construction above the façade walls, Gouda, Netherlands

[34] Ingrid Hermannsdörfer, Christine Rüb, 2005, pp.56-57.
[35] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, pp.27-28.
[36] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, pp.118-119.

The integrated PV modules are multifunctional building elements that generate power and provide rain protection for the attic walls and the façade in form of a canopy roof on top. Furthermore, the transparent back foil allows a semi-transparent visual appearance. The system is divided into three strings that are connected to a surveillance system, a distribution system and counter. These systems control the in and output of electricity to the public utilities' grid to reimburse the costs. The total area of 72.50 m² contains 51 laminates that have the same weight as glazing, approximately 17 kg/m², and a size of 1150 x 1150 x 8 mm. The cell technology is an AP-106 mono-crystalline silicon cell that is produced by Astro Power. Each module generates 111 Wp and the system a total capacity of 6.23 kWp (*refer to image 5.17*). [37]

A problem was the welded supporting structure that could not be produced with the same precision as the bolted construction. Furthermore, temperature changes during the building process made the structure less precise, but only small tolerances were acceptable. Therefore, one of the substructures was reassembled and welding was carried out on site. [38] The building design includes also other renewable features, such as a small thermal solar collector (2.5 m²) to provide DHW supply for cleaning, kitchen tab water and dishwasher, a balanced ventilation system that includes a heat recovery system and a building management system for outdoor climate regulation in order to control overheating. [39]

Plate 5.17
Horizontally installed PV laminates,
Mono-Crystalline Silicon Cells
Energy Output: 6.23 kWp
Total area: 72.50 m²

The refurbished student housing in Lausanne, Switzerland, was built in 1962. The existing concrete façade was poorly insulated and the tenants called for an upgrade to meet the current safety requirements and to provide lower maintenance costs. The new building

[37] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, pp.120-122.
[38] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, p.119.
[39] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, p.122.

envelope is insulated and covered with metal cladding. Furthermore, the south façade has an integrated photovoltaic system that generates power and creates a visual edge to the design. Overall, the upgrade in combination with the integrated PC system leads to a positive influence on the market value of this building, but it does not overpower the original building form. Therefore, this project can be seen as an excellent example for the third category. [40]

Plate 5.18
Student Housing in Lausanne,
Façade-integrated PV-modules of the first building,
Poly-crystalline silicon cells,
Energy Output: 14.40 kWp,
Area: 72.50 m²,

The Energy Office of Lausanne proposed to use a façade integrated PV system with large modules of 240 Wp each that were developed by Solarex. These modules have a size of 1870 x 1110 mm and weight of 26 KG. The total area that is covered is about 72.50 m² and has an energy output of 14.40 kWp. Overall, six strings of 10 PV modules were connected that provide 2.4 kWp each. However, these standard laminates fitted the building dimensions and could be easily integrated into the architectural design of the building. The principle of a ventilated façade was kept in order to provide cooling to the PV modules.[41]

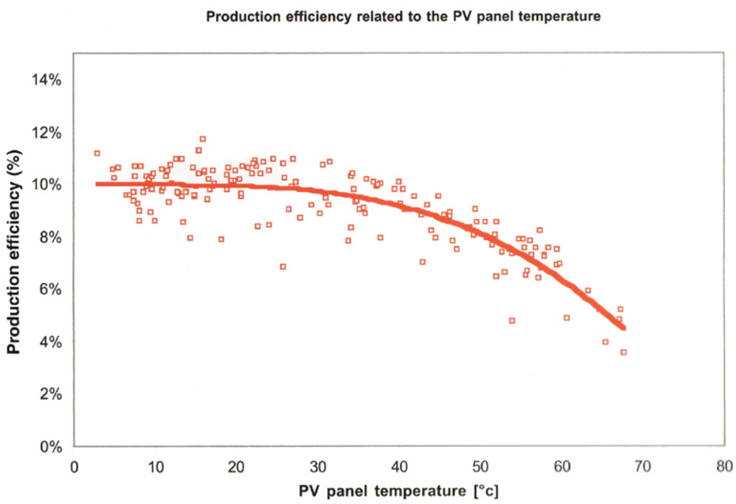


Plate 5.19
Production Efficiency related to the Temperature,

[40] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, p.147.
[41] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, p.148.

The Energy Office monitored the operation of the PV system and identified two weak points that were highlighted through the operation control measurement when the system started to generate power. An analysis showed that the efficiency decreased under strong insulation. Therefore, they studied the problem and noticed that the temperature of the module could reach high values. However, the reason was that the openings for air-cooling were closed and the problem was solved after it was corrected (*refer to image 5.19*). [42]

Another form of integration is to determine an architectural image through the introduction of a PV-system. For example, a typical roof can be transformed into a prominent feature through the replacing of the complete roof skin by a solar system. This can be a design element of the building's envelope and a characteristic for the entire project. [43] This concept was realised at the new housing area in Amersfoort in the Netherlands as part of the 1MWp PV project. The SCW-project that is shown as an example was focused on familiarisation with PV technology. Furthermore, it was used to improve the process of working with architects, property developers, contractors, the PV industry and others who were involved in the building-integrated PV-project. Therefore, the project comprises 50 row-houses that were designed and planned to integrate PV technology into the roofs construction in combination with thermal solar systems that were developed in cooperation with the social housing association. [44]

Plate 5.20
New Housing Area Nieuwland, Amersfoort, Netherlands, Energy Output:

The integrated PV-modules can be seen as multifunctional building elements that generate power and provide rain protection to the building. The introduced module type RSM 75, produced by Shell Solar, is a poly-crystalline silicon module with a size of 545 x 1185 mm.

[42] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, pp.149-150.
[43] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, pp.27-28.
[44] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, pp.124-125.

