EU COST Action TU-1205

Building Integration of Solar Thermal Systems (BISTS)

Deliverable 3.4 –

Fabricated BISTS prototypes optimised for increased efficiency and low cost.

Working Group 3 –

Investigation of new applications for innovative BISTS

Contributors:

Project (section 2): **Novel Solar-Thermal Collectors/Array with Increased Architectural Acceptance for Building Integration**

I. Vișa (leader), M. Comsit, A. Duță, M. Neagoe, M. Moldovan, B. Burduhos, D. Perniu, A. Enesca, L. Isac, M. Cosnita, I. Totu

R&D Centre Renewable Energy Systems and Recycling, Transilvania University of Brasov, Romania

Project (section 3): **Building Integrated Transpired Air Heater**

B. Norton, M. McKeever, D. Kennedy

Dublin Institute of Technology, Ireland

Project (section 4): **Modular Intergraded Solar/Thermal Flat plate collector**

S. Kalogirou (leader), G. Florides, A. Savvides, C. Christofi, C. Tsioutis, C. Vassiliades, R. Agathokleous

Department of Mechanical Engineering and Materials Science and Engineering, Cyprus University Of Technology, Cyprus

Project (section 5): **Concentrating Photovoltaic/Thermal Glazing (CoPVTG)**

A. Zacharopoulos (leader), T.J. Hyde, J.D Mondol, I. Lytvyn, M. Smyth

Centre for Sustainable Technologies, Ulster University, UK

Project (section 6): **Hybrid Photovoltaic/Solar Thermal (HyPV/T) Façade Module**

M. Mervyn (leader), A. Besheer, A. Zacharopoulos, J.D. Mondol, A. Pugsley

Centre for Sustainable Technologies, Ulster University, UK

Project (section 7): **Porter Building, Tel Aviv, Israel**

Y. Grobman, N. Chen and J. Cory

Axelrod Grobman Architects, Israel

Deliverable compiled by:

A. Zacharopoulos UK

S.M. Gomes Monteiro Silva Portugal

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1 Introduction

The report details the design and fabrication of BISTS prototypes developed by a number of research centres participating in the EU COST Action TU1205. The prototypes were based on innovative BISTS concepts that primarily aimed to cover large fractions of building heating (space and water) needs through solar thermal energy. Additional functions such as daylighting control and electricity generation were also considered. Developing such systems at low cost whilst maintaining high performance levels is deemed critical to their commercialisation potential.

The exchange of ideas and various networking and collaboration opportunities provided by the Action was key to the inception of the BISTS concepts. However the fabrication and subsequent experimentation of the prototypes was subject to the funding available to research centres from sources outside the Action. Five new BISTS concepts were developed and corresponding prototypes were fabricated:

- A novel solar thermal collector/array with increased architectural acceptance for building integration. (Universitatea Transilvania Brasov, Romania).

- A building integrated transpired air heater (Dublin Institute of Technology, Ireland).

- A modular intergraded solar thermal flat plate air collector (Cyprus University of Technology, Cyprus).

- A concentrating photovoltaic/thermal glazing (Ulster University, UK).

- A hybrid photovoltaic/solar thermal (HyPV/T) façade module (Ulster University, UK)

The report also presents a novel BISTS installation on the Porter Building in, Tel-Aviv, Israel (led by Porter School of Environmental Studies, Israel). This is a fully deployed BISTS and not a simple prototype.

2 Novel Solar-Thermal Collectors/Array With Increased Architectural Acceptance For Building Integration

2.1 Concept

The need to get power or heat from renewable energy sources is now well recognised at European and national level, due to the active measures taken in the past years for complying with the 20-20-20 EU Directive (2009/28/CE). Additionally, the development of the sustainable built environment (e.g. Nearly Zero Energy Buildings) is now subject of regulation at EU level and asks for implementing renewables on or near the buildings to meet a large share of the energy demand. Thus, implementing solar-thermal systems (STS) in the built environment is part of an ongoing effort and many barriers have to be lifted; thus, new solutions has to be found for thermal energy production, storage and management, as recognized also by the H2020 priorities. One main challenge is represented by the urban integration of the STS, which is a well addressed, yet unsolved problem. The best suited convertors for building integration are the flat-plate solar thermal collectors (FPSTC) which are mostly black or blue coloured, for obvious efficiency reasons but that have very low architectural acceptance. For façade and balconies integration there already were developed demonstrative projects, some involving coloured (others than black or dark blue) FPSTC but the solutions did not largely penetrate the market. Additionally, facades and urban structures may have very different geometries, not always suited to the rather large, state of the art FPSTC.

Following the analysis of the state of the art, a R&D project was developed aiming to develop flat-plate solar thermal collector arrays with various geometries, based on efficient solar thermal collectors adapted for urban integration, supporting the international effort towards sustainable communities. The project with the acronym EST IN URBA was granted in 2012, financed by the Romanian Agency for Research (ANCS-UEFISCDI), under the contract no. 28/2012. The project will be finalized in December 2016.

The project is divided in yearly work packages: Conceptual design (2012); Components design and development (2013); Components integration in the new FPSTC demonstrator, indoor testing and constructive optimization (2014); Functional optimization, prototyping and standardization (2015); Implementation of the FPSTC in facades and outdoor testing (2016).

The project proposes a “lego-type” interconnection of FPSTC with non-traditional shapes and colours allowing to build up facades with different geometries. To meet this prerequisite, average sized FPSTC are targeted (aperture area of 0.5…1,5 m2), with the shape and colour following aesthetical constraints, as for example with trapezium shape and red colour.

The project is developed under the coordination of Prof. dr. eng. Ion Visa, in the research Center Renewable Energy Systems and Recycling (RESREC), part of the R&D Institute of the Transilvania University of Brasov, Romania. It is a cooperation project also involving two other universities: Politechnica University of Bucharest (Team leader: Prof. dr. Aurelia Meghea) and the University of Civil Engineering in Bucharest (Team leader: Prof. dr. eng. Florin Iordache), along with a company, The Center for Technology, Innovation and Business, in Brasov, (team leader: Eng. Ioan Totu).

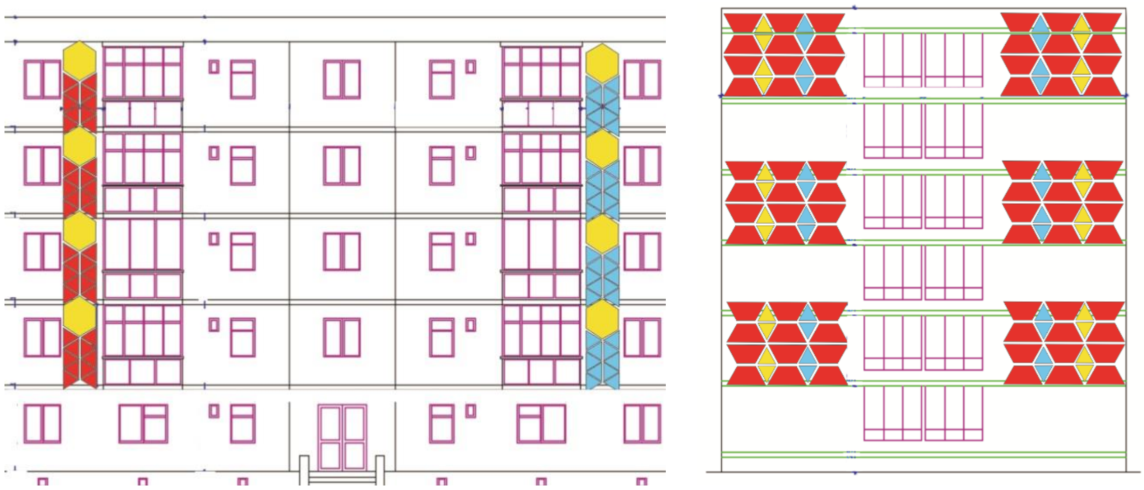
The RESREC team has interdisciplinary competences: Prof. dr. eng. Ion Visa (mechanical engineering, solar energy conversion systems), Prof. dr. eng. Mircea Neagoe (industrial engineering, STS tracking systems), Assoc. prof. dr. eng. Mihai Comsit (design), Lect. dr. eng. Moldovan Macedon (installations and mechanical engineering - STS modelling and implementation), Lect dr. eng. Bogdan Burduhos (electronics – solar radiation modelling and integrated BEMS); the team is completed by the group developing materials: Prof. dr. eng. Anca Duta (solar energy materials), Prof. dr. Dana Perniu (thin films deposition techniques for absorber coatings), Prof. dr. Luminita Isac (advanced characterisation) and Assoc. prof. dr. Alexandru Enesca (self-cleaning glazings). The project involved young Ph.D. students (4) and research assistants (2).

2.2 Application

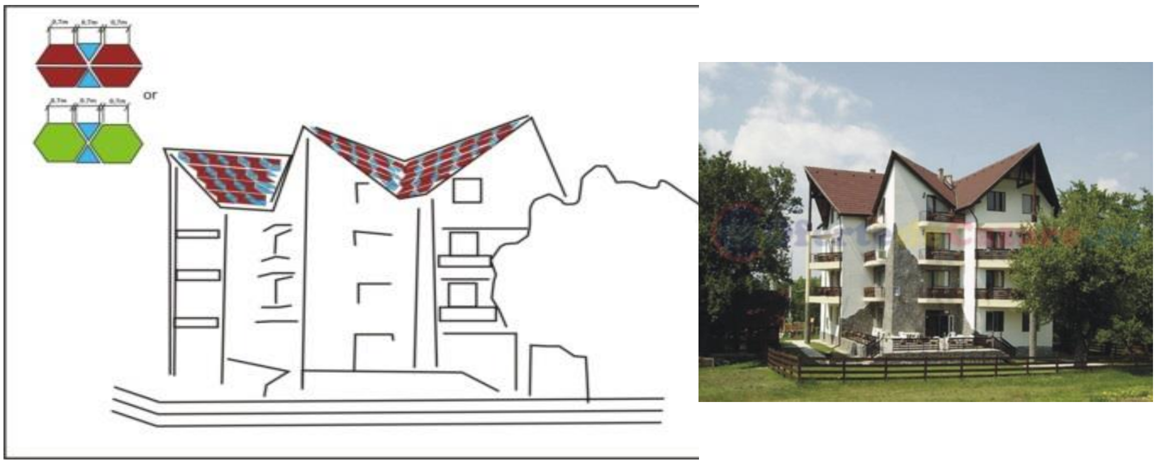
Typical applications of the project are the visible parts of the buildings, as facades or tilted roofs. The initial design pre-requisites of the lego-type solar-thermal arrays are:

- To be able to cover various wall and roof configurations;
- Flexible design, of lego type, matching collectors with different shapes and/or colours;
- Implementable on new or retrofitted buildings;
- Fixed ST arrays or with limited tracking;
- Mounting should allow equilibrated hydraulic pressure;
- Urban/architectural acceptance.
- To be able to significantly contribute in meeting the thermal energy demand in buildings located in temperate continental climates.

Thus the lego-type array concept can apply in various configurations, as presented in Fig. 2.1:



(a)



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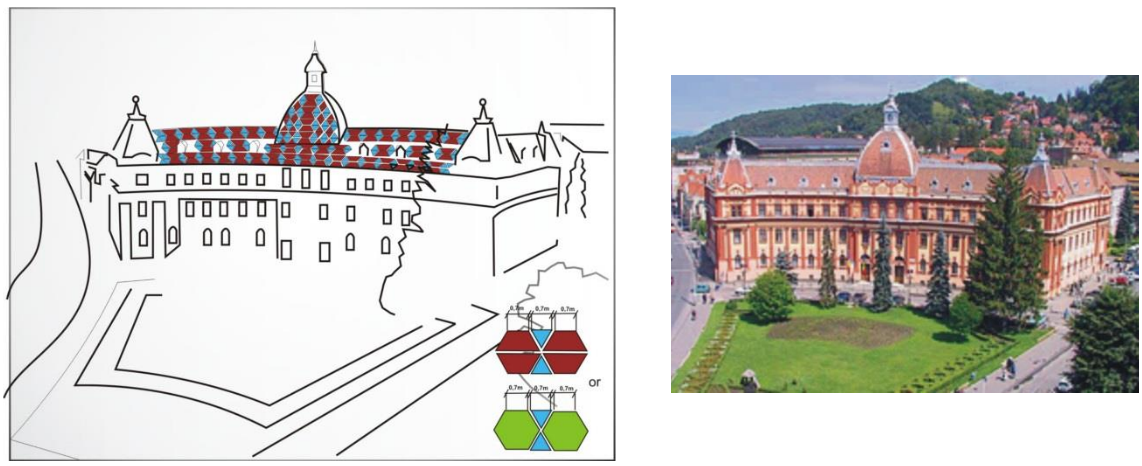


(c)

Fig. 2.1. Concept of lego-type arrays implemented in: (a) facades of multi-family blocks of flats; (b) visible parts of the rooftops suitably exposed to solar radiation; (c) historical buildings

Implementation can be done on multi-family buildings facades, Fig. 1a; this allows fulfilling the obvious functionality (thermal energy production) and can increase the urban acceptance of the rather monotone city districts, mainly consisting of blocks of flats built in the previous century. In this case, the shape and the colour of the building blocks (trapeze FPSTC) and of the entire array are important mainly for aesthetical purposes. However, the arrays can be implemented on roofs with unusual shapes (Fig. 1b) when the aesthetical features are complementary to the main function, of thermal energy production. A similar case is valid for historical buildings, where plenty of challenges have to be faced for preserving the „spirit of the city" while increasing the buildings' sustainability, Fig. 1c.

2.3 Physical Description

2.3.1 Physical description and detailing

The new trapeze solar-thermal collector

The building block in the lego-type solar-thermal arrays with increased architectural and urban acceptance is *the trapeze FPSTC*. The main new/innovative features embedded in this collector are presented in Fig. 2.2:

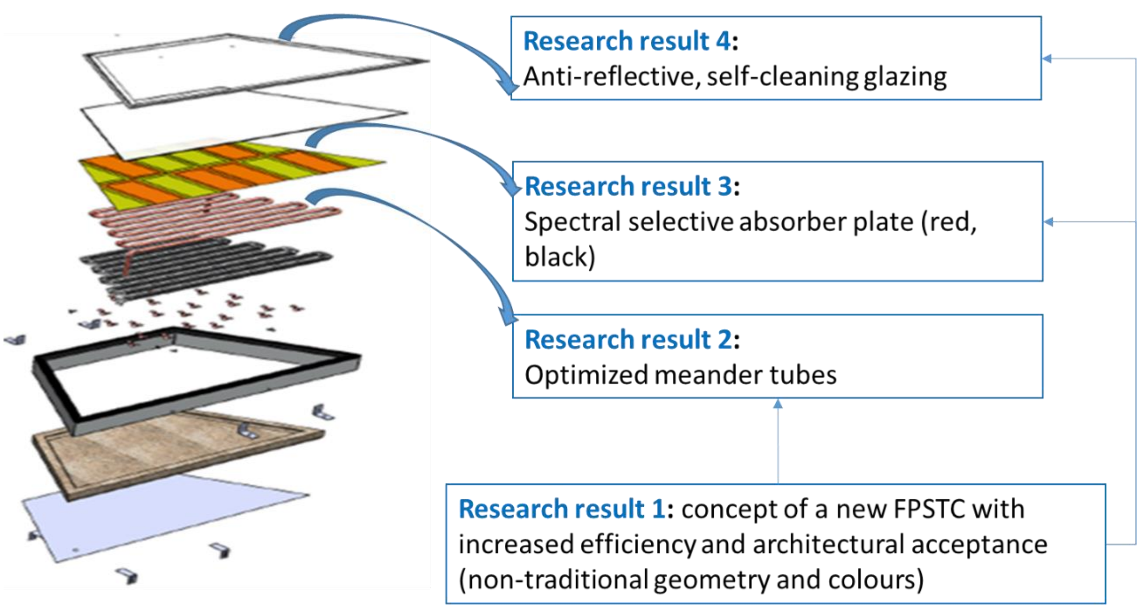


Fig. 2.2. New/innovative features in the trapeze solar thermal collector

Following the design and modelling step (TRL 2), a demonstrator was stepwise optimised (TRL3) as already published (Visa I., et al., Applied Thermal Engineering, 90, 2015, pp. 432–443). The main components subject of optimisation were: the absorber substrate (optimised choice: copper), the meander tube register (length, tube diameter, distance between meanders), the insulation (material, thickness and position inside the collector), the glazing (with special anti-reflecting and self-cleaning coating); the contact tubes – absorber was found – as expected - to have a significant influence on the overall performance of the collector. In the demonstrator, intermediate contact through copper clamps was used.

Starting from this demonstrator, in a second step, the prototype was developed (TRL4), considering manufacturing and scaling up issues.

The re-design mainly considered

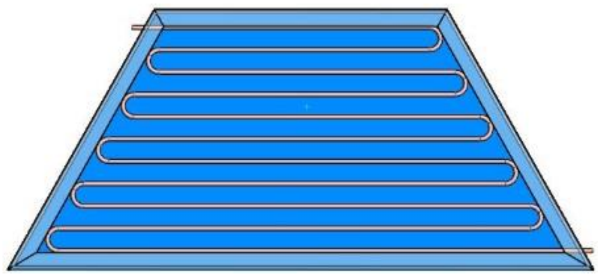
- The components: the casing and the insulation,
- The assembly process: the solution for connecting the meander tubes with the absorber plate.
- The overall sustainability of the product: the absorber coating was re-optimized: starting from the initial rather energy intensive deposition process (spray pyrolysis deposition) and ending up with a much less energy intensive process, cold spraying of inks prepared through a green chemistry rout, sol-gel.

The solar-thermal array

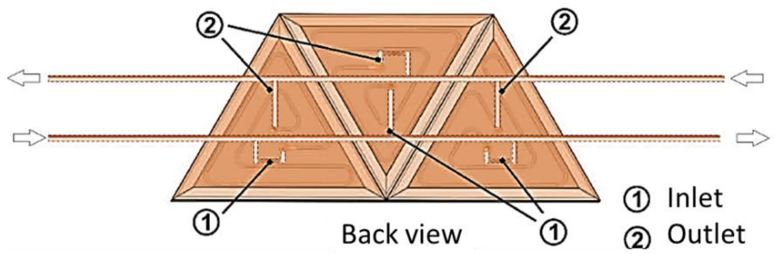
Linking the trapeze solar-thermal collectors in arrays considered serial and parallel connections. These were modelled considering the thermal transfer.

In concrete terms, important is the inlet/outlet connections and, so far, these are positioned on the parallel edges of the trapeze, Fig. 2.3a.

Central inlet/outlet positions can be considered, although these raises significant hydraulic challenges. These central connection, Fig. 2.3b, can be well applied for roofs mounting as presented for a model considering triangle collectors:



(a)



(b)

Fig. 2.3. Inlet/outlet options of the FPSTC for arrays development: (a) for vertical facades of trapeze FPSTCs; (b) for flexible geometry of roof-mounted arrays

2.4 Engineering drawings

Following the design pre-requisites, the trapeze FPSTC has an overall area of 0,67m^2. The detailed design of the meander tubes is presented in Fig. 2.4 while the detailed design of the entire collector is given in Fig. 2.5:

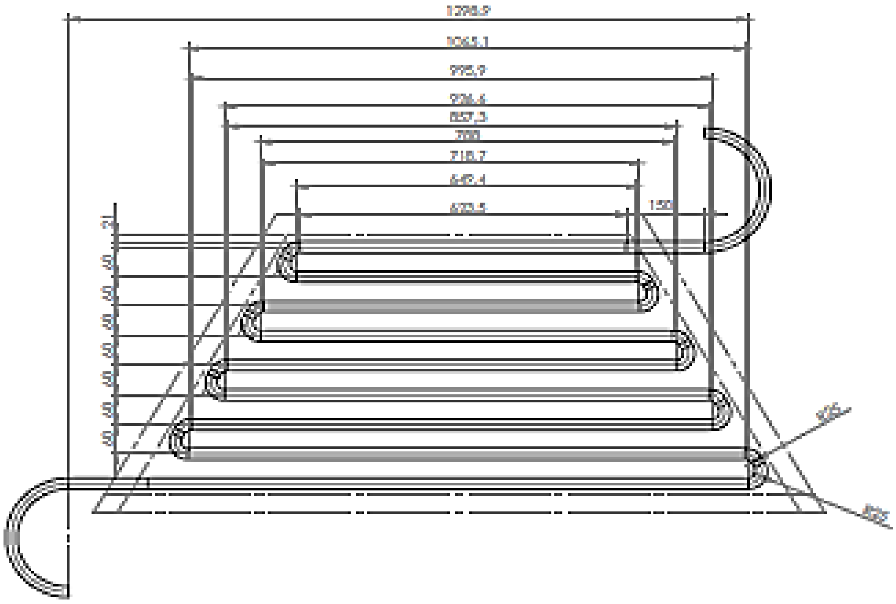
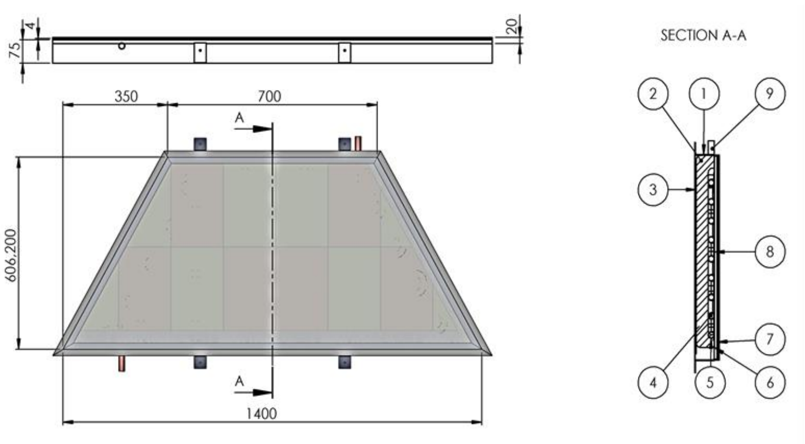


Fig. 2.4. Detailed design of the meander tubes



(1) metal casing with rectangular profile (surface zinc thermal treatment);

(2) mineral wool insulation;

(3) aluminium back plate (0.7mm);

(4) copper tubes;

(5) spectral selective absorber plate on aluminium substrate;

(6) copper elements for mounting the absorber plate

(7) glazing with anti-reflective and self-cleaning coating;

(8) PVC profile;

(9) fittings for the hydraulic elements

Fig, 2.5. Detailed design of the trapeze collector

2.4.1 Materials (quantity and quality), durability, duration

A synthetic presentation of the materials embedded in the prototype is given in Table 2.1:

Table 2.1. Materials in the main components of the trapeze FPSTC

Component	Material	Amount of material to develop one collector
Casing	Steel plate with zinc surface thermal treatment	4 m
Back plate	Steel plate with zinc surface thermal treatment	0,7x700x1500mm
Insulation	Mineral wool	50 mm thickness
Meander tubes	Copper tubes (Ø22mm)	10 m
Absorber plate – substrate	Aluminium plate	0,7x700x1500mm
Absorber plate – red coating	Iron oxide(s) nano-sized pigment	93.6 g
Absorber plate – black coating	Nickel sulphide nano-sized pigment	162 g
Glazing	Polymeric glass	Glass sheet: 4x700x1500mm Plastic fixing: 2m bar
Anti-reflective and self-cleaning coating	Silica/Titania/Au nano-sized coating (insuring the solar radiation transmittance: T > 80%)	1.05 g

2.5 Physical fabrication

2.5.1 Fabrication process (stages, steps, effort, images, techniques, specialisms)

The general flow for developing the trapeze FPSTC prototype is presented in Fig. 2.6, while in Fig. 2.7 several images during the prototype development are included:

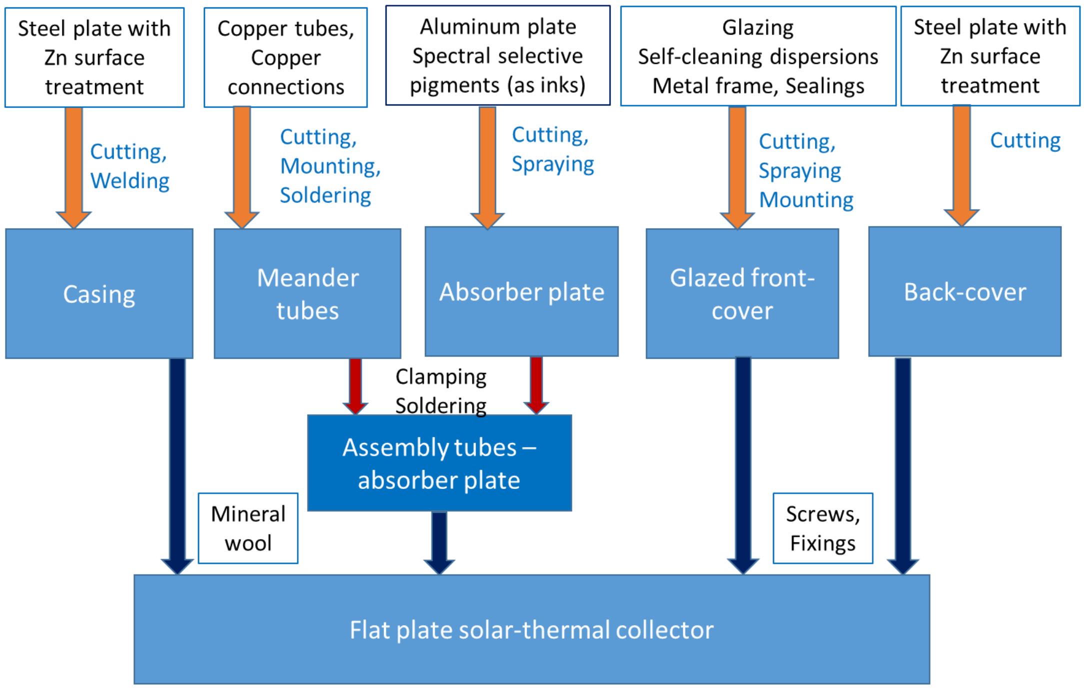


Fig. 2.6 General flow for manufacturing the prototype of the trapeze flat plate solar thermal collector

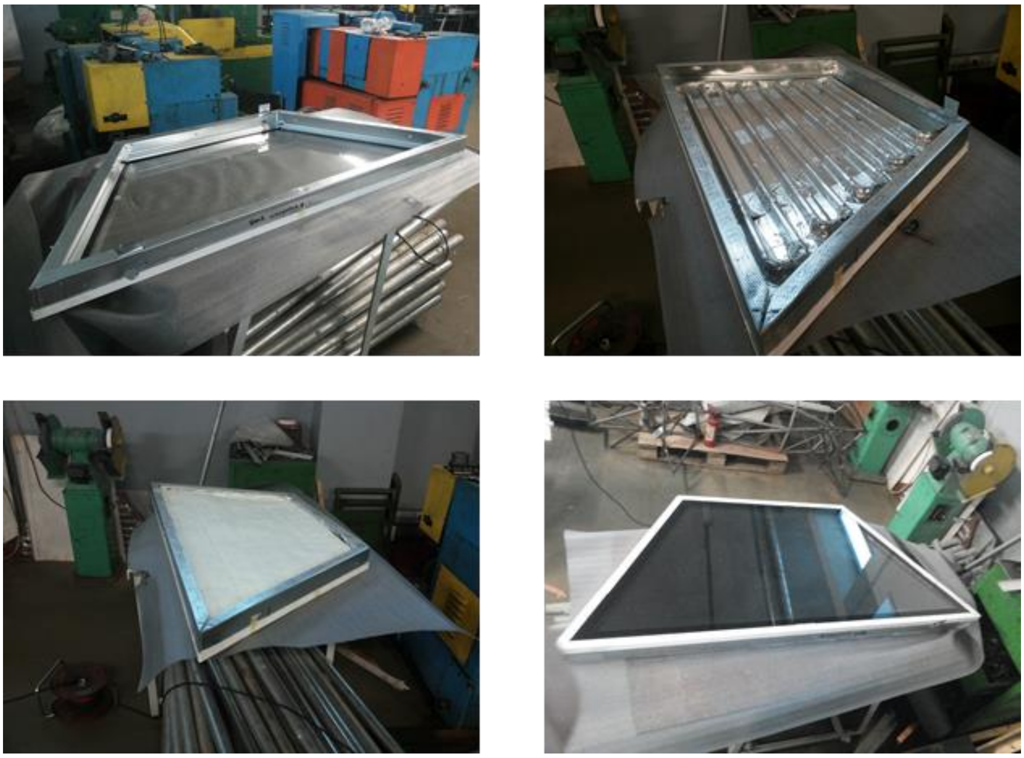


Fig. 2.7. Steps in developing the prototype

The red spectral selective absorber plate was obtained in black and in red colours, starting from an aluminium plate (99.7% Al), subjected to cleansing (nitric acid), controlled roughing (acid/alkaline successive treatment), rinsing; this substrate was infiltrated with iron oxides particles, as Fig. 2.8 shows. The oxide particles were obtained through a room temperature technique (sol-gel synthesis) and were deposited through spraying (industrial technology), at 100^{o}C.

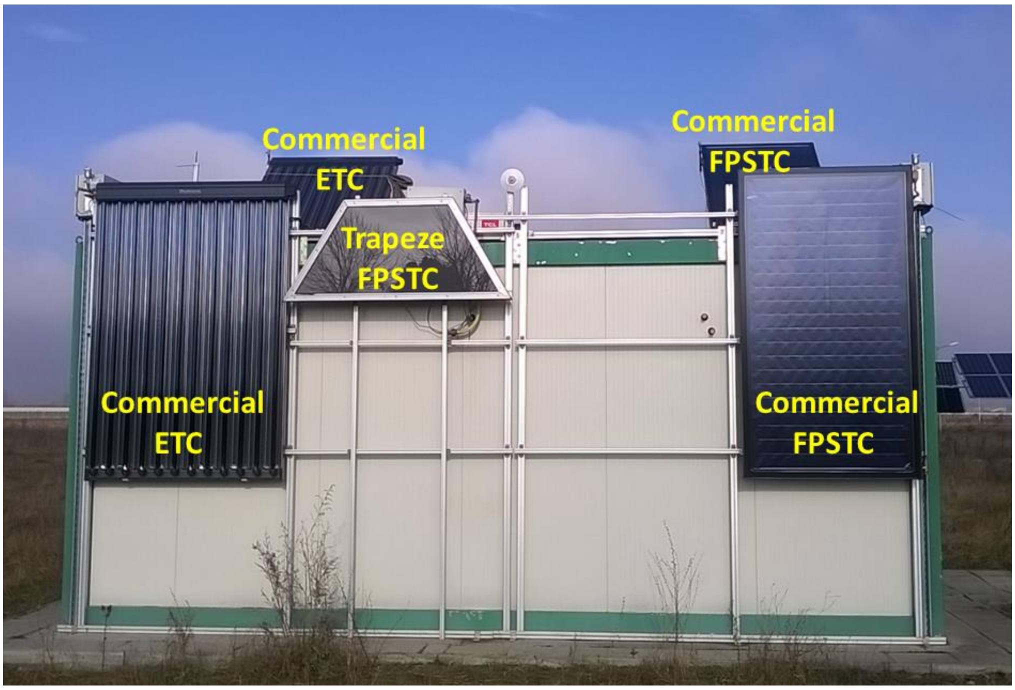
(a) (b) (c)

Fig. 2.8. Steps in manufacturing the absorber plate: (a) aluminium substrate; (b) roughened aluminium substrate; (c) red spectral selective coating ($Al/Al_2O_3/FeO_x$)

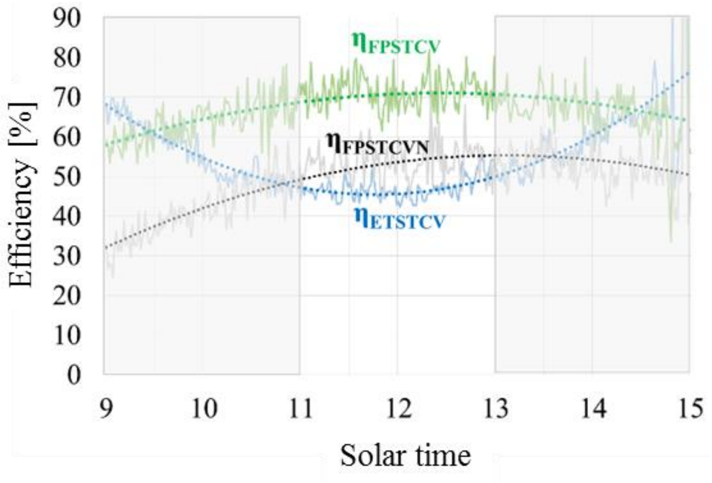
The anti-reflective and self-cleaning glazing was obtained starting from the polymeric glass, successively cleaned with water and alcohol. The anti-reflective coating was obtained from dispersions/inks containing silica and titania nano-particles deposited in a layer – by layer spraying process. Standard "heavy duty" photocatalytic tests (using methylene blue as pollutant/dirt simulator) showed a self-cleaning capacity of about 40% after 4 hours under solar simulated radiation.

2.5.2 Assembly process (stages, steps, effort, images, techniques, specialisms)

To develop the façade, the trapeze FPSTCs have to be assembled, following serial or parallel connections. However, in meeting a certain energy demand, the facades design has to use infield data (energy output and solar to thermal conversion efficiency). To collect these data, the FPSTC was vertically installed on the façade of the solar-thermal laboratory, in the R&D Institute of the Transilvania University. The experimental set-up includes one commercial FPSTC and one evacuated tube collector, installed on the same façade, along with similar commercial collectors installed on the laboratory flat roof, tilted at the optimal angle of 35°. The experimental set-up is presented in Fig. 2.9.



(a)



(b)

Fig. 2.9. (a) Outdoor set-up for comparative outdoor testing the trapeze flat plate solar-thermal collector and commercial collectors of flat plate (FPSTC) and evacuated tubes (ETC) types; (b) efficiency variation of the vertically mounted trapeze collector (FPSTCVN), of the commercial flat plate collector (FPSTCV) and of the commercial evacuated tube collector (ETSTCV), during June 23, 2015

For the vertically mounted collectors, the efficiencies were calculated and one example for a day close to the summer solstice is given in Fig. 2.9b.

2.6 Modular configuration

2.6.1 Units size and dimensions

The building block of the new solar-thermal facades has the dimensions as described in Fig. 2.5.

2.6.2 Modularisation and upscaling

The isosceles trapeze geometry of the unit flat plate solar-thermal collector allows developing modular structures. The limit in assembling the collectors into arrays is given by the connection geometry (parallel or serial); while for parallel connections the hydraulics is the main optimisation feature, for serial connection, the output temperature of the last collector in the series will govern the number of units in a row. Preliminary modelling shows that optimally no more than four collectors are recommended to be serially connected. Further on, modelling showed that the trapeze collector can be linearly up-scaled at dimensions as presented in Fig. 2.10. For these collectors, modularisation can be translated to the manufacturer, by delivering assemblies of two collectors.