The arrays are not connected and, therefore, each house unit has its own PV system that provides a total capacity of 2.25 kWp. The cross section of the bottom of the PV roof shows that small ventilation gaps are part of the construction in order to allow a flow of air behind the modules and to provide cooling to the PV modules. The gutter section is only used for those sections of the roof where there is a vertical wall below. Otherwise, the eave provides rain water protection for the façade. [45]

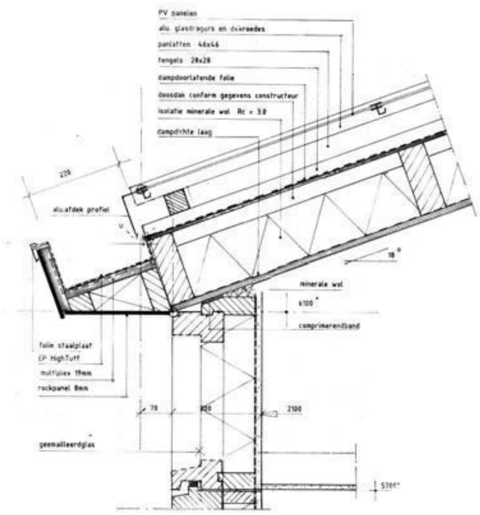


Plate 5.21
Cross Section of the Bottom of the PV Roof, Amersfoort, Netherlands, Building-integrated PV-Cells

The last category refers to the use of PV systems to explore a new architectural concept. The solar office at the Doxford International Business Park in Sunderland, United Kingdom, can be used as a good example in this case. It is a new office building that adopts this strategy (*refer to image 5.23*) and presents an architectural design that addresses all environmental and energy conservation issues. It is the first speculatively constructed office building that has a BiPV façade, which is still the largest constructed solar façade in Europe. It clearly demonstrates that solar design and BiPV have to be combined to create a new architectural design that would be future-proof. [46]

However, the goal was to develop a more radical low-energy building design that would meet the requirements of the commercial market. Therefore, the PV system is integrated into the building envelope which generates a total capacity of 55,100 kWh/a. This amount of electrical power represents between one third and one quarter of the electricity that is expected to be used by the building over one year. During the summer, the system feeds the surplus into the public utilities' grid and takes it back to guarantee a constant supply of power in the winter. [47]

[45] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, pp.128-129.
[46] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, p.154.
[47] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, pp.154-155.

Plate 5.22
Solar Office,
Doxford International Business Park, Sunderland, United Kingdom

The building design was considered to introduce mono-crystalline or poly-crystalline modules because they were more suitable than amorphous silicon modules in terms of their efficiency and proven durability. Furthermore, the appearance of the cell was important and the sparkle that was offered by the poly-crystalline cells determined the choice over the mono-crystalline cells. One of the major problems was the amount of solar heat gain that was provided by the integrated PV system. During winter, the heat gain is used to assist in heating the building and to reduce the overall energy consumption. During summer, the heat is used to ventilate the office space by using the stack effect. The stack effect, describing the rise of air that is warmer and less dense than surrounding air, works in combination with several mechanical vents that are installed at the bottom and at the top of the PV-façade to provide cooling to the arrays. [48]

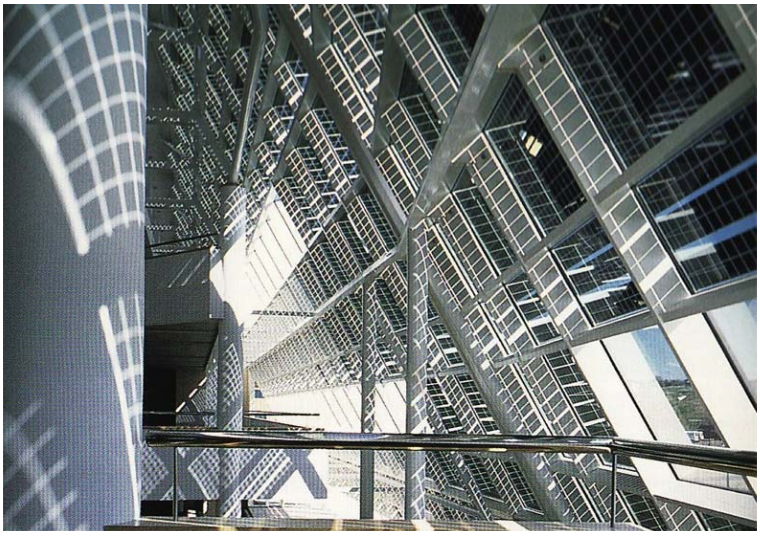


Plate 5.23
PV-façade of the Solar Office,
Integrated Inclined Façade PV,
Energy yield: 55,200 kWh/a,
Over 400,000 opaque cells

[48] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, pp.156-157.

5.4.3 CALCULATION OF A PHOTOVOLTAIC MODULE SYSTEM

Different technologies and systems are developed for different conditions and climates. In this case, it is the responsibility of an architect to analyse which specific PV-system and which specific solar system is important and should be used for a particular project. For example, a New Zealand household uses about 10,000 kWh every year. That is an average of 27.5kWh per day. [49] Mono-crystalline silicon cell modules have the highest efficiency, between 12% and 15%. That means that an array of 6.5 m² is enough to generate a maximum of about 1 kWh of electrical power under standard conditions, but this kind of cell is made from pure mono-crystalline silicon which leads to higher costs than other PV-technologies. [50] The amorphous silicon cell module, also know as thin-film cell module is rigid and flexible and is ideal for curved surfaces. Furthermore, it is cheaper in terms of manufacturing, which results in lower costs. On the other hand, this module has a lower efficiency, typically between 6% and 8%. Therefore, 16.5 m² are required to generate a maximum of about 1 kWh of electrical power under standard conditions. [51] Overall, the choice of the PV system is always related to the climate zone, the location of the building, the shape of the building, the financial resources of the client and the choice that has to be made between an island or stand alone system.