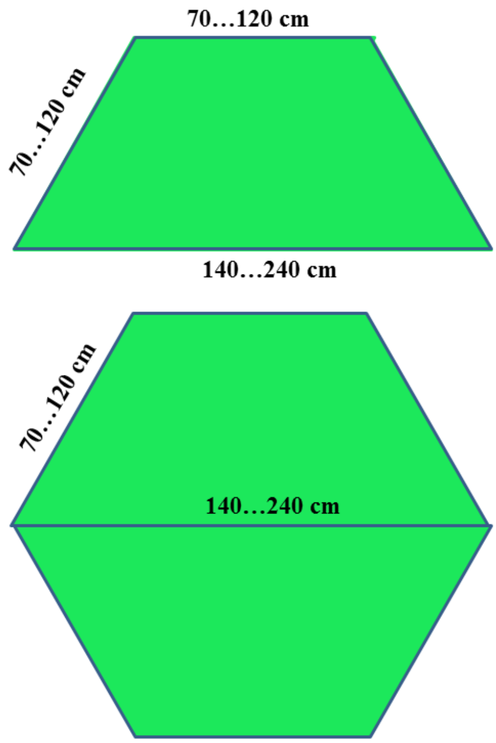


Fig. 2.10. Modular units of two trapeze FPSTC possible to be delivered by the manufacturer

Considering the building of the RESREC R&D Centre, building integration was developed at conceptual level, as presented in Fig. 2.11:

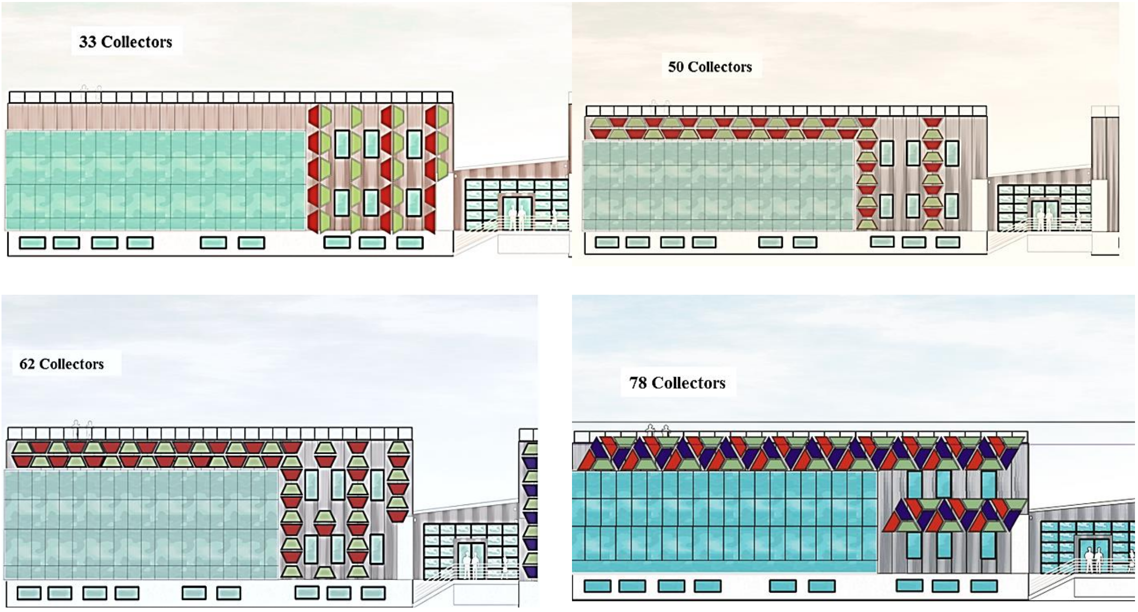


Fig. 2.11. Solar-thermal arrays integrate on the facades

The development and testing of the solar-thermal facade is ongoing and the results will be comparatively analysed at the end of 2016.

2.6.3 Product development (potential for commercialisation, mass manufacturing, DfM)

The EST in URBA project has as final outcome a prototype façade. A pre-feasibility study developed by the industry partner considered, for market implementation, only existent technologies. The feasible alternative is to develop an integrated approach for the design, development and implementation of customised projects, for urban integration, thus embedding products and knowledge for tailored finite products adapted to the end-users (building owners). It was estimated that for a 10 m^2 array system with variable geometry, the number of implemented arrays/year (after finalizing the project) will be: year I: 4; year II: 6; year III: 10; year IV: 12.

A cost – benefit analysis on the project's implementation shows that the financial investment of the industry partner will be recovered in: 4.21 years. The solely risk presumed to have success with this project is associated to the political and financial instruments supporting the implementation of solar-thermal systems in the built environment.

During the project development, two patent applications were submitted and are under evaluation:

1. Visa I., Duta A., Neagoe M., Comsit M., Moldovan M., Burduhos B., System of flat polygonal solar panels modular built for being integrated into the facades, RO128860(A0)
2. Vișa I., Comsit M., Duță A., Neagoe M., Saulescu R., Ciobanu D., Moldovan M., Burduhos B., Perniu D., Enesca A., Isac L., Mihoreanu C., Ienei E., Totu I., Modular solar collector to optimize the conversion efficiency and increase the architectural acceptance, RO130275 (A0)/29.05.2015

3 Building Integrated Transpired Air Heater

3.1 Concept

The "solar plenum" is an air heating solar collector which integrates an asymmetric compound parabolic concentrator with a tertiary reflector sector that reflects solar radiation into a downward facing absorber surface. Being downward-facing, convection heat loss from the absorber surface is inhibited. The concentration of insolation to an absorber leads to it being at a much higher temperature than ambient. Air enters the solar plenum via a grille beneath its glazed aperture. That glazed aperture prevents external wind perturbing the convection suppression at the absorber. Air is conveyed through the solar plenum by a fan. Heat is removed by the air passing through pin holes in the transpired absorber. The flow rate is maintained at a rate that allows air plumes to pass through the thermally stratified air layers beneath the absorber without significantly diminishing the thermal insulation of the absorber provided by the stratification.

This product involves the design and development of a Concentrating Transpired Air Heating (CTAH) unit. This air heating solar collector comprises of an inverted perforated absorber and an asymmetric compound parabolic concentrator (see Figure 1) that increases the intensity of solar radiation incident on the perforated absorber. The development included optimum system components considering efficiency, compatibility, cost, weight and scaling. The average thermal efficiency was found to be approximately 55%-65% with average radiation above 400 W/m^2 for flow rates in the range of 0.03 kg/s/m^2 to 0.09 kg/s/m^2. Experimental results at air flow rates of 0.03 kg/s/m^2 and 0.09 kg/s/m^2 showed a temperature rise of 38^{o}C and 19.6^{o}C respectively at a solar radiation intensity of 1,000 W/m^2. As the pressure drop in the system was found to be 10 Pa for an air flow rate of 0.1 kg/s/m^2 between the inlet and the outlet, the required fan power consumption was very small in comparison to the recovered energy. Thermal efficiency remained high at higher air flow rates.

3.2 Applications

Details of the typical applications for the case study technology – climate, building type, retrofit, new build, façade, roof, etc.

Solar Air Heating Collectors have applications in space heating and space ventilation, timber seasoning, curing of industrial products and drying.

At present, two main types of Solar Air Heating Collectors exist commercially: Unglazed Solar Air Heating Collector (USAHC) and Glazed Solar Air Heating Collector (GSAHC). The basic difference between two main types of solar air heating collectors is presence of glazing cover and design of absorber surface. The device can also be used for cooling building at night time, removing heat from the various rooms in an efficient and low cost method.

3.3 Design and construction of the concentrator system

The design consists of the integration of a Transpired Air-heating Collector (TAC) and an Asymmetric Compound Parabolic Concentrator (ACPC).

3.3.1 Construction of the concentrator system

A diagram of the CTAH system is presented in Figure 3.1. A perforated absorber has been incorporated in the design which faces downward to reduce radiation loss. The perforated surface allows air to flow through the absorber which enhances heat transfer between the absorber and the flowing air. Solar air heaters are generally constructed using metal plates as the absorber of the incident solar radiation which introduces conduction losses. Instead of a heavy metal absorber, a nonconventional low conductive light weight carbon fibre absorber has been used. A fan is placed at the end of the air duct to extract air through the perforated absorber. This heated air can be transported to the required environment or supplied through a simple flexible hose to another unit for accumulating more heat. The input of the system is insolation at the aperture. The available insolation varies for local climate and orientation of the aperture. The concentrator of the system works as an amplifier which increases the amount of solar radiation on a decreased absorber area. The heat from one absorber can be transferred to a number of other absorbers, placed adjacent to the first one, in order to accumulate the solar energy to produce a clean, high temperature air for use in a building.

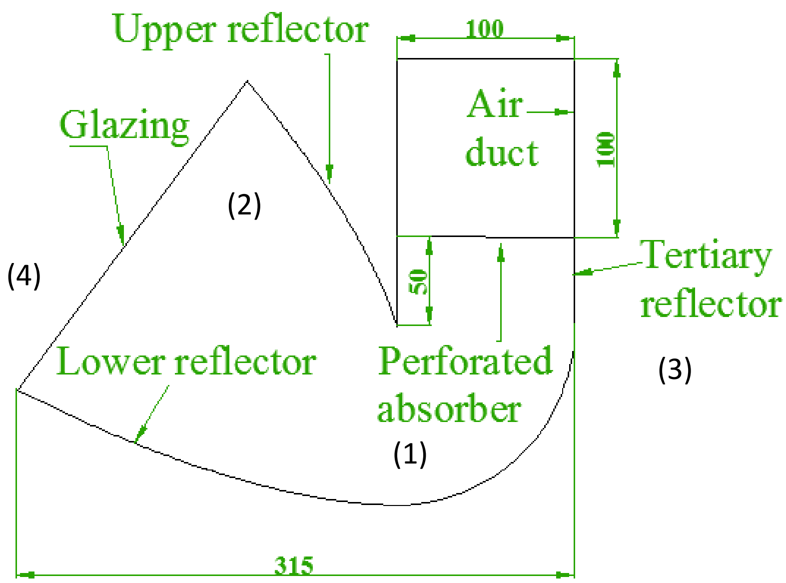


Figure 3.1: Schematic of the Collector

The upper reflector is a combination of primary parabolic and straight tertiary reflectors. The lower reflector is a combination of parabolic primary, circular secondary and straight tertiary reflectors. The secondary circular part of the concentrator concentrates all incident radiation on the inverted absorber. A parallel reflector section just below the inverted absorber helps to improve the stratified thermal layer below the absorber which enhances the heat transfer mechanism. Concentration of solar radiation becomes necessary when higher temperatures are desired. Heat losses from the collector are proportional to the absorber area. A glazing cover has been introduced which works as the heat trap for the emitted radiation from the absorber surface. A high transmittance glazing material (Low e) reduces the optical loss. The glazing surface is also necessary to provide protection from dust deposition, rain, wind and wildlife.

3.4 Materials (quantity and quality), durability, duration

The concentrating reflector, transpired absorber and the glazing cover are the main components of the system. The unit is built from thin gauge sheet material, shaped and cut to the specified dimensions. The physical length of the unit can be cut to suit the mounting wall dimensions. Reflector material (95% total light reflection) from a company in Germany called Alanod. The main properties of this material is shown in Table 3.1.

Properties	Parameters	Values
Mechanical	Tensile strength (Mpa)	160-200
	Yield strength (Mpa)	140-180
	Elongation a 50%	≥ 2
	Bending radius	≤ 1.5 fold of thickness
Optical	Total solar reflectance %	95%
	Front side	PVD-improved
	Reverse side	Anodised
Physical	Density (g/cm^2)	2.7
	Heat resistance (1000h)	1500C
Dimension	Max. Width (mm)	1250
	Thickness (mm)	0.5
Warranty	10 years	

Table 3.1: Properties of Mirosun reflector material

The glazing material cover of the unit is a sheet of 6 mm thick low iron glass. The glazing surface protects the reflecting and absorbing surfaces and reduces thermal losses from the absorber. It has a maximum transmittance of 96% and a refractive index of 1.526

3.5 Physical fabrication

3.5.1 Fabrication process

The unit can be produced as a flat-pack and is modular in design and construction. The sections are formed from flat sheet, laser cut or profile cut, assembled and folded together on-site and of light weight to be erected by a 2 person team. The length of the unit can be produced to suit the building width or to customer requirements. The units can be used individually or are stackable to enhance energy accumulation.

3.6 Modular configuration

3.6.1 Units size and dimensions

The end plate dimensions are shown in Figure 3.2.

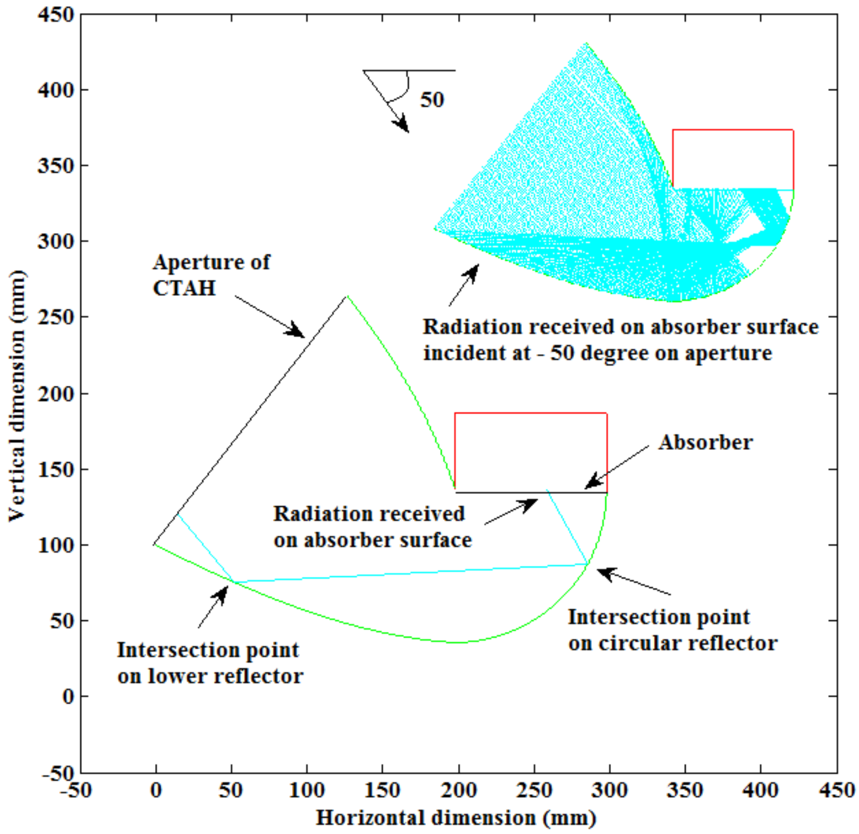


Figure 3.2. End plate dimensions

3.6.2 In situ artist impression

Artist's impressions of the Solar plenum are shown in Figures 3.3a and 3.3b.

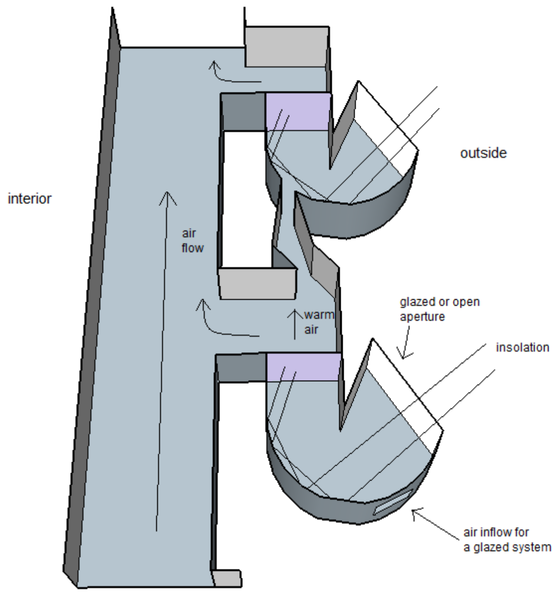


Figure 3a. Artistic impression of Solar Plenum

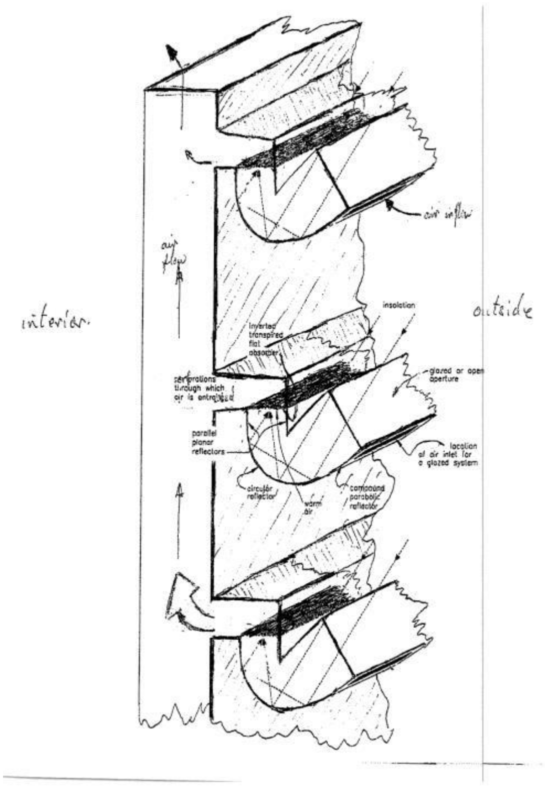
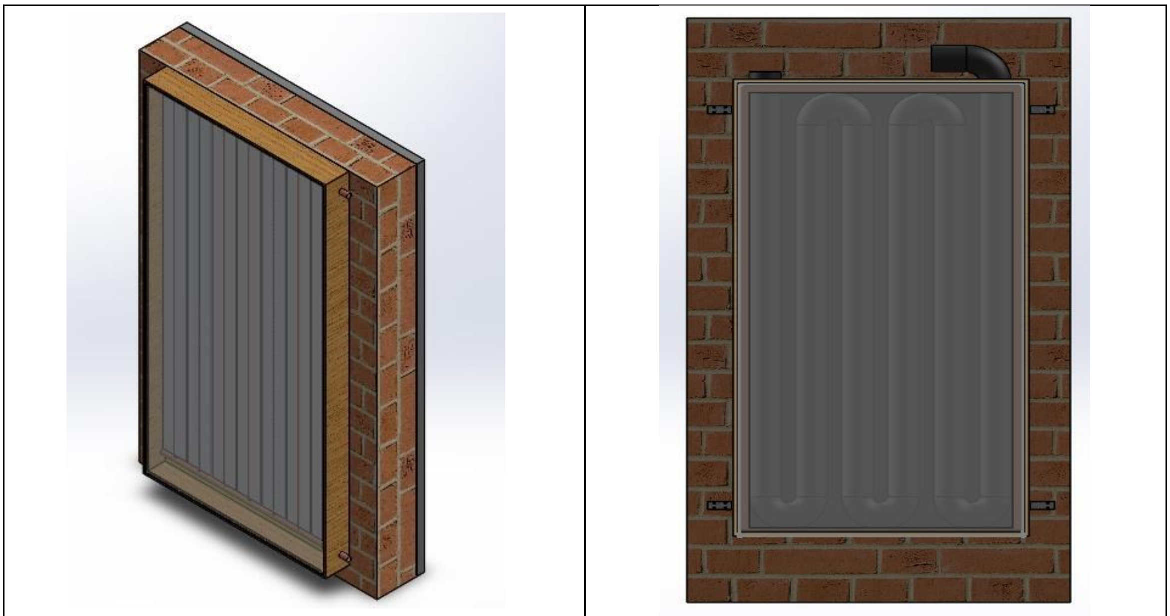


Figure 3b. Artistic impression of Solar Plenum

4 Modular Intergraded Solar/Thermal Flat plate collector

4.1 Concept

Existing building materials can act as the back plate of a flat plate collector. An integrated water or air collector can thus be build on a building façade or roof. Using copper pipes and water as a circulating medium, or air in ducts, the falling solar energy can be absorbed and transformed into heat. The units are proposed to provide additional thermal insulation to the building, whilst producing useful amounts of hot water or air that could be used for the occupant needs and comfort.



(a) (b)

Figure 4.1: Image of the prototypes untilising the building materials as a back plate and providing (a) hot water and (b) air, for the occupant needs

The constructed unit utilises the face of an existing brick wall where an extra insulation is placed on the front face of the wall.

In the case of the hot water collector, a conventional copper plate with copper pipes is positioned in front of the insulation and the unit is framed in a wooden box and covered with glass. Using the same operating principle as a flat plate collector the unit heats domestic hot water by catching and storing solar energy. The working Heat Transfer Fluid (HTF) is water, that can be stored in an insulating vessel and be used when needed. It can also be used as a circulating fluid of the heat exchanger of a hot water cylinder.

In the case of the hot air collector, the hot air can be circulated either directly in a room to race its temperature or blended with the air in a duct system.

4.2 Application

The modular façade integrated Solar/Thermal Flat plate collector, as all other similar BISTS, is designed to:

- Reduce building cooling loads in warm climates and heat loss in cool climates by providing additional insulation to the building fabric
- Provide direct thermal energy generated on site by either heating water or air and therefore lower the power requirements of the building
- Reduce the carbon footprint of the building by using renewable energy

The units being modular can be used in the façade or roof of a building. These units can be used across a range of domestic and commercial building structures and typologies, substituting common envelope elements in both existing and new structures.

4.3 Physical description

4.3.1 Physical description and detailing

Engineering drawings were prepared for full size modules taking into account available construction and engineering material specifications and dimensions. The drawings were followed and the prototypes were fabricated according to specifications. Figure 2 shows the four prototype units mounted onto a building wall.

Figure 4.2a, shows the integrated hot water collector. The unit was enclosed in a wooden frame, with dimensions 1.72 m x 0.92 m and 120 mm deep, that was mounted on a vertical brick wall 1.8 m x 1.2 m x 200 mm thick, facing south and covered with 40 mm plaster on the backside. In the frame an insulation layer of glass wool, 30 mm thick, was placed on the wall. The absorbing plate consists from seven, 1.6 m x 0.15 x 0.4 mm thick, corrugated copper strips on which 7 copper pipes of 15 mm in diameter were welded. The absorber was placed in front of the insulation and covered with a 5 mm glass. In this case the system was connected to a hot water cylinder allowing the system to work with natural convection.

Figure 4.2b shows the integrated hot air collector utilising an aluminium foil duct. The unit was enclosed in a wooden frame, with inside dimensions 1.72 m x 0.92 m and 170 mm deep, that was mounted on a vertical brick wall 1.8 m x 1.2 m x 200 mm thick, facing south and covered with 40 mm plaster on the backside. In the frame an insulation layer of glass wool, 30 mm thick, was placed on the wall. In front of the insulation was placed an absorbing mild steel plate, 0.4 mm thick, and 5 loops of aluminum tube (6 running lengths) of 100 mm in diameter and painted black. The enclosing frame was covered with a 5 mm glass. Additionally, the system was connected to a two speed air fan for extracting the air of the collector.

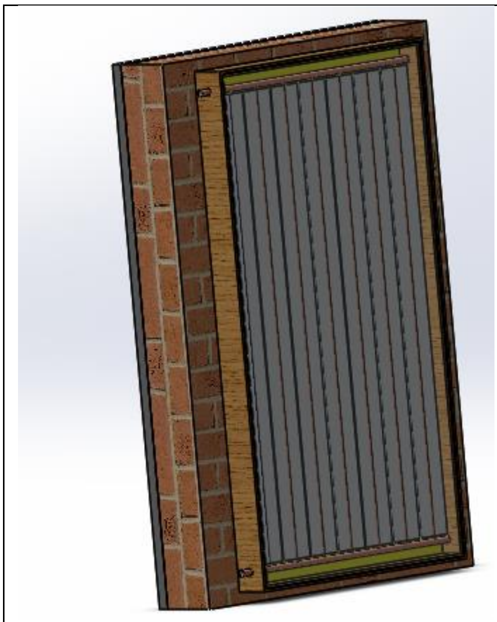
Figure 4.2: Prototype constructions, (a) integrated hot water collector (b) integrated hot air collector utilising an aluminium foil duct (c) integrated hot air collector with internal metal separators (d) integrated hot air collector with a mild steel square tube duct.

Figure 4.2c shows the integrated hot air collector with internal metal separators. The unit was enclosed in a wooden frame, with inside dimensions 1.735 m x 0.94 m and 76.6 mm deep, that was mounted on a vertical brick wall 1.8 m x 1.2 m x 200 mm thick, facing south and covered with 40 mm plaster on the backside. In the frame an insulation layer of glass wool, 50 mm thick, was placed on the wall. In front of the insulation was placed a mild steel plate, 1.0 mm thick. On the plate seven vertical mild steel separators were glued with high temperature silicone. In this way 8 linked compartments were created, forming a continuous tube. On top, an absorbing mild steel plate 0.6 mm thick was glued with high temperature silicone. The absorbing plate was then painted black. The enclosing frame was covered with a 5 mm glass. The sites of the wooden frame in this case, were also insulated. Additionally, the system was connected to a two speed air fan for extracting the air of the collector.

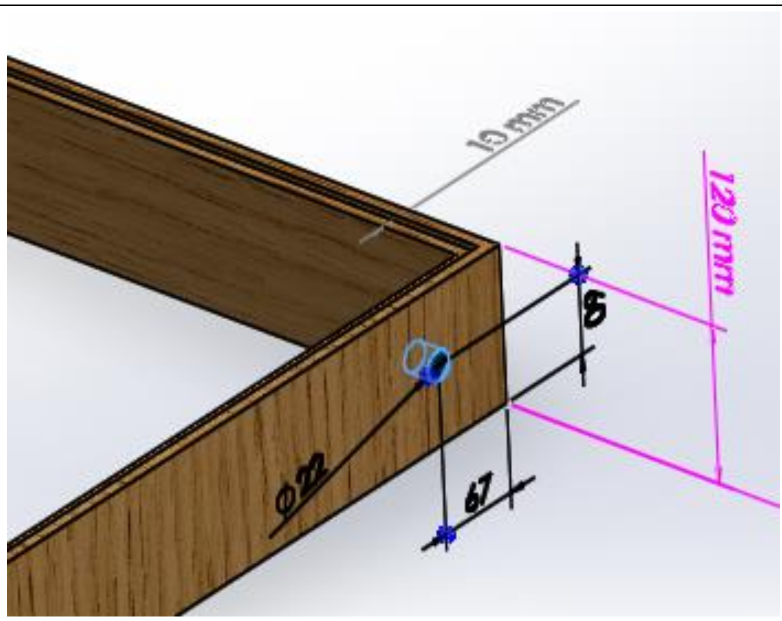
Figure 4.2d shows the integrated hot air collector with a mild steel square tube duct. The unit was enclosed in a wooden frame, with inside dimensions 1.635 m x 0.84 m and 76.6 mm deep, that was mounted on a vertical brick wall 1.8 m x 1.2 m x 200 mm thick, facing south and covered with 40 mm plaster on the backside. In the frame an insulation layer of glass wool, 50 mm thick, was placed on the wall. In front of the insulation was placed a mild steel absorber plate, 0.5 mm thick. On the plate a continuous welded pipe, made of six vertical mild steel runs of square tube 6 cm x 6cm x 1.5mm thick, were placed. The absorbing plate and the tube was then painted black. The enclosing frame was covered with a 5 mm glass. Additionally, the system was connected to a two speed air fan for extracting the air of the collector.

4.3.2 Engineering drawings

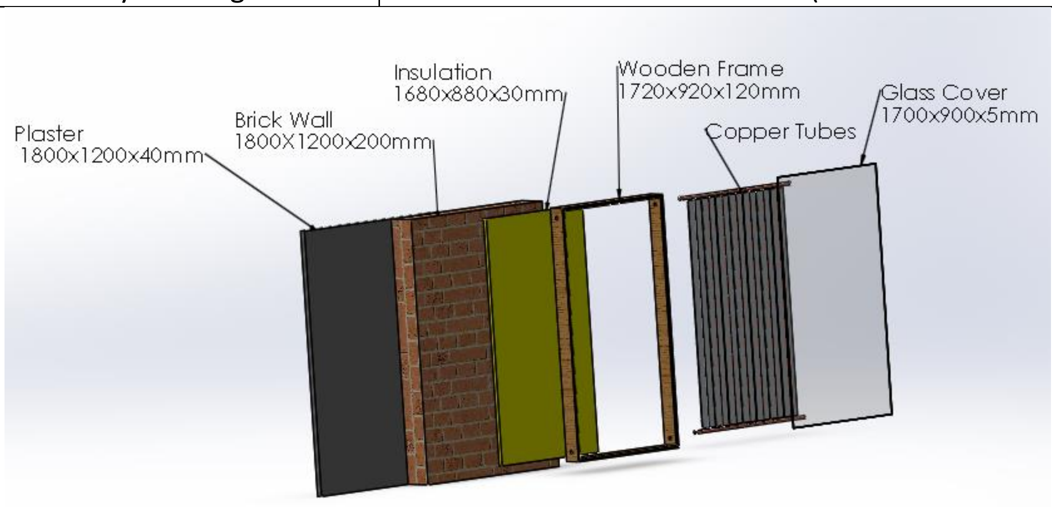
(a) Integrated hot water collector



Assembly drawing

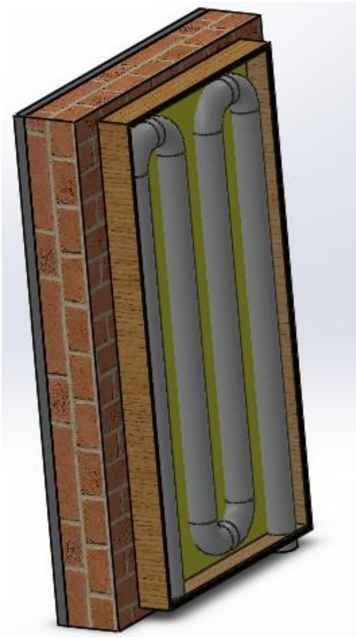


Detail of wooden frame (dimensions in mm)

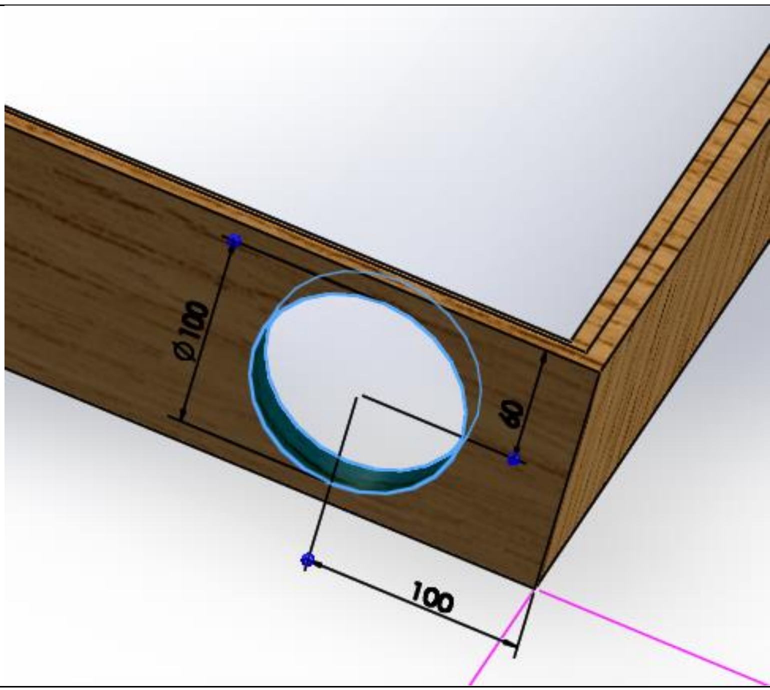


Expanded assembly showing details

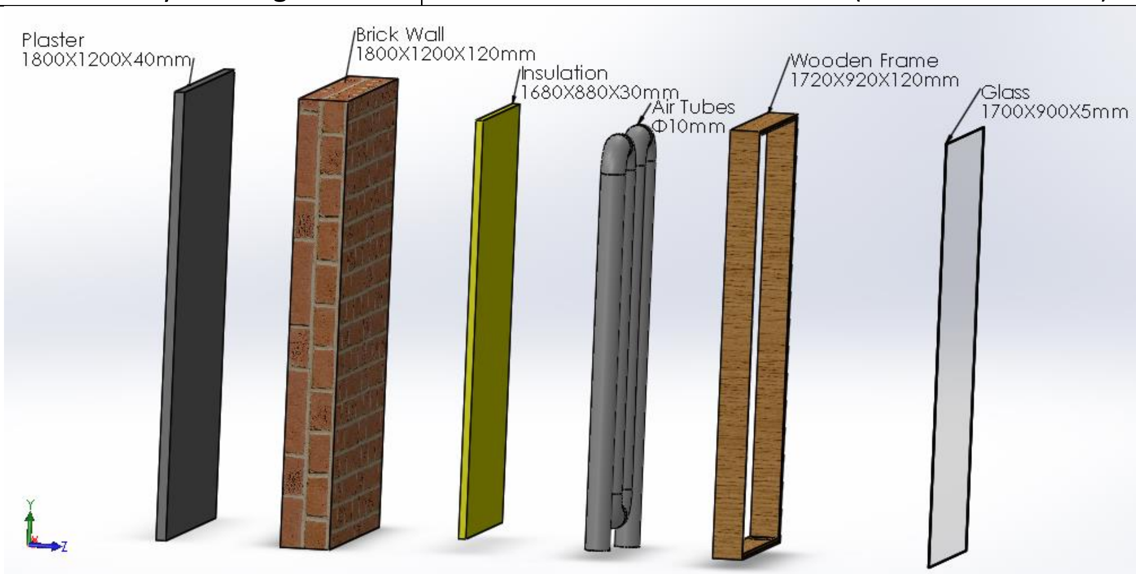
(b) integrated hot air collector utilising an aluminium foil duct



Assembly drawing

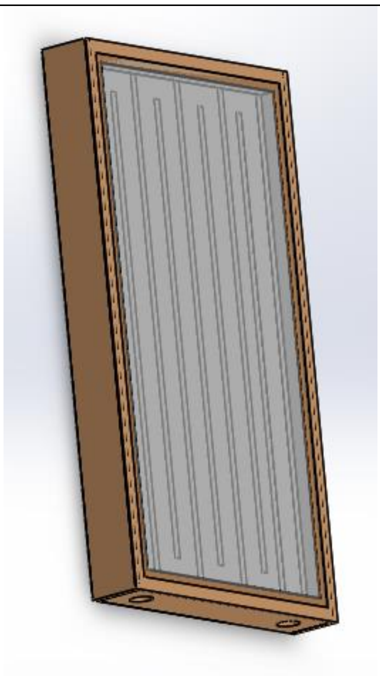
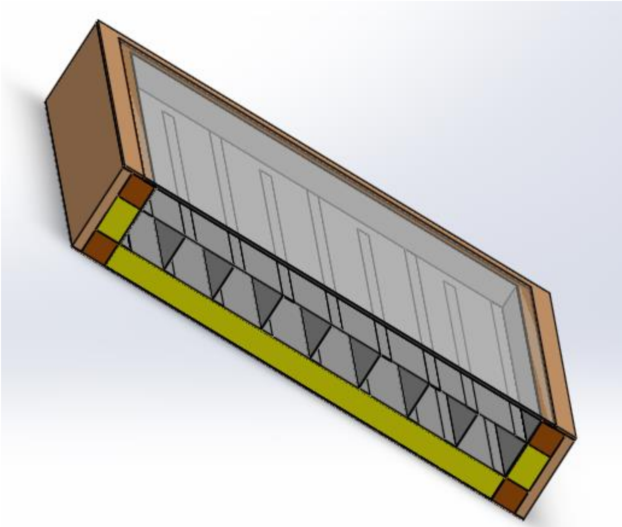
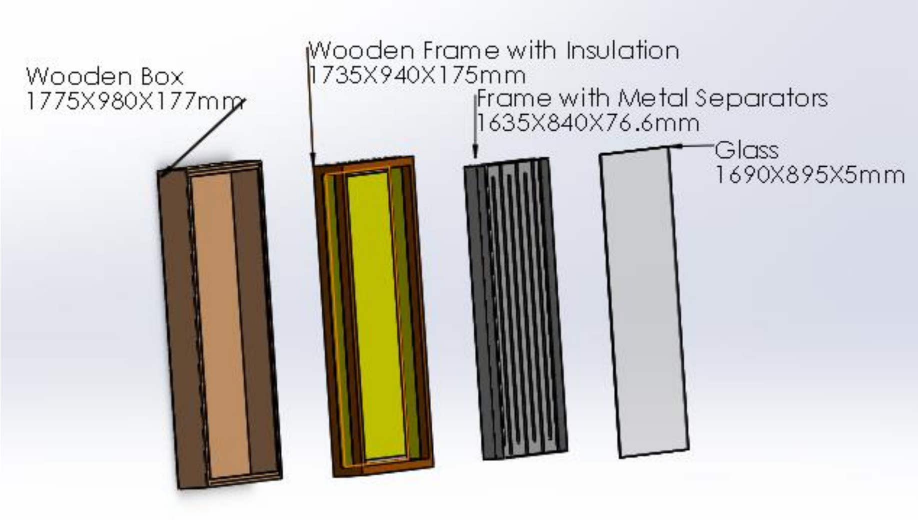


Detail of wooden frame (dimensions in mm)



Expanded assembly showing details

(c) integrated hot air collector with internal metal separators

	
Assembly drawing	Section through the middle, showing separators in position, with insulation and top glass
 	
Expanded assembly showing details	

4.3.3 Materials

The full size prototype units constructed and tested at the Cyprus University of Technology can accept a number of modifications in order to suit specific building constructions and product requirements. The presented units though, consist of the following material components:

(a) integrated hot water collector

- Frame
  - Wood, 1.72 m x 0.92 m x 15 mm thick
  - Peripheral insulation, glass wool 30 mm
  - Fixed on the wall with 4 galvanised steel angle brackets

- Enclosed construction
  - Backside insulation, glass wool 30 mm
  - 7 absorbing corrugated copper strips 1.6 m x 0.15 x 0.4 mm thick, on which 7 copper pipes 15 mm in diameter were welded.
  - Copper heater and riser 22 mm in diameter.
  - Matt black absorber paint on front surface (spray applied)

- Cover
  - 5 mm glass of (specifications?)