5.5. RECENT DEVELOPMENTS

The decrease of the availability of fossil fuel resources as well as political developments, such as the situations in Iraq and Afghanistan which proved that fossil fuel security becomes questionable, are pushing hard on the development of PV systems. Therefore, government investments in research and development of new and clean energy technologies and resources are rising. At the moment, PV technology is not advenced enough to replace the conventional fossil generation. But things are going to change. [52]

A recent development in research of photovoltaic technologies, are printable plastic solar cells. In Germany, scientists of the Siemens concern are developing a printed organic solar cell that provides a current efficiency of 5 %, but experimental studies are still in progress. They expect to reach an efficiency of 7 % and that this development would be an attractive proposition if the cell is cheap enough for the market. However, organic solar cells are not

[49] Department of Building and Housing, *Photovoltaic cells*, Wellington, New Zealand, Retrieved Mai 07, 2008 from the World Wide Web: http://www.smarterhomes.org.nz.
[50] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, pp.23-24.
[51] Prasad, Deo. (ed.) Snow, Mark. (ed.) 2005, pp.23-24.
[52] Peter F. Smith, *Sustainability at the Cutting Edge – Emerging technologies for low energy buildings*. Oxford, UK: Architectural Press, 2007, p.xii.

efficient enough to compete with classic silicon cells, but they can open up new fields of application and could supply e.g. the power for small mobile devices. [53]

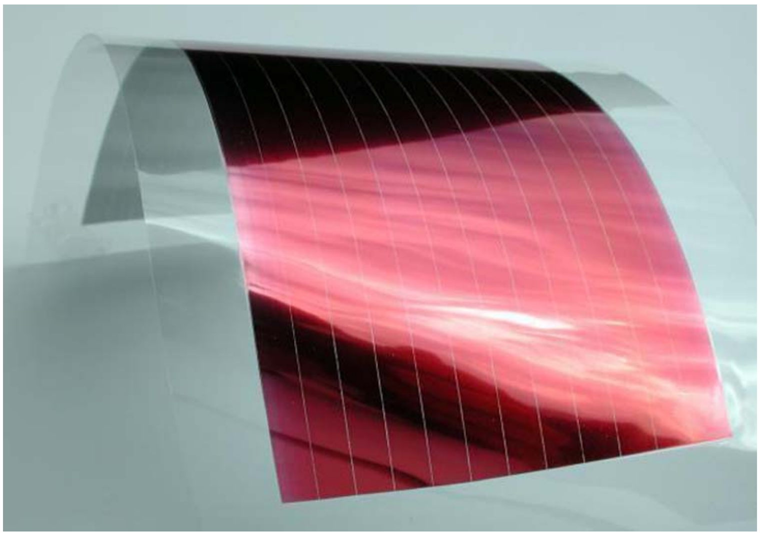


Plate 5.24
Flexible and printable PV-cell,
Small as the page of a book,
Fraunhofer Institute for Solar Energy Systems (ISE),

Another recent developed PV technology that is already available on the market is the cut-to-size module. This module can be adjusted directly on site. The construction is quite simple: substrate glass with the PV cells is laminated onto a larger pane of glass, which is normally of the same size. This size difference provides a rim of ordinary glass around the cells that can be cut-to-size on the site without damaging the PV module, which, of course, cannot be cut. [54]

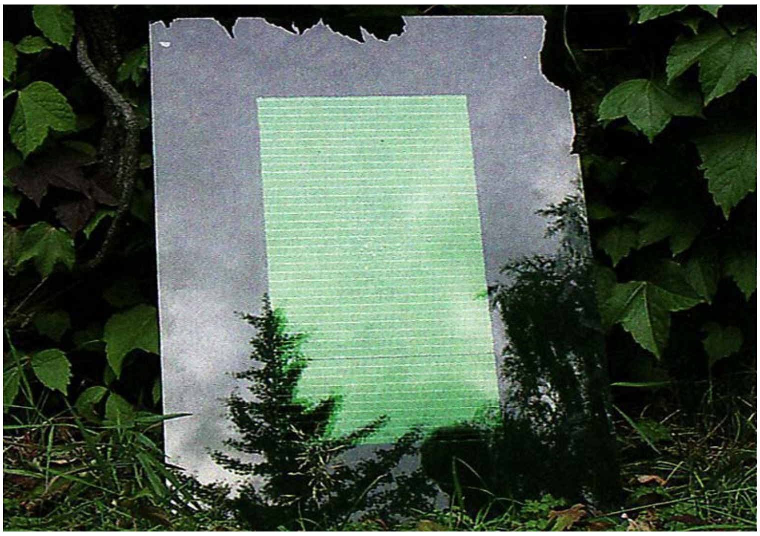


Plate 5.25
Cut-to-Size Test Module,
Test module with glass rim,
Thin-film technology,

Soon, the next photovoltaic generation, based on nanotechnology will be available on the market, which could provide e.g. better optical properties than those of solid thin films.

[53] Peter F. Smith, 2007, p.71.
[54] Ingrid Hermannsdörfer, Christine Rüb, 2005, p.47

Government, such as Germany and Japan, have already supported this recent development and realised economies of scale. Furthermore, in a future energy scenario, residential and commercial buildings are becoming a major rule in the overall energy supply. They will be the power stations of the future through a soaring application development of PV-cells to generate solar energy in order to feed it into the public grid. Energy Saving Trust (EST) stated that around 30 % to 40 % of the United Kingdom's electricity could come from installations on buildings, if this scenario was realised until 2050. [55]

[55] Peter F. Smith, 2007, p.xii.