- Insulated hot water tank
  - capacity 100lt

- Miscellaneous
  - Screws and bolds
  - Sealants (1 tube of silicon)
  - Copper pipe 22mm in diameter
  - 22 mm Copper pipe compression fittings
  - Copper pipe insulation - Armaflex Class O Tube Black 2m x 25mm x 28mm

(b) integrated hot air collector utilising an aluminium foil duct

- Frame
  - Wood, 1.72 m x 0.92 m x 15 mm thick
  - Peripheral insulation, glass wool 30 mm
  - Fixed on the wall with 4 galvanised steel angle brackets

- Enclosed construction
  - Backside insulation, glass wool 30 mm

    - Mild steel plate 1.7 m x 0.885 x 0.4 mm thick
    - 5 loops of aluminum tube (6 running lengths and 11m in total) of 100 mm in diameter, painted black
    - Matt black absorber paint on front surface (spray applied)
- Cover
    - 5 mm glass of (specifications?)
- Air fan
    - Power 25 Watts
    - Air mass flow 0.019 kg/s

- Miscellaneous
    - Screws and bolds
    - Sealants (1 tube of polyurethane foam)

(c) integrated hot air collector with internal metal separators

- Frame
    - Wood, 1775X980X177 mm, 20mm thick
    - Peripheral insulation, glass wool 50 mm
    - Fixed on the wall with 4 galvanised steel angle brackets

- Enclosed construction
    - Backside, glass wool 50 mm
    - Mild steel back plate 1635X840X1mm
    - 7 separator Length1561mm, Π-Section 25X75X25mm, 0.8 mm thick plate.
    - Mild steel top plate 1631X836 x 0.6mm
    - Matt black absorber paint on front surface (spray applied)
- Cover
    - 5 mm glass of 1690X895mm
- Air fan
    - Power 25 Watts
    - Air mass flow 0.019 kg/s

- Miscellaneous
    - Screws and bolds
    - Sealants
    - High temperature silicone

(d) integrated hot air collector with a mild steel square tube duct

- Frame
    - Wood, 1.72 m x 0.92 m x 15 mm thick
    - Peripheral insulation, glass wool 30 mm

    - Fixed on the wall with 4 galvanised steel angle brackets

- Enclosed construction
    - Backside insulation, glass wool 30 mm
    - Mild steel plate 1.7 m x 0.885 x 0.4 mm thick
    - Mild steel square tube 6 cm x 6 cm x 1.5 mm thick, (6 running lengths and 11m in total), painted black
    - Matt black absorber paint on front surface (spray applied)
- Cover
    - 5 mm glass of (specifications?)
- Air fan
    - Power?
    - Ratings?
    - Air mass flow 0.019 kg/s

- Miscellaneous
    - Screws and bolds
    - Sealants

4.4 Physical fabrication

4.4.1 Fabrication process

The full size prototypes were mainly constructed from ready made parts found easily in the market. In a few cases, as for example in the case of the production of the mild steel plate of the integrated hot air collector utilising an aluminium foil duct, an industrial scale cutting and bending machine was used. In other cases a cutting band saw and a welding machine were needed for the fabrication of the absorbing square tube. The prototype units were completed to specifications as detailed in the engineering drawings. Figures 3 to 6 detail the collectors' fabrication.

Figure 4.3. Positioning the ready-made absorbing plate in the integrated hot water collector

Figure 4.4. Positioning the aluminium foil duct in the integrated hot air collector utilising an aluminium foil duct

Figure 4.5. Fixing the internal metal separators in the integrated hot water collector with internal metal separators

Figure 4.6. Painting black the integrated hot air collector with a mild steel square tube duct

4.4.2 Assembly process

Once all parts were placed inside the frames and when needed were painted black, thermocouples were positioned at the appropriate places for monitoring the system temperatures. Finally, the units were sealed with the glass covers. Pyranometers and air flow meters were also placed in the right places for carrying out the performance tests. Figure 4.7, shows the monitoring instruments in position for testing the performance of the integrated hot air collector utilising an aluminium foil duct.

Figure 4.7. Pyranometer, air flow meter and temperature sensors in position for testing the performance of the integrated hot air collector utilising an aluminium foil duct.

4.5 Modular configuration

4.5.1 Unit size and dimensions

The complete units have a finished rectangular module size of approximately 1.7m x 0.9m. All connection ports are designed with access at the unit sides. The final mounting bracketing arrangement is to be determined.

4.5.2 Modularisation and up-scaling

The operation of the building integrated flat plate collectors was conceived to be modular with the configuration of the units in either series or parallel. Figure 4.8, shows an example of how a set of two coloured flat plate collector array can change the appearance of a building facet and Figure 4.9, shows one of the possible interconnections of the building integrated flat plate collectors. The full-scale systems could provide heat tailored to a building load and occupant needs.

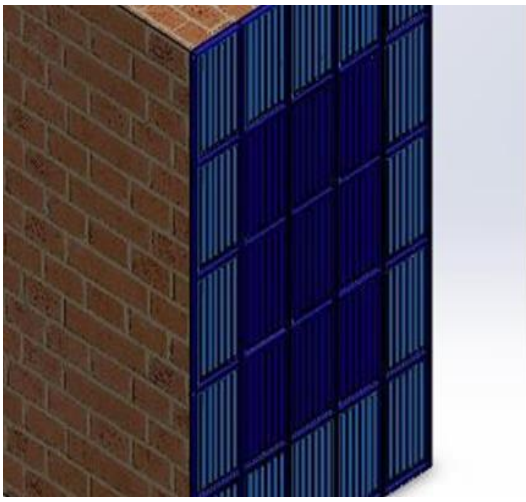


Figure 4.8: A system of two coloured flat plate collectors covering a building facet (side and front view).

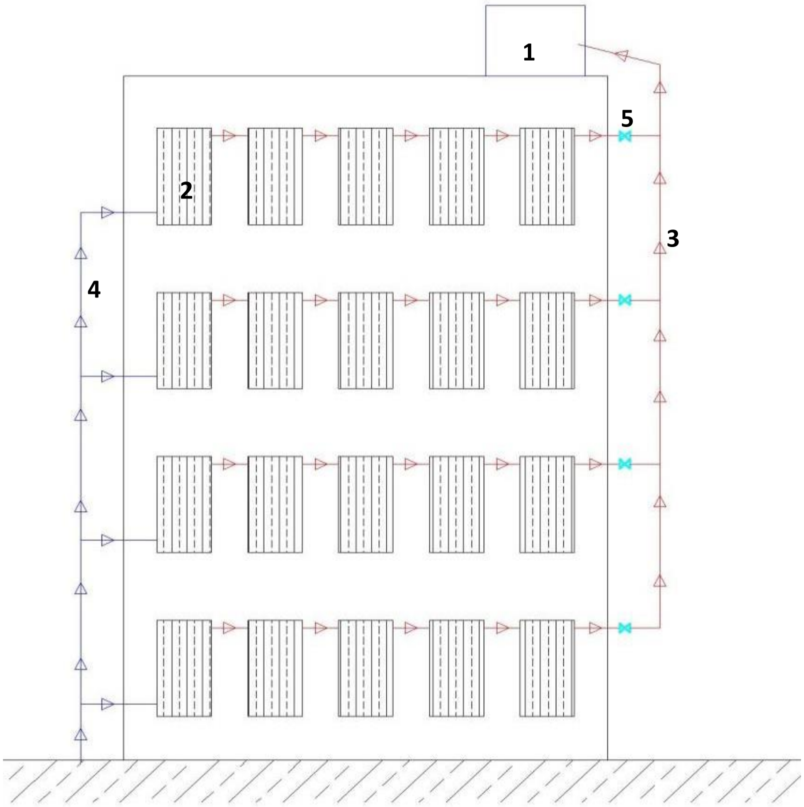


Figure 4.9: One of the possible interconnections of the building integrated flat plate collectors

4.5.3 Product development

To commercialise the building integrated flat plate collectors is not difficult because of the large scale production of the common flat plate collectors. Readymade components can easily be found and the tailored-made parts can simply be manufactured with standard industrial processes. Various materials can also be interchanged (e.g. the wooden frame with plastic or aluminium material) without affecting the efficiency.

5 Concentrating Photovoltaic/Thermal Glazing (CoPVTG)

5.1 Concept

Many modern buildings (commercial and domestic) incorporate large glazed areas following architectural expression, providing improved daylighting and wellbeing for their occupants. However conventional fenestration systems have poor insulating properties (compared to traditional constructional elements) resulting in excessive heat loss during cold conditions and increased cooling loads during warmer, sunnier conditions. Integrating advanced glazing with renewable energy generation technologies whilst controlling daylight penetration can create comfortable building internal spaces while ensuring lower energy bills and associated carbon emissions.

Transparent concentrating lens for PV façade building integration have been developed to enable increased electricity generation per unit area of PV material compared to conventional PV panels. Prototype transparent concentrating PV lens were fabricated and experimentally characterised. The results demonstrated that by using the concentrating lens, almost double the amount of electricity per unit of PV material can be generated compared to conventional PV panels. Daylighting control is possible by tailoring the concentrating lens design to allow incident solar radiation to enter the building at different times during the day. By combining the concentrating lens with a flat glass pane into a double glazing unit and evacuating the cavity, convective heat losses can be eliminated.

The Concentrating PV/Thermal Glazing (CoPVTG) façade technology combines glazing based solar concentrating elements coupled with PV/Thermal absorbers. It can provide solar generated electricity and heated air through the PV/T absorbers while insulating the building thermally. The glazing based concentrating elements are designed to allow the sunlight to enter the building and provide natural daylight when required while redirecting it onto the PV/T absorbers to generate electricity/heat when solar gains need to be minimised to reduce cooling demands.

The technology consists of a double glazing panel where the outside pane of glass is shaped into a series of concentrating lens. A thin layer of photovoltaic cells is placed at the focus of the concentrating lens to act as PV/T absorber. The inner pane of glass is a conventional flat pane. Forced air flow between the two glass panes can be used to remove waste heat from the back of the PV and use for space heating or pre-heating purposes. To increase the thermal insulation properties of the technology a third (optional) flat glass pane can be used in front of the concentrating lens pane and the resulting cavity can be filled up with inert gases such as argon or evacuated to eliminate convective heat loss (Figure 5.1).

Depending on the design of the concentrating lens, a part of the incident solar radiation can reach the PV/T absorbers generating electricity and waste heat while the rest can travel through the unit to provide daylight to the building interior. Using total internal reflection (TIR), the lens design can produce a seasonal effect with more light allowed into the building at low incidence angles (i.e. in the winter months) and less light at high incidence angles (i.e. in the summer). Figure 5.2 demonstrates how by using TIR different amounts of light can be collected onto the PV/T absorbers or transmitted through the glazing unit depending on the incident angle of the solar radiation.

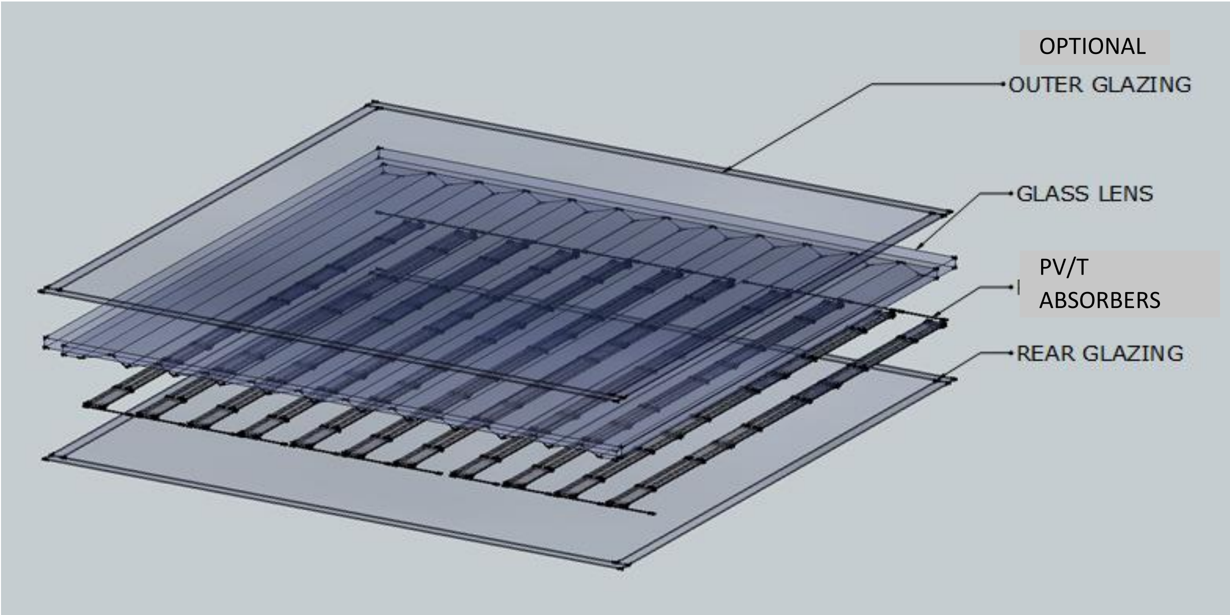


Figure 5.1. The CoPVTG technology combining concentrating glass lens with PV/T absorber elements.

For a 30^o incidence angle the PV cells receive the beam radiation light which is directly incident on them. The remaining radiation is refracted through the lens and transmitted to the back of the unit. At a 55^o incidence angle all beam solar radiation is reflected onto the PV/T absorbers by TIR at the back of the glass lens. The few rays missing the absorber at the bottom of the unit are due to edge-effects related to the size of the concentrating glass pane. Depending on the design of the concentrating lens there is a critical incidence angle that switches “on” or “off” the TIR of the solar radiation at the back of the glass lens. Glass lens that can control daylight transmission to the rear of the unit (i.e. into the building) for a specified range of incidence angles of solar radiation can be designed for a given building and geographic location.

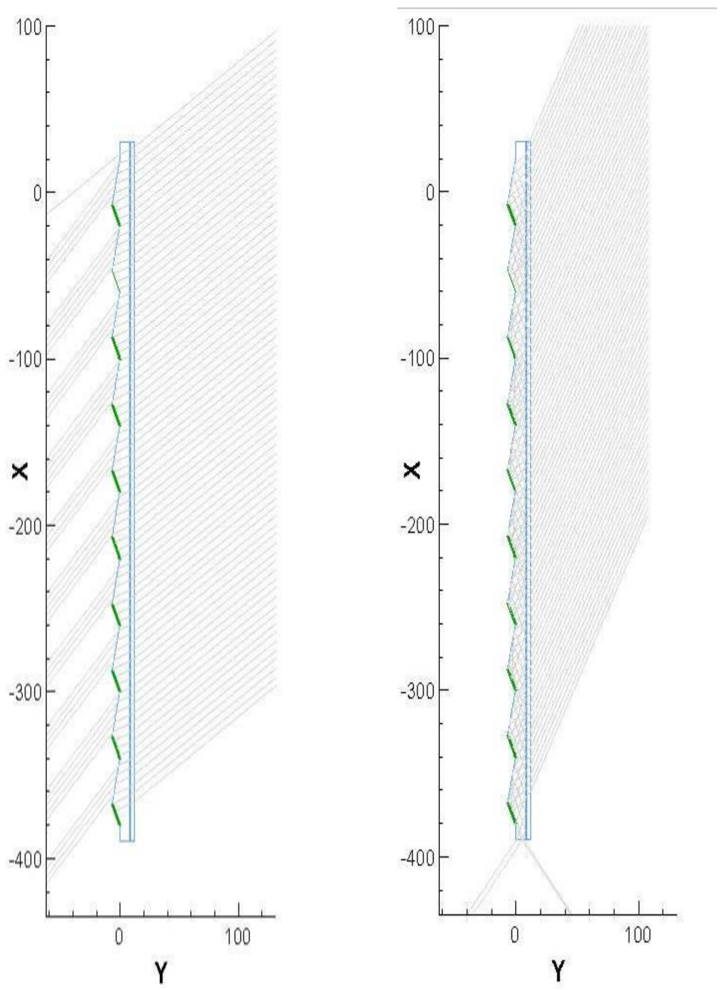


Figure 5.2. Ray trace diagrams demonstrating the control of light transmittance through the CoPVTG by TIR at the concentrating lens. Light incident at 30° (left) and 55° (right) from the perpendicular to the surface of the glazing.

5.2 Application

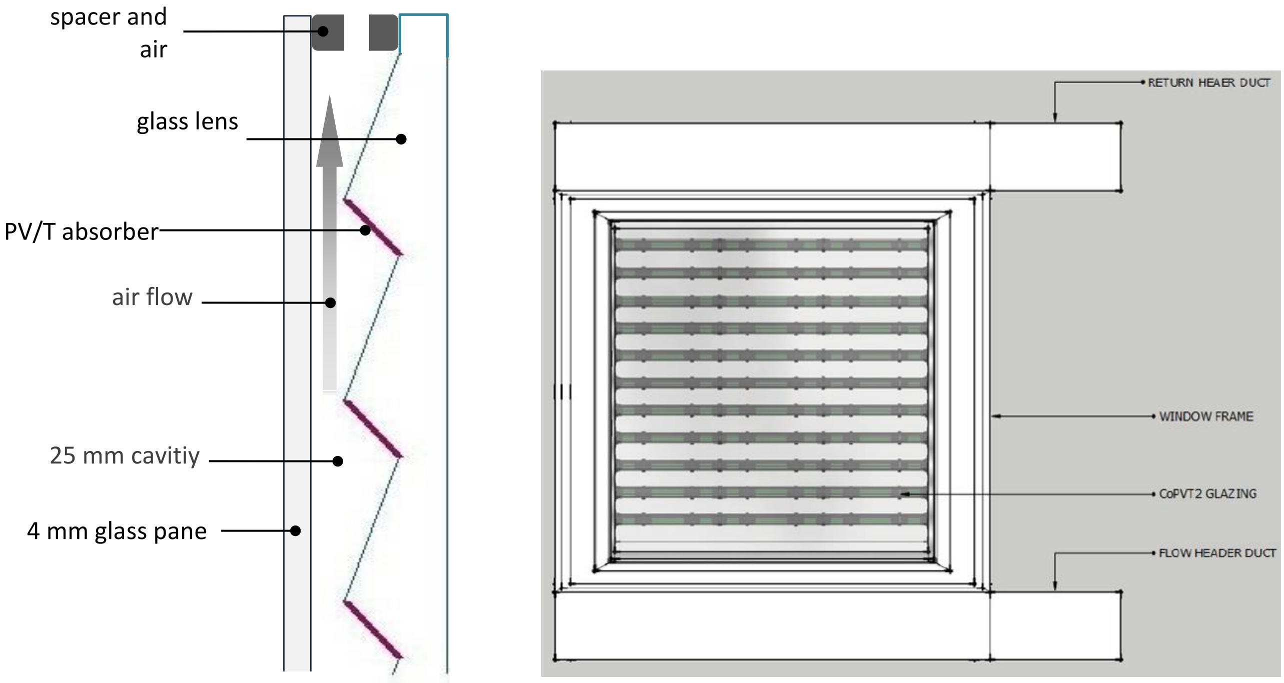
As a modular multifunctional building component based on conventional double glazing, the CoPVTG is designed to be compatible with traditional façade structures and fenestration framing arrangements, facilitating direct integration into new and retrofit building applications.

The multi-functionality of the unit provides a unique product concept. And is predominately seen to be a modular system for use in façade mounted applications for commercial building types.

5.3 Physical description

5.3.1 Physical description and detailing

A prototype 500mm x 500 mm CoPVTG unit was fabricated using an outer 15 mm (max) thickness concentrating lens pane and an inner 4 mm thickness flat glass pane (figure 5.3). A 25 mm cavity was formed between two glass panes using appropriate size spacers which accommodated the air inlet and outlets at the bottom and top of the cavity respectively (figure 3a). 33 multi-crystalline PV cells configured as 11 strips of 3 cells each were bonded at the focus of the concentrating lens using opti-clear silicon resin. Green coloured cells were used (C-Cell range by LOF Solar) to achieve better aesthetics. A UPVC window frame was used to mount the fabricated CoPVTG unit (figure 5.3a). The frame had a slot cut out along its top and bottom to allow the air to flow through the unit. The air was supplied by flow and return header ducts with slots cut identical to that of the window frame allowing a clear passage of air. The fabricated CoPVTG inserted into the PVC window frame is illustrated in figure 5.3b.



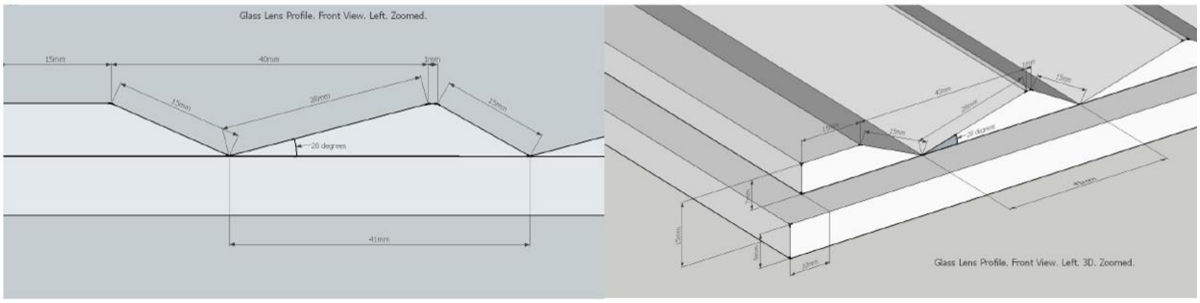
(a) (b)

Figure 5.3. a) Cross section of the fabricated CoPVTG prototype and b) schematic of the prototype unit inserted into a PVC window frame (right).

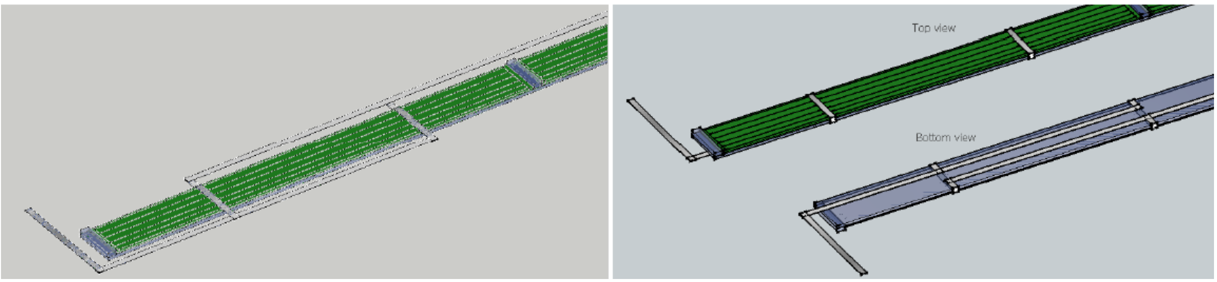
Both header and return flow ducts were covered with polystyrene insulation to minimise heat loss. A DC fan was used to produce and control an air flow through the CoPVTG glazing cavity using a power supply.

5.3.2 Engineering drawings

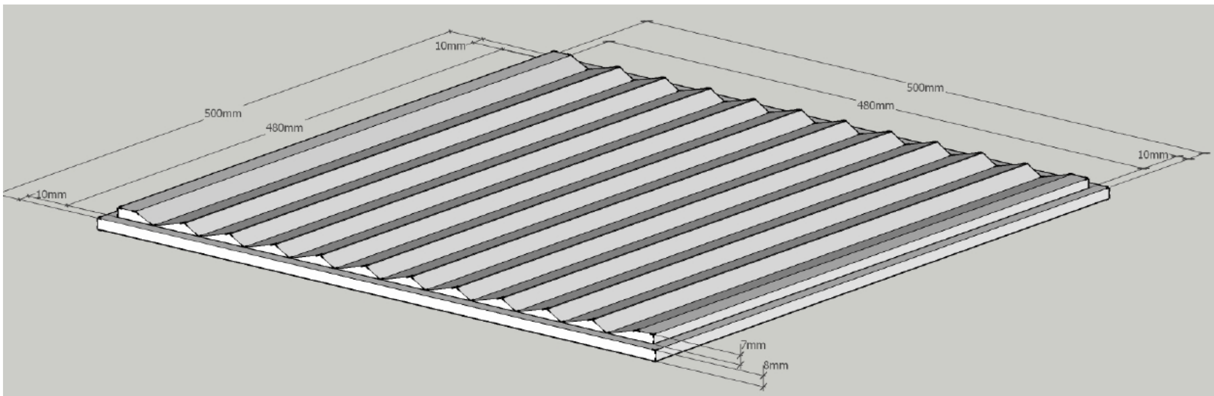
Concentrating lens



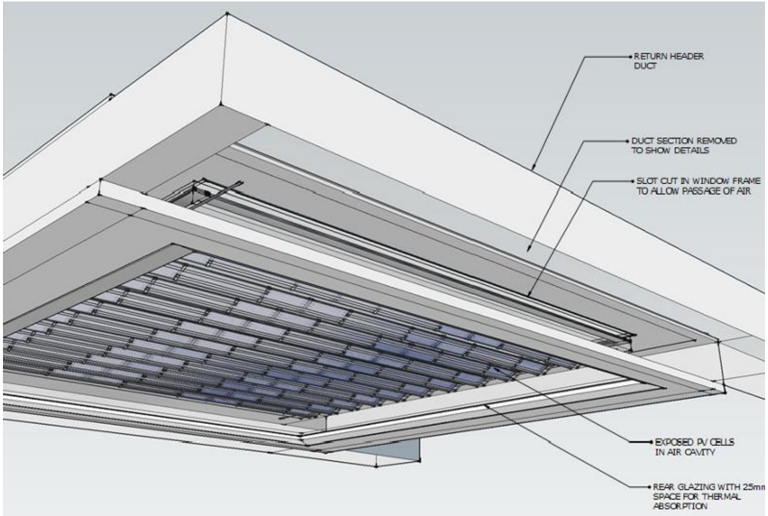
PVT absorbers



Concentrating glass



CoPVTG integrated with inlet and outlet ducts



5.3.3 Materials

The full size prototype unit fabricated, assembled and tested at Ulster University is still in its infancy in terms of product design. A number of design enhancements and developments are ongoing. The prototype unit consists of the following material components:

Concentrating PVT glazing unit

- Opti-white glass pane 1 x500 mm x500 mm x15 mm (concentrating glass lens pane)
- Opti-white glass pane 1 x500 mm x500 mm x4 mm (flat pane)
- Poly-Si solar cells 33 x0.2 mmx156 mm x15 mm
- Connecting ribbon for solar cells 1 mm x 2.5 mm x6100 mm
- Opti-white glass strips 12 x15 mm x48 mm
- Opti-white glass spacers 60 x15 mmx 1 mmx 2 mm
- Opti-clear, UV stable silicon 85ml (bonding solar cells onto glass)

Window frame and inlet-outlet air ducts

- Conventional UPVC window frame to accommodate 500 mmx 500 mm double glazing unit
- 25 mm spacer for double glazing
- UPVC ducting 1400 mmx 50 mmx 100 mm
- DC air fan
- Polystyrene insulation

5.4 Fabrication and assembly process

The concentrating glass lens unit was fabricated by CNC machining using cutting tools, specifically fabricated for the given The PV cells were connected in series forming 11 rows of 3 cells each. To prevent damaging the cells during the fabrication of the prototype each row of 3 cells cells was mounted onto the opti-white glass strips. The 11 rows of cells were then bonded onto the corresponding focal planes of the concentrating glass lens using opt-clear silicon.

A UPVC window frame would be utilised to mount the concentrating PV glass as double glazed unit. The window frame had a slot cut out along its top and bottom to allow air to flow through the unit (Figure 5.4). This would be supplied by the flow and return header ducts which have slots cut identical to that of the window frame allowing a clear passage of air flow.

Figure 5.4. The UPVC window frame used to mount the glazing. Slots on the upper and lower sections allow for the air to flow through the glazing cavity.

Figure 5.5. The inlet and outlet header air ducts attached on the UPVC window frame.

Header ducts for the flow and return were made up, using 100mm x 50mm uPVC ducting. The slots were cut on the 50mm side of the ducting to be identical to the slots cut in the window frame. Brackets were then attached to the header ducts so that they could be securely fitted to the window.

The ducts were attached using metal brackets, these screwed into the duct and into the window frame making for a very sturdy attachment. To ensure air tightness so as to not affect the results, silicone sealant was applied to the window and the duct before they were attached together (Figure 5.5).

A fan was needed that would be easily controllable; a DC fan was sourced from an old PC that was no longer in use. This can be easily controlled and would be able to be set for the flow rates needed. An adapter was made so that the fan would fit onto the ducting.

The header ducts were covered with insulation which was securely taped to the window frame ensuring a good tight fit. The concentrating PVT glass was placed into the window frame (Figure 5.6) and the second, flat glass pane placed behind using the double glazing spacer to create a 25 mm wide cavity between the two glass panes. The full prototype is presented in figure 5.7.

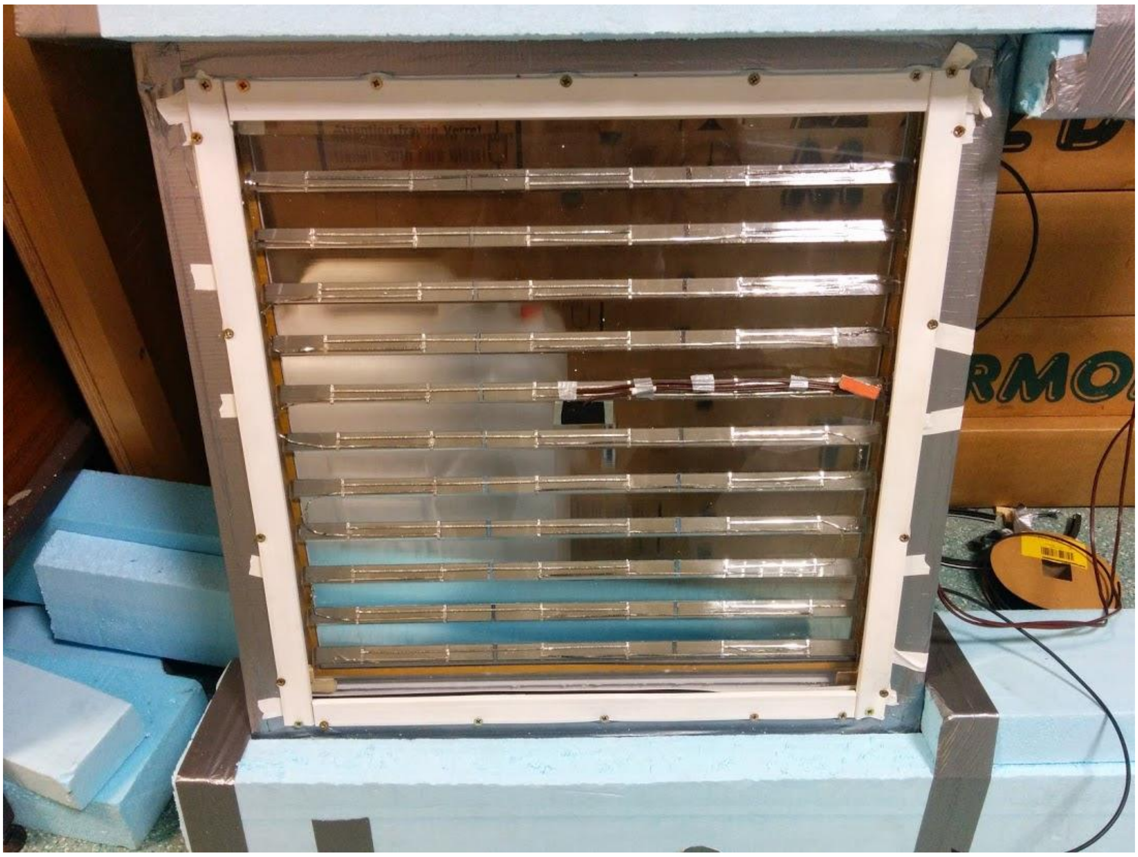


Figure 5.6. The concentrating PVT glass fitted into the UPVC window frame with integrated air ducts.

Figure 5.7. The full CoPVTG prototype.

5.5 Modular configuration

5.5.1 Units weight and dimensions

The complete prototype unit (excluding ducting) has dimensions of 600 mmx 600mm x50 mm. The weight of the unit is approximately 10.5 kg.

5.5.2 Modularisation and upscaling

The CoPVTG technology is both modular and scalable in the same way as double glazing. The size of a single unit can be several m^2 and is limited only by the structural strength of the building frame supporting the glazing. A number of units can be connected in series or parallel (both electrically and thermally) to allow maximum coverage of a given building façade. However the requirement of air ducting could impose some restrictions as it will make necessary the use of air handling units. The CoPVTG can potentially be operated in conjunction with a heat pump was also considered whereupon collected/stored heat quality could be improved via the use of the heat pump powered by the PV array.

5.5.3 Product development

The CoPVTG has been proved as a concept. The focus now is on determining the best method for manufacturing it in a large volumes. The formation of the concentrating PVT lens either by cutting them from glass (e.g. CNC machining) or using acrylics or other synthetic materials need to be investigated. A third option may be casting. The bonding of the PV cells onto the focal planes of the prisms is also an important area of investigation as the opti-clear silicon used for the prototype is both time consuming and expensive. The use of cells which are the by-product of the manufacturing process of PV panels can offer a saving compared to using PV strips cut from full size cells.

6 Hybrid Photovoltaic/Solar Thermal (HyPV/T) Façade Module

6.1 Concept

The innovative modular HyPV/T façade concept integrates a novel cascade thermal diode configuration in an Integrated Collector/Storage (ICS) solar water heater with PV cells into a single multi-functional facade element (figure 6.1). It builds upon research conducted over 12 years, combining innovative solar technologies with building architecture. Installed on a building façade, the unit is proposed to provide additional thermal insulation, whilst producing useful amounts of hot water and generating electricity.