6. CASE STUDIES

In order to study the current problems of building-integrated solar systems in New Zealand's sustainable architecture, it is necessary to identify the stage of development. Therefore, this chapter illustrates 4 different examples of sustainable buildings in New Zealand that have been planned and built during the last few years. These projects are at the forefront of the sustainable movement in New Zealand and prove that sustainable design offers benefits to the building and its occupants, especially in combination with thermal solar and PV-systems. Therefore, the chapter illustrates the sustainable concepts and examines the integrated solar systems into the architectural design. Overall, the chapter shows that some building standard systems do not perfectly fit and the situation calls for innovative solutions. In this case, the chapter indicates that the design of the systems themselves as well as the design of the sub-structures has to be reviewed by the architect. [1]

6.1. THE WADESTOWN SOLAR HOME, WELLINGTON, 2002

The Wadestown Solar Home is designed by its owner, Aonui Architecture director Richard Wright in 2002. The building is designed for two adults and three children and contains an additional office area for the studio of Aonui Architecture. The project includes passive and active solar design elements, as well as some innovative ideas. Furthermore, the integration of building automatism in terms of active solar management leads to additional minimisation of costs. This building was the subject of research and publication to maintain and to support the development of natural energy building systems by Aonui Architecture. [2]

Plate 6.1
The Wadestown Solar House,
Wellington, New Zealand, 2002

[1] Ingrid Hermannsdörfer, Christine Rüb, *Solar Design: Photovoltaics for Old Buildings, Urban Space, Landscapes*. Berlin, Germany: Jovis Verlag, 2005, p.19.
[2] Aonui Architecture Limited, *Wadestown Solar Home*, Wellington, New Zealand, Retrieved Mai 07, 2008 from the World Wide Web: http://www.aonui.co.nz/sustain/ESD_projects/solarhome_esd.html.

6.1.1 SUSTAINABLE CONCEPT

The scope of solar design is to reduce the consumption of conventional energy and to provide a high quality of thermal efficiency. Therefore, north facing walls are 80% glazed to provide maximum solar gain that affects the solar absorbing tiled suspended slabs and heats up the upper air volume. [3] A fan drives the heated air below the suspended slabs to a basement “rock bin” to store the converted heat as thermal energy. This “rock bin” consists of 15 tonnes of concrete kerb blocks that are recycled in order to keep the CO_2 emissions of concrete on a low level. Therefore, it has to be noted that each tonne of cement produces approximately 700 Kg of CO_2. However, the concrete kerb blocks provide a capacity of thermal storage that is equivalent to 200 standard electric night store heaters. This thermal energy can be used for at least about a week to provide a level of temperature around 4°C throughout winter. Furthermore, this process can be reversed to keep the climate inside the house cool during the summer. [4]

Plate 6.2
Glazed North facing Walls,
North facing walls are 80% glazed to provide maximum solar gain, Wellington, New Zealand, 2002

In order to keep overheating under control, a simple automatic control system to open and close windows and building-integrated thermometers at specific locations inside the building provide indoor thermal comfort. The inside temperature is usually 21°C and the louvre windows lower the daytime temperatures by approximately one degree. They are only closed because of wind and rain, as well as during the night time for security reasons. In winter, the system automatic keeps the windows normally closed. [5]

[3] Solarhomes Limited, *Wadestown Solar Home*, Wellington, New Zealand, Retrieved Mai 07, 2008 from the World Wide Web: http://www.aonui.co.nz/portfolio/residential/solarhome.html
[4] Solarhomes Limited, 2008 from the World Wide Web: http://www.solarhomes.com/03-portfolio/wadestown/portfolio-wadestown.html
[5] Aonui Architecture Limited, 2008 from the World Wide Web: http://www.aonui.co.nz/sustain/ESD_projects/solarhome_esd.html.

6.1.2 INTEGRATED ACTIVE SYSTEMS

According to the building design of the Wadestown Solar Home, the architect Richard Wright gave a statement that was published in the Dominion Post in September 2002:

> "Lots of people have very efficient solar-heating systems but they are add-ons. My thesis is that the technology is so important that it should be added into the architecture."
>
> *Richard Wright in the Dominion Post, September 2002* [6]

The answer to this statement by Richard Wright is his innovative idea of the upper floor balustrade that is a functional and decorative architectural element on one hand and an interior thermal solar water pre-heating system on the other hand. The balustrade has an area of 8 m² and consists of slender copper pipes. These pipes are heated by the sun through the glazed north facing walls. During sunny days, the water circulates through the copper pipes to be pre-heated by the sun to save energy. [7]

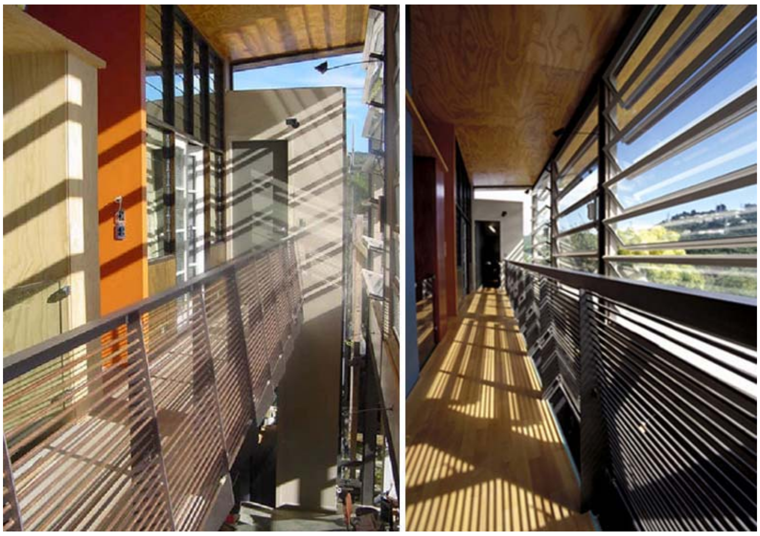


Plate 6.3
Solar Water Heating,
Interior thermal solar water pre-heating system

However, it needs to be asked if this innovative idea is usable for other sustainable projects. In order to exploit the thermal solar heat, the slender copper pipes needs to be un-insulated. That might lead to an expectable absorber efficiency of the system in terms of the thermal heat transfer, but the emission efficiency might be high as well. Furthermore, a lower environmental impact does not automatically apply, if the life cycle of the slender copper pipes is taken into account. Overall, this research paper assumes that this system is an

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[6] Solarhomes Limited, 2008 from the World Wide Web: http://www.solarhomes.com/03-portfolio/wadestown/portfolio-wadestown-diagram.html.