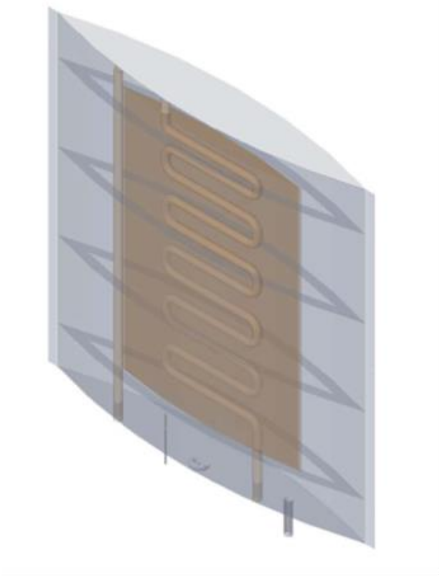


Figure 6.1: Image of the prototype HyPVT unit based on an elliptical profile

The unit is a step improvement and advancement on prior art based on a thermal diode ICS solar water heater, using the same operating principle to pre-heat domestic hot water by catching and storing solar energy. The innovative thermal diode promotes solar collection during the day but reduces thermal losses at night whilst incorporating an integrated PV module. The design is based on two structural vessels, arranged to create a cavity between the walls of the inner (thermal storage) and outer (solar absorbing) vessels. In this instance, the vessels are flat and rectangular, allowing for solar radiation to be captured effectively during the solar day and aid easier façade integration. The cavity contains a liquid/vapour phase change material as the working Heat Transfer Fluid (HTF) which is maintained at a sub-atmospheric pressure. The HTF is in direct contact with the solar absorbing surface of the outer vessel (and effective wetted surface area). During collection periods solar radiation incident on the outer (absorbing surface) vessel, causes the HTF to evaporate at low temperature thus producing a vapour. The vapour fills the cavity and condenses on contact with colder inner (thermal storage) vessel surface with the collected thermal energy transferred to the water store through latent heat exchange. Condensed water runs down the vessel wall to the HTF reservoir, upon which the produce of evaporation/condensation is repeated. During non-collection periods no heat transfer takes place as the HTF temperatures are not high enough to cause evaporation. The inner store is now thermally isolated from the outer vessel, thus retaining the stored heat for longer periods.

6.2 Application

The modular façade integrated HyPVT solar collector is designed to:

- Reduce heat loss in cool climate conditions and reduce cooling loads in warm climate conditions by adding an additional insulating element to the building fabric
- Provide an energy saving by augmenting the thermal energy and power requirement of the building by direct on site generation
- Integrate renewable energy technology to comply with current building regulations and reduces carbon footprint

The multi-functionality of the unit provides a unique product concept. The unit is predominately seen to be a modular system for use in façade mounted applications (note: an inclined version is being developed). The unit can be used across a range of building structure buildings.

6.3 Physical description

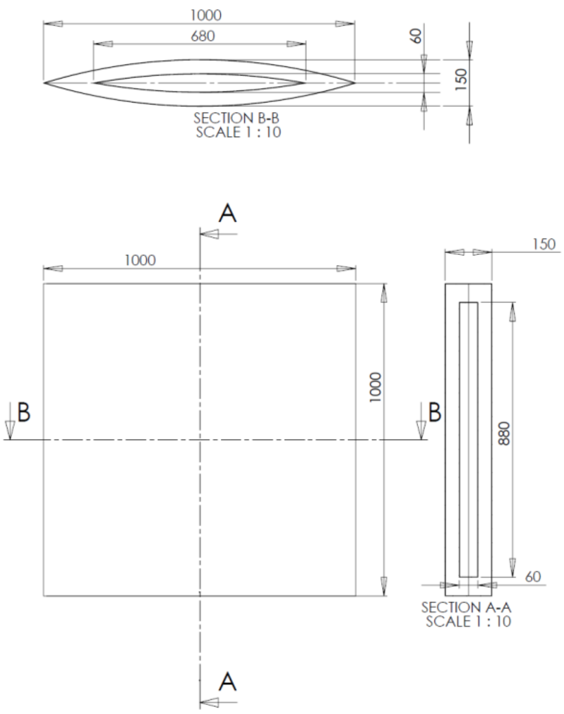
6.3.1 hysical description and detailing

A full size prototype design was developed and engineering drawing prepared. The drawings were supplied to fabrication specialists and the prototype HyPVT unit completed to specification. Figure 6.2 details the prototype unit complete with PV module. The unit was designed with elliptical (Egyptian eye) profile, with dimensions 1m x 1m and 150mm deep, to provide an inherent structural strength to withstand the forces put upon the vessel under evacuation. The basic unit was made from an external 1.2mm thick SS 304 outer vessel supported by an internal exo-skeleton. The inner (thermal storage) vessel was of a similar elliptical profile with a volume of 27 litres under no vacuum and of 28.1 litres when under vacuum. A value of 30 litres per m^2 is deemed suitable for ICS type solar water heaters by much of the presented literature.

Figure 6.2: Prototype HyPVT unit with PV panel ready for testing

The HyPV/T collector unit is proposed to be encased in a weather tight enclosure. The sides and back are made from white acrylic capped ABS and along with a 50mm thick insulating layer, form the outer unit casing. The aperture front is made from clear (UV treated) PETG which is a suitable transparent aperture material.

6.3.2 Engineering drawings



6.3.3 Materials

The full size prototype unit fabricated, assembled and tested at Ulster University is still in its infancy in terms of product design. A number of design enhancements and developments, along with DfM process are ongoing. The presented unit however, consists of the following material components:

Vessels

- Outer Vessel
  - 2 off 1m x 1m x 1.2mm 304 grade Stainless Steel sheet (TIG welded together)
  - 2 off end plates 1m x 0.075 x 1.2mm 304 grade Stainless Steel sheet (TIG welded together)
  - Internal structural support approx. 1m x 0.2m 1.2mm 304 grade Stainless Steel sheet (TIG welded together)
  - *Thermal diode and HTF (IP protection)*
  - Matt black absorber paint on front surface (spray applied)

    or

  - Keratherm KP 98 bonding paste (brush applied if using PV option)
- Inner Vessel
  - 2 off 0.68m x 0.88m x 1.2mm 304 grade Stainless Steel sheet (TIG welded together)
  - 2 off end plates 0.68m x 0.075 x 1.2mm 304 grade Stainless Steel sheet (TIG welded together)
  - Internal structural support approx. 0.68m x 0.15m 1.2mm 304 grade Stainless Steel sheet (TIG welded together)
- Tank plumbing fittings
  - Approx. 0.6m long 15mmØ Stainless Steel pipe (TIG welded)
  - 4 off compression fittings to suit
  - 3 off 15mmØ isolating valves
  - Approx. 0.1m long 6mmØ Stainless Steel evacuation pipe (TIG welded)
  - 1 off 6mmØ evacuation isolating valve
  - Approx. 1m long 15mmØ flexible overflow hose

PV Panel (*optional*) - Solbian Sun Power Flexible Marine Solar (SP-112Q) module

- Peak Power Pmax 112W
- Nº of Cells 36
- Rated Voltage Vmp 19.7V
- Open Circuit Voltage Voc 24V
- Rated Current Imp 5.7A
- Short Circuit Current Isc 6.1A
- Dimensions mm 855 x 800
- Thickness mm 2
- Weight Kg 1.6

Casing element

- 1.1m x 1.1m x 0.25m deep outer back casing made from 3mm thick white acrylic capped ABS sheet (vacuum formed)
- 1.1m x 1.1m 2mm thick clear (UV treated) PETG transparent aperture casing
- Insulation (approx. 1.1m x 1.1m x 50mm thick Extruded Polystyrene Foam (XPS) (Blue Board)
- Screws (approx. 20 off 4mm self-taping screws)
- Sealants (approx. ¼ tube of silicon)

Mounting element

- Brackets (TBD)
- Screws and bolts (TBD)

6.4 Physical fabrication

6.4.1 Fabrication process

A full size prototype was fabricated in-house were possible with specialist fabrication included if needed. The prototype HyPVT unit was completed to specification as detailed in the engineering drawings. Figures 6.3 and 6.4 detail the vessel's fabrication.

Both the inner and outer vessels were fabricated from 1.2mm thick 304 grade Stainless Steel sheet. The various elements were cut from full size sheets and formed to the exact requirements. The front and back sheets of the inner vessel were initially tack (TIG) welded together, along with any structural elements and pipe connections. Once the vessel was checked, the vessel was fully welded. The same process was carried out for the outer vessel, and before the front panel was put in place, the inner vessel was fixed inside and secured. Again, after checking, the unit was fully welded. Once the unit was finished, the welds and surfaces were cleaned using a pickling paste.

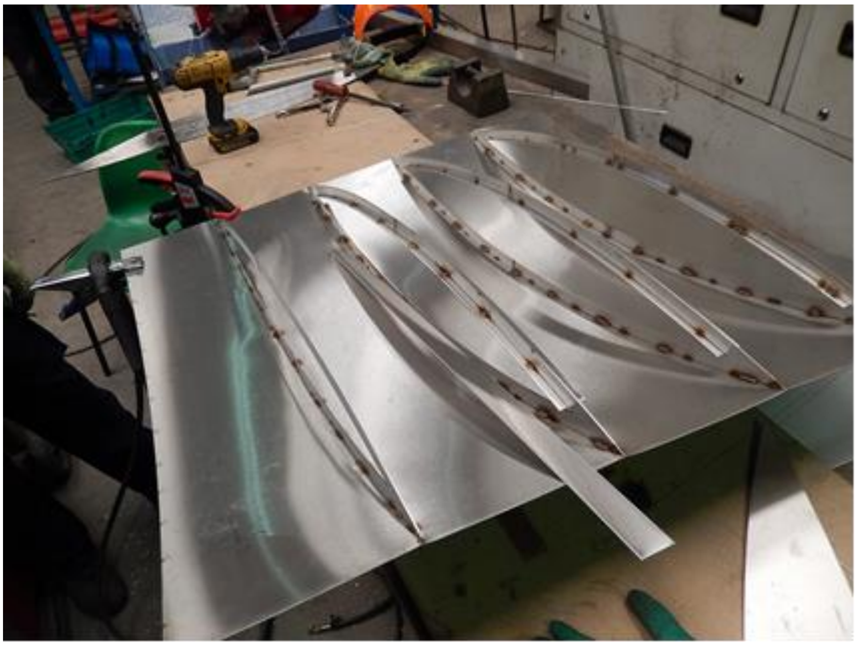


Figure 6.3: Fabrication process of the prototype HyPVT unit

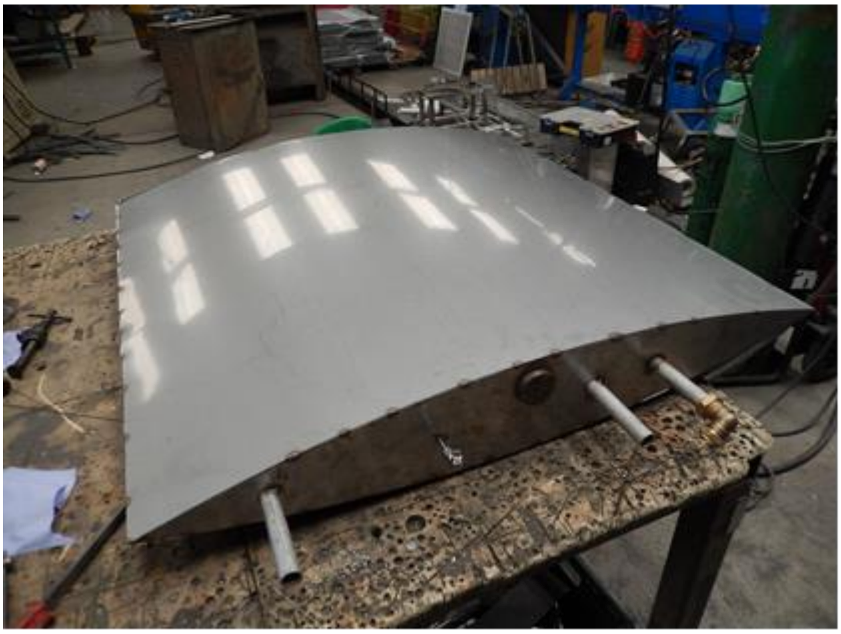


Figure 6.4: Final assembled prototype HyPVT vessel prior to welding and spraying

The outer casing element was made from a vacuum formed sheet of 3mm thick white acrylic capped ABS sheet. An initial template was produced and a local specialist created the final unit. The outer transparent aperture casing was made from 2mm thick clear (UV treated) PETG sheet that was cut to suit the back casing deimmensions.

6.4.2 Assembly process

Once the vessel and casing elements were fabricated, the various items were assembled. Depending upon the function, the outer absorbing surface of the vessel was either coated with sprayed matt black absorber paint finish (for solar thermal only) or Keratherm KP 98 bonding paste (brush applied) if using the PV/T option. At this stage all vessel fittings and valves were attached. The vessel was now placed into the outer casing, complete with back insulation. The vessel and insulation were secured using screw brackets and glue, respectively and all joints effectively sealed using the silicon. The front aperture cover was then inserted and fixed using the silicon gasket and screws. Figure 6.5 details the vessel (in solar thermal form) in a temporary casing prior to performance testing under a solar simulator.

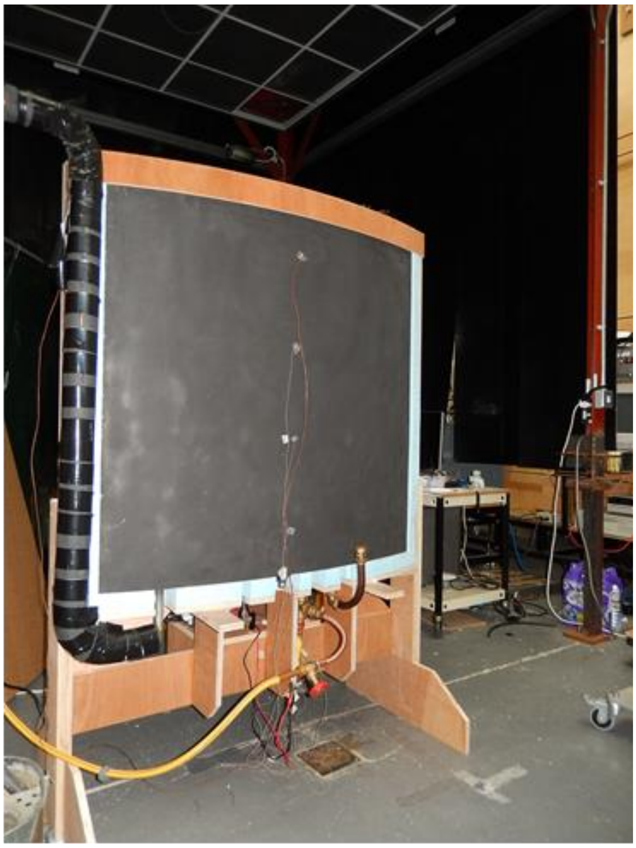


Figure 6.5: Prototype HyPVT unit in solar thermal option ready for testing

6.5 Modular configuration

6.5.1 Units size and dimensions

The complete unit has a finished rectangular module size of 1.1m x 1.1m and 0.25m deep. All connection ports are designed with access at the unit base. The final mounting bracketing arrangement is to be determined.

6.5.2 Modularisation and upscaling

The operation of the HyPVT system was always conceived to be modular and the configuration of units in either series or parallel (both electrically and thermally) was key to its wider deployment. Figure 6.6 indicates the evolution from a single small scale demonstrator unit through to the full size prototype and then on to the envisaged modular array. Scaled up, the system could provide power and heat tailored to a building load. The potential to be operated in conjunction with a heat pump was also considered whereupon collected/stored heat quality could be improved via the use of the heat pump powered by the PV array.

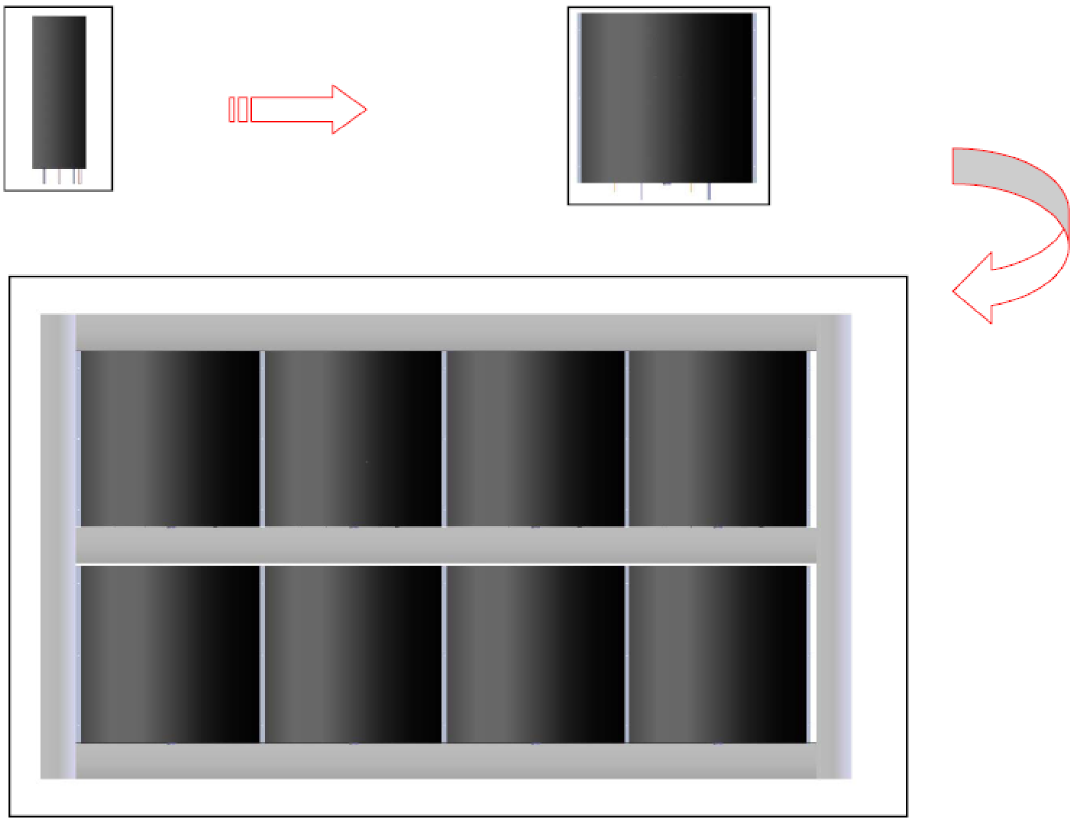


Figure 6.6: HyPVT modular concept

5.3 Product development

To date, several concepts are being pursued to commercialise the HyPVT unit, these include optimising component design to improve performance and cost effectiveness, streamlining the fabrication and assembly process through Design for Manufacture (DfM), evaluating mass manufacturing options and seeking commercial partnerships. This work is ongoing.