[7] Solarhomes Limited, 2008 from the World Wide Web: http://www.solarhomes.com/03-portfolio/wadestown/portfolio-wadestown-esdfeatures.html.

innovative idea in terms of the integration of solar systems, but in terms of the material and its efficiency it might be not usable for other projects.

6.2. THE POWERED LIVING HOUSE, NELSON, 2004

The Powered Living House was built by Philip Hay Builder in Nelson, in 2004, and designed by Helen Richards, a British qualified Architect. [8] The concept of the house is about a passive solar design as well as the aspect to provide a healthy environment to the occupants. Energy efficient lighting and a thermal solar system installed at the top of the roof save energy and provide DHW supply. Furthermore, the architectural concept is designed to be highly flexible and to adapt to many different situations without compromising style or performance. Overall, Richards's design maintains reasonable construction costs. She estimated the building costs at around NZD 1500 per square metre. [9]

Plate 6.4
The Powered Living House, Designed by the British qualified Architect Helen Richards, Nelson, New Zealand, 2004

6.2.1 SUSTAINABLE CONCEPT

The front of the Powered Living House, facing the true north within 30°, includes large double glazed windows with a higher resistance to maximise the gain of solar heat and to eliminate condensation. In order to minimise heat losses, the roof and the timber-framed exterior walls (cladded with Zincalume, plaster and Lawsons cypress) are insulated with "Woolbloc" insulation as an alternative to fibreglass. This insulation is 1.5 times higher than the standard building regulation recommendations. It also indicates specific materials that stand for low emission toxicity and sustainability. All timber and joinery materials as well as the paint are selected for off gas emissions and sustainability. [10]

[8] Helen Richards, "Solar home with style", *Electrical Technology*, October/November, 2004, p.9.
[9] Powered Living, *The Powered Living House*, Nelson, New Zealand, Retrieved Mai 08, 2008 from the World Wide Web: http://www.poweredliving.co.nz/designs.html.
[10] Powered Living, 2008 from the World Wide Web: http://www.poweredliving.co.nz/construction.html.

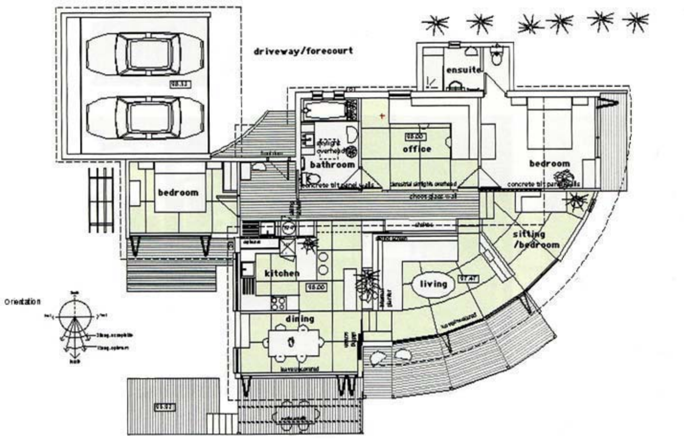

Plate 6.5
Ground Floor Plan,
Room arrangement is considered in terms of the heat gain, loss and airflow,

The design of the layout offers a floor area of 180 m², which includes a double garage, three bedrooms, two bathrooms, a home office and an extensive living area. The indoor thermal comfort of the house is related to the sun's daily and annual cycles. Therefore, the room arrangement is considered in terms of the heat gain and loss, and airflow in order to reduce the requirement for heating and cooling systems. [11] Internal walls and benches in the bathroom and in the kitchen are made of concrete to provide thermal mass inside the house that is necessary to store thermal heat and to level out the peaks and troughs of temperature. Furthermore, the 150 mm thick, polished concrete floor inside the house is mostly uncovered to maximise solar heat gain and the insulation underneath the concrete floor prevents heat drain to ground. [12]

Plate 6.6
Coloured Concrete Floor,
Exposed coloured concrete floor to provide thermal mass for heat storage and temperature regulation,

Overheating is still a major problem and passive ventilation is considered to minimise this effect. Temperature controllers are placed in each room to control the solar heat fluctuations

[11] Johann Bernhardt, *A deeper shade of Green: Sustainable Urban Development, Building and Architecture in New Zealand*. Auckland, New Zealand: Balasoglou Books, 2008, p.190.
[12] Helen Richards, 2004, p.9.

inside the house. Furthermore, the horizontal shading devices of the building are designed to keep the thermal solar gain under control and to avoid over heating. During winter, the sun is lower in the sky and enters underneath the solar device, heats up the house. During summer, the sun is closer to the vertical and is blocked by the shading devices. [13] Overall, the building provides an internal temperature that ranges between 25°C in the summer and 16°C during the winter and has not required any form of back up heating over the last 4 years. [14]

6.2.2 INTEGRATED ACTIVE SYSTEMS

The design of the Powered Living House contains a thermal solar collector that is installed on the top of the roof. This active solar system exploits solar radiation and provides 90% of the DHW supply to the occupants, but is not integrated into the building design. Furthermore, it is installed as a technological bonus and not realised by the architect Helen Richards as an active solar design element. However, the research process showed that it was difficult to find any specific resources that provide more information about this installed solar system. [15]

Another active system that is installed into the building is a rainwater collection system that collects rainwater from the roof and stores it in a tank outside the building. This water is used for water conservation and to supply the toilet flushing or to water the garden. [16] In combination with water saving devices, this rainwater collection system provides around 60% of the building's water supply. [17] However, a PV-system that could generate electricity in order to reduce the consumption of conventional power is not implied. Therefore, the research paper comes to the conclusion that this building might be a good example of sustainable architecture in New Zealand, but it does not support the idea of building-integrated solar systems.

6.3. THE LANDCARE RESEARCH BUILDING, AUCKLAND, 2004

The new Landcare Research Building is located at the Tamaki Campus of the University of Auckland. This building is designed by Chow:Hill Architects and includes a series of facilities, such as laboratories, support areas, glasshouses, collection areas for the New Zealand Arthropod collections, the National Fungal Collection and the International Plant Micro-organism Collection, as well as offices for Landcare Research, the Ministry of Agriculture and Forestry and the University collaborators. In order to create a building that becomes a leading

[13] Heather and Kerry Wood, "A standard solar house", Energy Watch 36, March, 2005, p.18.
[14] Johann Bernhardt, 2008, p.190.
[15] Johann Bernhardt, 2008, p.190.
[16] Richards, Helen. 2004, p.9.
[17] Johann Bernhardt, 2008, p.190.

example of sustainable design in New Zealand, a strong environmental focus was given by the client. Overall, the site, the building envelope, the fitout and the services are designed to meet these goals. [18]

Plate 6.7
The new Landcare Research Building, Auckland, New Zealand, 2004

6.3.1 SUSTAINABLE CONCEPT

The building is a three storey building that is organised around courtyards and circulation areas. Double glazed windows allow maximum gain of sunlight, provide insulation and reduce condensation. During the night, the windows are closed to provide a comfortable indoor temperature. Furthermore, the building envelope is highly insulated to reduce heat loss. It consists of precast concrete elements and block walls that are layered with R4 fibreglass insulation, a ventilated cavity, a vapour seal layer and are cladded with cedar weatherboards or metal cladding. R4 fibreglass insulation is also used in the construction of the office facades and in the roof that is highly insulated with R5 fibreglass. [19]

As known, fibreglass is the most common residential insulating material, but health and safety issues include a potential cancer risk if this material is absorbed into the body by inhalation. Especially in context to the goal to design a leading example of sustainable design in New Zealand, the paper identifies that it seems to be wrong to install fibreglass insulation. Therefore, it should be introduced an alternative insulation material, such as cellulose insulation produced of recycled paper instead of fibreglass.

[18] Chow:Hill Architects, *The Landcare Research Building*, Auckland, New Zealand, Retrieved Mai 09, 2008 from the World Wide Web: http://www.chowhill.co.nz/architecture-landcare.html.
[19] John Sutherland, David Turner, “Green, but not wacky”, *Architecture New Zealand*, September/October, 2004, p.84.

Plate 6.8
Fibreglass Insulation Material,
R4 and R5 fibreglass insulation is used in the construction of the office facades and the roof

The new Landcare Research Building is designed with energy modelling software that analyses natural light, thermal solar heat and ventilation during the day and throughout the year, which determines the optimal placement of windows and shading devices. External aluminium sunscreens with an angle of 30° are installed over the windows to control the thermal solar gain at the North and North-West façade. Inside the building vertical and horizontal blinds are installed as additional shading devices. However, it has to be noticed that they are not effective against solar overheating. A canopy at the entrance is introduced to provide shade and protection to the glazing and the entrance area. At the North-East façade only internal vertical blinds are installed which are less effective. [20]


Plate 6.9
External Sunscreens and Canopy,
North façade with its external aluminium sunscreens and the entrance canopy,

Renewable materials and materials with a low-embodied energy were used in the construction of the building. For that reason, the National Australian Buildings Environmental Rating System (NABERS) has been used to monitor the sustainable performance of the

[20] John Sutherland, David Turner, 2004, p.84.

project during the design process. NABERS rates the environment of the building with a projected rating of 60%, which assesses the impact of the building on land, choice of materials, waste of energy, water consumption, interior, resources, transport and waste management. [21] According to information from Stuart Mackie in 2007 from Chow:Hill Architects, Auckland, the energy consumption is between 60% and 70% less than that of a conventional building.

6.3.2 INTEGRATED ACTIVE SYSTEMS

Active systems such as low energy light fittings, reverse heat-cycle pumps, a wind-powered generator and a thermal solar system are installed to reduce the building's energy consumption. The installation of active air conditioning in some offices, laboratories and collection spaces is provided with two rooftop Eco-Air units. The combination of the Eco-Air units and reverse heat-cycle pumps, which offer variable refrigerant volume (VRV) and recover heat from exhaust air, minimises heat loss by the ventilation system and leads to a high energy efficiency. Therefore, the internal temperatures in laboratories and offices are between 17° to 25°, preventing the need of air-conditioning in these spaces. [22] The wind-powered generator provides energy for a pump that is used to drive rainwater from a storage tank into a tank that is located onto the roof. Afterwards, the water is used in the urinals, ground floor toilets flushing and for the glasshouse irrigation, as well as for the garden irrigation to provide a sustainable form of energy that reduces the buildings water consumption as well as the energy consumption from the public grid. Overall, the projected water usage of the Landcare Research Building is expected to be 50% lower than the consumption of a conventional building. [23]

The thermal solar system is located on the roof of the building. Two Solahart 302K Black Chrome X11 units with an absorber area of 11.32 m² are installed to provide DHW to the laboratories and the cafeteria. The system is thermosiphon based with a hot water storage tank above the collectors, which works with an anti-freeze solution, combined with a closed loop system. That allows using the thermal solar system during the whole year, even if the temperature is under 0°C. [24] In terms of building integration, the design contains the same critical point as the Powered Living House by Helen Richards. Chow:Hill Architects did not integrate the thermal solar system into the building envelope. Furthermore, they did not

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[21] Chow:Hill Architects, 2008 from the World Wide Web: http://www.landcareresearch.co.nz/about/tamaki/environmental_rating.asp.

[22] John Sutherland, David Turner, 2004, p.78.

[23] John Sutherland, David Turner, 2004, pp.80-83.

[24] Landcare Research - Manaaki Whenua, *Alternative Energy Sources*. Auckland, New Zealand, Retrieved June 12, 2008 from the World Wide Web: http://www.landcareresearch.co.nz/about/tamaki/alternative_energy.asp.

realise that this active solar element can be integrated into the building design instead of adding it to the building only as a technological bonus.

Plate 6.10
Solahart 302K Black Chrome X11, A thermal solar system with a total absorber area of 11.32 m² is installed to provide DHW to the laboratories and the cafeteria

However, the most obvious gap in terms of building-integrated solar systems is the missing introduction of PV-modules. The external aluminium sunscreens with an angle of 30° that are installed over the windows at the North and North-West façade are perfectly suited to add PV-technology to the building design. This building has proven to be a successful example in terms of energy efficiency and sustainable architecture in New Zealand, but in context to the brief that called for a building that would present a leading example of sustainable design, it is not understandable that the introduction of PV-technology is missing.

6.4. THE MERIDIAN ENERGY HEADQUARTERS, WELLINGTON, 2007

Meridian Energy Limited, a New Zealand-based company, generates the largest proportion of New Zealand's electricity and is certified as the first carbon neutral energy company in New Zealand. The new Meridian Energy Headquarters, the Kumutoto Project, has been planned and designed by Studio of Pacific Architecture and Warren and Mahoney. It is a four storey building located at Wellington's waterfront and has a natural synergy with Meridian's focus on renewable electricity generation and sustainability. It sets new benchmarks for energy efficiency and water conservation and provides a healthy and productive work environment. The New Zealand Green Building Council has awarded the Kumutoto building a 5 star Green Star NZ certified rating (*refer to chapter 1.3*). [25]

[25] Alan Barbour, "Smart Building for Wellington Waterfront: Wellington's waterfront will soon have New Zealand's first Greenstar building, with plenty of wow factor for its occupants", *Build*. June/July, 2007, p.56.

Plate 6.11
The Meridian Energy Headquarters, The Kumutoto Project is a four storey building, located at Wellington's waterfront, Wellington, New Zealand, 2007

6.4.1 SUSTAINABLE CONCEPT

In order to control indoor air quality, building heating, ventilation and air conditioning (HVAC) system uses 100% outdoor air with an air to air heat exchanger to reduce heating and cooling energy. Also the staircase in the core of the building performs a key function in the building's air and ventilation system. It provides natural air circulation inside the building by acting as a chimney which uses the stack effect to circulate the air on each floor. Furthermore, the high thermal mass of concrete in the core of the building, not covered by ceilings or other cladding provides thermal energy storage, which reduces the amount of mechanical heating and cooling that is required to keep the building comfortable. The heat is absorbed during the day and released back into the environment at night, creating a cool environment for the next day. [26]

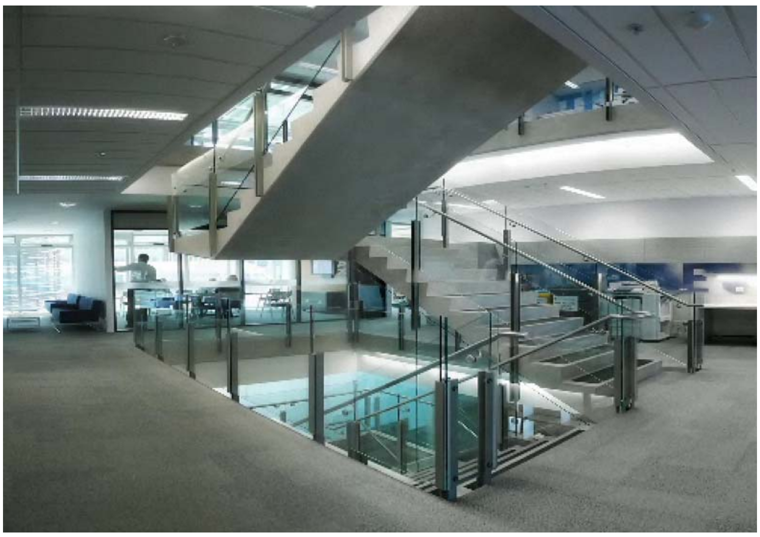

Plate 6.12
Staircase (Stack Effect),
The staircase in the core of the building performs a key function in the building's air and ventilation system

[26] Peter Isaac, "First ground up NZ green building", *New Zealand Construction News*. Vol.2, Issue 3, May, 2007, p.13.

6.4.2 INTEGRATED ACTIVE SYSTEMS

The design of the building envelope is a key element in achieving the project objectives. The double skin façade controls the building's temperature and ventilation requirements to provide an optimal internal temperature. Solar gains are controlled with active shading elements by using hydraulic louvres and automatic blinds as well as automatically controlled windows for natural ventilation. These elements are housed within a glazed façade that is controlled by the building management system and allows large amounts of natural light to most areas of the building. This system drops and recedes in response to the external temperature and the amount of solar gain that affects the building. These features significantly reduce the overall energy needed to keep the building at an optimal temperature. [27]

Plate 6.13
Double Skin Façade,
The double skin façade controls the building's temperature and ventilation requirements to provide an optimal internal temperature

The "electronic brain" of the building is the building management system (BMS) that automatically controls all the building's moving parts, such as the mechanical louvres, the blinds and the windows to balance comfort and energy efficiency. A weather station that is located on the roof helps the BMS to monitor the inside and outside climate constantly and to determine the prevailing weather conditions. It also adjusts the temperature and the light to optimal levels for the occupants. [28] Furthermore, a rainwater collection system collects the rainwater that falls on the roof and stores it in a single 16,000 litre tank that is held in the services area. This water is used for water conservation and to supply between 70% and 80% of all the toilet flushing that occurs in the building, which depends on how much rain there is in any particular season. [29]

[27] Alan Barbour, 2007, p.57.
[28] Alan Barbour, 2007, p.58.
[29] Meridian Building, *Introducing New Zealand's Greenest Building*. Wellington, New Zeland, Retrieved April 30, 2008 from the World Wide Web: http://www.meridianbuilding.co.nz.

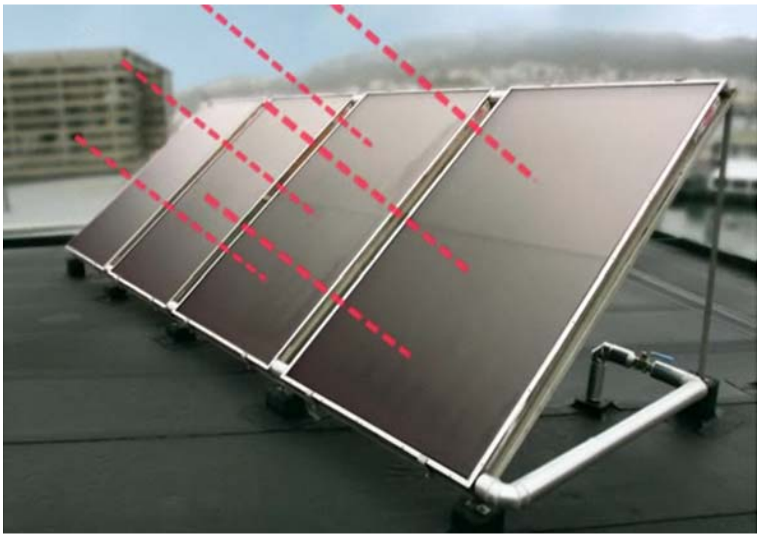

Plate 6.14
Thermal Solar System,
Eight thermal solar collectors provide 80% of the building's DHW supply

According to the Meridian Building website, the early sheds on the waterfront had saw-toothed roofs as an integral part of their design. Therefore, the architectural design of the new Meridian Energy Headquarters has emulated this effect in order to reflect the heritage aspect of the building's location and for the more practical functions. Located on the roof are eight thermal solar collectors that provide DHW for 80% of the buildings needs, such as showers, cleaning and kitchen hot water. [30] However, the solar system is added to the architectural design as a technical bonus and, therefore, it does not support the idea of building-integrated solar systems.

Especially in context with the fact that Meridian Energy Limited is a carbon neutral energy company that generates electricity, it is surprising that PV-technology was not applied in this project. As already mentioned by the architects of the Kumutoto Project, the roof structure is perfectly suited to integrate and to support large arrays of PV-modules, but they argued that large scale installations would not be viable and only a future proofing strategy until now. [31] However, the research paper shows that this technology is already available and it is possible to install such large scale installations.

[30] Meridian Building, 2008 from the World Wide Web: http://www.meridianbuilding.co.nz.
[31] Meridian Building, 2008 from the World Wide Web: http://www.meridianbuilding.co.nz.

7. CONCLUSION

The climate change in combination with the increase of energy costs and the decrease of fossil fuel resources is forcing the change to renewable energy resources and is pushing hard on the development and advancement of solar technologies. Furthermore, the application of these technologies has to be done in combination with the reduction of greenhouse gas emissions in order to stop climate change and to reduce global warming. Buildings are using almost 35% of the overall energy supply in New Zealand that is still produced to 35% by burning coal, gas and oil at power plants. Therefore, solar technologies have to be integrated into New Zealand's architectural design to become a part of a new energy supply security that lowers the consumption of conventional energy and reduces the emissions of carbon dioxide.

7.1. SOLAR SYSTEMS AND SUSTAINABLE ARCHITECTURE

In order to establish the integration of active solar systems in New Zealand's architecture it is necessary to initiate a rethinking in architectural design and building construction. The rethinking leads to a new kind of sustainable design which can be called "future-proof". This design is about maximising the building's energy efficiency and reducing the building's energy consumption. Therefore, the building design combines passive solar design and integrated active solar systems, such as photovoltaic and thermal solar systems. The goal has to be the integration of these systems into New Zealand's sustainable design to convert solar energy into usable thermal heat and electricity and to reduce the consumption of conventional energy.

However, the integration of active solar systems in building design is not simply the replacement of materials and building components. The systems have to be noticed as important building design elements by the architects and designers. They have to take up their responsibility to persuade their clients of sustainable design and to ensure that photovoltaic and thermal solar systems are considered from the early stage on. Therefore, these systems should not be added only as a technological bonus. They have to be integrated into the building envelope or introduced as multifunctional elements such as window shutters, loggias and canopies that are combined with photovoltaic cell technology. The market offers different standard and custom-made systems, but creative and innovative ideas are necessary to create aesthetic architectural concepts that enable a sensitive introduction of solar systems.

7.2. BUILDING-INTEGRATED SYSTEMS

The goal has to be the full integration of photovoltaic and thermal solar systems into a building design that calls for a truth to the material. As a tenet of modern architecture, the truth to materials indicates that the nature of any material should not be hidden. Therefore, this tenet is the direct link to achieve a high quality of building-integrated photovoltaic modules and thermal solar collectors. There must be a commitment to these systems and their application in architectural design as a design element. Of course, there might be exceptions in terms of historical buildings, but generally the systems should be clearly visible and a significant part of the architectural design.

The explored case study projects show that New Zealand's leading architects are starting to realise their responsibility in order to ensure that new buildings are designed and built with new standards of sustainability. Furthermore, they are starting to integrate sustainable concepts in their projects to minimise the costs to the client and to reduce the building's carbon dioxide emissions. On the other hand, the case studies also illustrate that solar systems are still not integrated as important design elements and, furthermore, the application of photovoltaic systems is virtually missing. The reasons might be the gap of the availability of government incentives and that some architects are still not up to date with the development of photovoltaic systems - however, the research report proves that these systems are definitely evolved enough to be integrated into New Zealand architecture.

Overall, the research paper concludes that photovoltaic and thermal solar systems have to be combined with sustainable design concepts to become a normal and self-evident part of architectural concepts. Furthermore, this development guarantees a wider usage of thermal solar and photovoltaic systems in a high quality of building integration. Therefore, the paper assumes that it is just a matter of time until building-integrated photovoltaic and thermal solar design is going to increase in New Zealand, as it already does in Europe.

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