7 Porter Building, Tel Aviv, Israel

7.1 Introduction

The Porter School of Environmental studies (PSES), Tel-Aviv, Israel, building was designed as a "green building". The building design utilized environmental parameters (such as solar radiation, wind, acoustics and more) in determining the form that the building would take and its position on the site. The building makes use of passive and active technologies for production of energy, energy conservation and recycling of waste and water.

7.2 Description of the building

This chapter presents the new building of the Porter School of Environmental Studies (PSES), located on Tel-Aviv University campus. It incorporates classrooms, graduate student rooms, offices, an atrium, a cafeteria, an auditorium and a green roof. It also provides various internal spaces for informal activities such as meeting places for students and researchers, as well as government officials, industry representatives, and members of environmental organizations, involved in the school's activities.

7.3 Design concept and building features

The Porter School was designed on a site that served as a Parking lot and was previously the dumpsite for building debris of the Tel Aviv University. It is located on one of the highest hills in Tel Aviv overlooking the Cities of Tel-Aviv and Ramat Gan and the Yarkon metropolitan park. The site is exposed to the harsh condition of the Israeli southern sun radiation and to the acoustic pollution from the automobile and rail transport rising for Israel’s busiest highway (Figure 7.1).

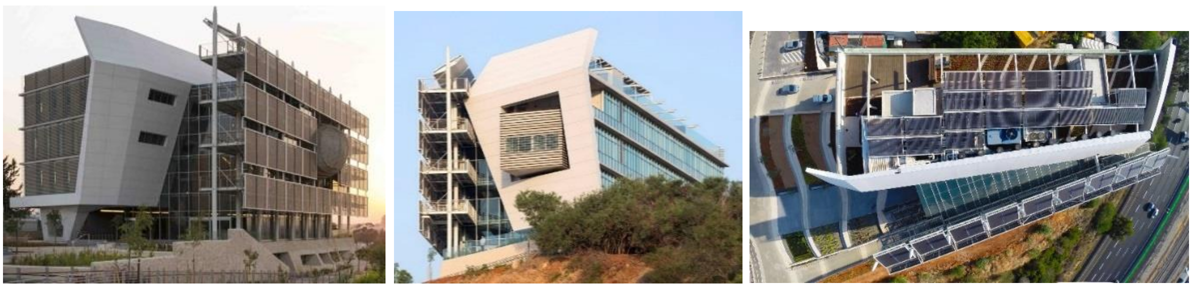


Figure 7.1 – General views of Porter Building (west, south, east and north façade and roof)

The building form is a rectangle stretched out along an east-west axis. The south facing area is due to the public and the main offices and other functions are located on the northern façade area. An atrium connects these two areas housing the public activities and the main building circulation paths. The main materials of the building are exposed concrete, Euro panel cladding tiles, wood (mainly bamboo) and metal. The colour scheme of the building is mainly white grey and natural wood.

The auditorium, which is the largest function of the building, is located in the basement, with an independent entrance (designed using ideas from vernacular traditional terraces design) for external events. The main conference room of the building is “the capsule” (Figure 7.2). “The capsule” creates a balance in the composition of the south façade and serves as a screen on which the building’s energy savings and regional air pollution can be publically projected.

Figure 7.2 – “The capsule” view from outside and inside

Shading of the main building is accomplished with an "Eco-wall", an area with one row of indoor / outdoor occupied spaces, used as open laboratories or closed plug-in rooms for visiting researchers, situated along the South side of the building. These spaces are minimally conditioned and act as a buffer to control the solar radiation incident upon the building.

The form of the main mass of the building and the angle between the “Eco-wall” and the main mass of the building were defined to integrate natural light conditions and natural ventilation. It creates a *Venturi* effect that enhances airflow for natural ventilation and a wind turbine. The inclined walls of the main building mass were created and optimized to contain future photovoltaic cells.

The south facade of the “Eco-wall” is covered with an array of solar thermal tubes which produce hot water and shade the “Eco-wall” spaces. The hot water also serves to heat the building during the winter and power an absorption cycle chiller to cool the building in summer.

A four-storey atrium is the center of the buildings mixed-mode ventilation strategy. Equipped with solar chimneys at the roof level (Figure 7.3), the stack effect generated helps to provide ventilation to most of the building when conditions permit (Figure 7.4). Supplementary ventilation as well as air conditioning is provided by a rooftop makeup air unit equipped with energy recovery. At the zone level, spaces are conditioned by fan coil units, 4-pipe active chilled beams, and radiant floor. Occupancy and photo-sensors throughout the building tune the lighting system to the precise level required as dictated by space use and available daylight.

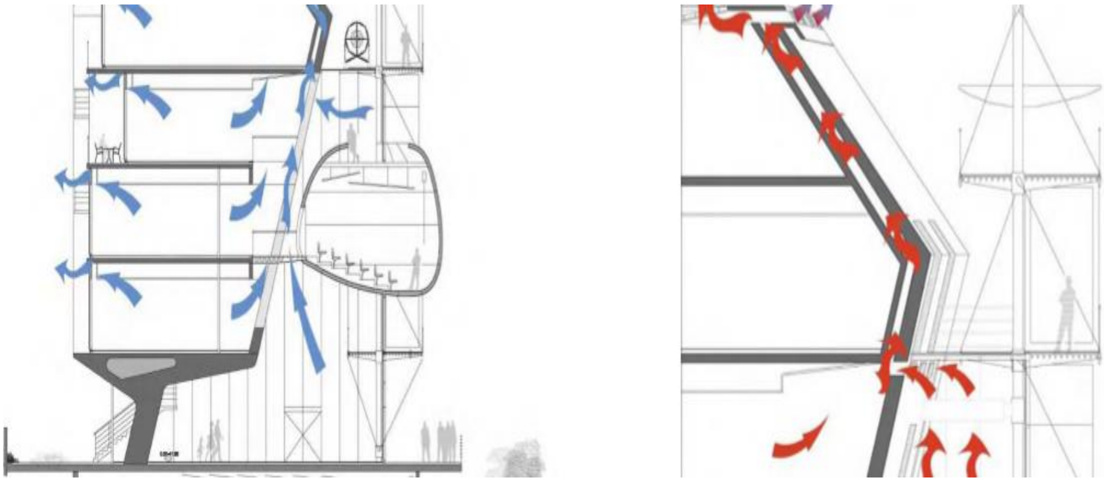


Figure 7.3 – Passive ventilation scheme (left) and hot air chimney - hot air discharges through special chimneys in the building envelope (right)

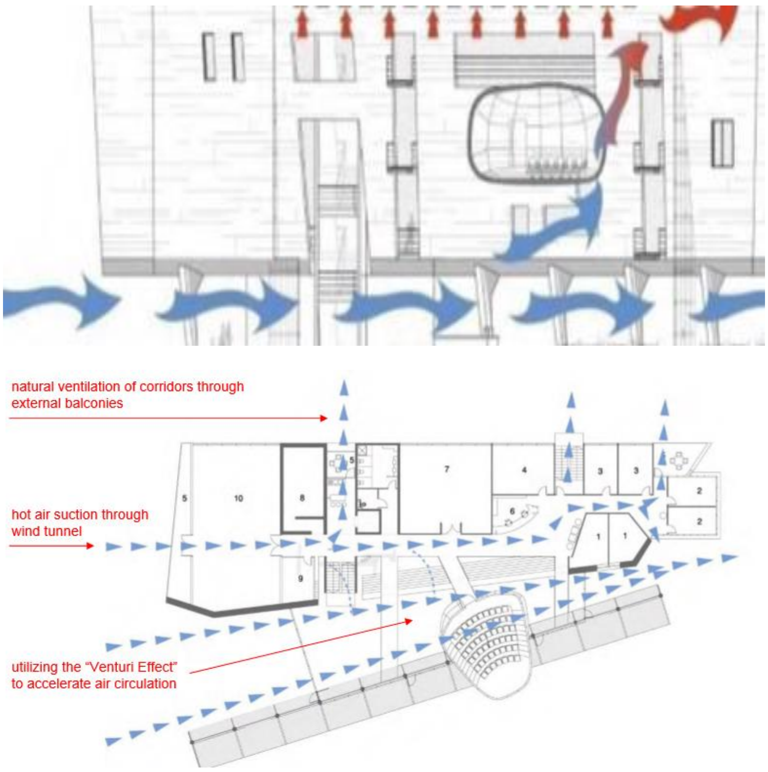


Figure 7.4 – Passive ventilation through Main Atrium

The building incorporates the following technologies:

- A thermo solar air-condition system running on energy created via a system of vacuum tubes on the building facades and roof (Figure 7.5). This system (the air condition system or the vacuum tubes system) transfers energy surplus generated in the building to adjoining buildings in the campus;
- Chilled beam system for air condition – an air condition diffuser that works about 20% more efficiently than normal systems (works on higher temperatures and does not need strong electric fans to distribute the cool air);

- A computer controlled natural ventilation system that allows natural ventilation and night cooling in predefined conditions;
- A computer control system for artificial illumination and shading curtains;
- A green roof;
- A grey water system that reuses water from the showers, kitchenette and air-condition to irrigate the green roof and the landscape;
- Floor heating and cooling.

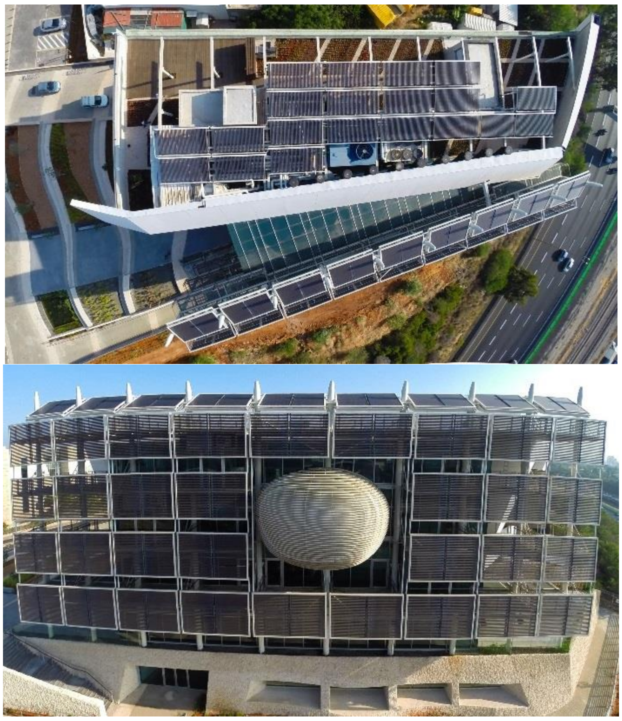


Figure 7.5 – General view of the vacuum tubes installed on the building roof and façade

7.4 Building Controls

The building operates with a Building Automation System scheduled on between 05h and 21h.

7.5 Cooling / Heating Plant Systems

7.5.1 Hot Water Loops

A 5000 liter hot water storage/transfer tank exchanges energy between hot water loops. A coil within the tank transfers energy to the medium hot water loop (50ºC). Boiler water is circulated on an open loop with the tank, and solar thermal water circulates on an open loop between the tank and the HX-1.

Three separate arrays of evacuated tube solar-thermal collectors provide hot water to the building. One array is mounted vertically on the façade of the "Eco-Wall". The second is mounted at an angle on the "EyeBrow" above the EcoWall. The third is mounted horizontally and shades mechanical equipment on the roof. 24 m^3/hr of water is circulated through the three arrays by P-1 at a common supply and return header. Design temperatures produced by the loop are 98ºC supply and 83ºC return. Heat is transferred via HX-1 to a loop, pumped by P-2 serving the hot water tank which has a separate gas boiler as backup heat source. 24 m^3/hr at 95/80ºC.

P-5 sends 24m^3/hr of hot water at 95ºC directly from the water tank to the absorption chiller, which operates on 10ºC ΔT. A heat exchanger within the hot water tank is pumped by two secondary loops (P-7 and P-8) which respectively serve the radiant floor slab circuit (in Winter) and air-side coils (FCUs, AHUs, IUs) with 50ºC supply / 40ºC return water.

7.5.2 Chilled Water Loops

The chilled water loop is designed in primary / secondary configuration. Then entire system is capable of producing 66 m^3/hr of chilled water at 7ºC. The absorption chiller produces 36 m^3/hr chilled water at a nominal 7ºC in optimal conditions. When the auditorium unit is running, or when the total building load on the chilled water loop exceeds the 60-ton capacity of the absorption chiller, a second air-cooled chiller rated at 70 tons capacity and connected to the primary loop is activated. Pump P-9 circulates primary chilled water of the absorption chiller to and from CHS/R primary headers. The air-cooled chiller has dual integral pumps which circulate CHW to the primary loop. Both chillers are connected to a common header.

The supply side header is connected to three secondary loops served by pumps P-10, P-11 and P-12. The first (P-10) is delivers chilled water at 7ºC to Fan coil units on each floor, as well as the basement Auditorium Air Handling unit. The second (P-11) is connected via a 3-way mixing valve to the tertiary loop which delivers water at 14ºC to the induction units at each floor. In summer, this loop also serves the radiant floor slab loops. Return water from this system is partially recirculated through Pump P-11, which is boosting the primary flow of 15 m^3/hr of 7ºC water to 26m^3/hr of mixed water at 14ºC.

The third (P-12) delivers up to 36m^3/hr of chilled water to a heat exchanger (HX-4). This connects to a cooling system serving data center located in an adjacent building. In this way, the solar thermal collectors and the constant operation of the absorption chiller are taken full advantage of by essentially exporting renewable energy produced on the site of Porter.

7.5.3 3.1.3. Absorption Chiller

The 60-ton capacity absorption cycle chiller is energized by a heat medium (hot water) above 85ºC heated by a solar energy heat source and its condenser is cooled by a cooling tower. The absorption chiller uses a solution of lithium bromide and water, under a vacuum, as the working fluid. Water is the refrigerant and lithium bromide, a nontoxic salt, is the absorbent. Refrigerant, liberated by heat from the solution, produces a refrigerating effect in the evaporator when cooling water is circulated through the condenser and absorber. In the cooling cycle there are four dominant stages: generator, condenser, evaporator, and absorber. The energy consuming compressor stage of a conventional refrigeration cycle is obsolete in the absorption cycle.

The absorption chiller runs whenever solar hot water is available. When solar-thermal water is available and there is little or no cooling load in the building, the chiller runs at maximum capacity and sends any excess chilled water to another (existing) building on campus which always has cooling needs due to the presence of a data center. The capacity of the chiller exceeds the maximum production rate of the solar thermal arrays – solar thermal energy is never dumped or wasted.

7.6 Cooling tower

An open circuit cooling tower (Figure 7.6) is used to reject heat emitted on the condenser side of the absorption chiller unit. A variable speed fan regulates the cooling tower airflow so that leaving condenser water is at or below 30ºC going back to the chiller. Constant volume pump P-3 (84 m^3/hr) serves this loop.

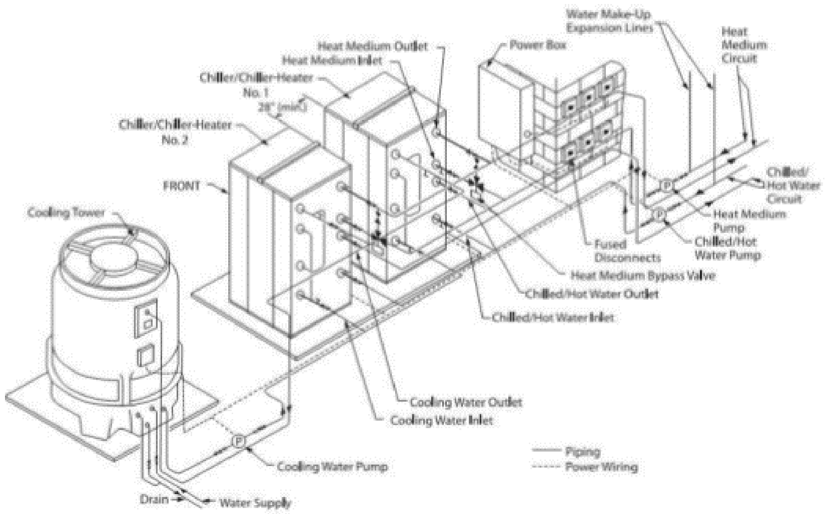


Figure 7.6 – Cooling tower

7.6.1 Air-Cooled Chiller

A 70-ton capacity High-Efficiency Trane air-cooled chiller with scroll compressors provides 70 tons capacity of chilled water to the main chilled water header. It uses refrigerant R-410a. This chiller is only in operation after the load of the building exceeds the capacity of the absorption chiller (e.g., during periods when there is insufficient solar insolation to produce 85ºC water, etc. or building loads are greater than 60 tons.). Minimum load is 30%. At design conditions, this chiller operates at 3.18 EER and at 4.64 EER under Eurovent Testing conditions. Twin pumps integral to the chiller provide CHW circulation.

7.6.2 Solar Thermal Evacuated Tubes

A total of 705.4 m^2 of U-Pipe evacuated solar thermal collector tubes are integrated into the façade of the "Eco-Wall" (422 m^2), above the "Eco-Wall" (108 m^2) and on the roof (175 m^2) as shading elements which produce most of the heating and cooling energy for the building. The array is connected via Pump P-1 (24 m^3/hr, VSD) and HX-1 to the Hot Water Storage Tank. The solar collectors are allowed to operate on a schedule of 6 am to 8pm in summer and 7am to 5pm in winter. Control valves keep the output temperature of the array between 75ºC and 120ºC. Variable speed pump P-2 operates the HW loop side of the HX-1 and modulates between 0 and 100% flow as the fluid temperature is between 30 and 100 ^{o}C.

7.6.3 Boilers

A natural gas boiler with capacity of 116 kW provides hot water flow, via Pump P-14 at 8.4 m^3/hr to a heat exchanger within the 5000 liter Hot Water Storage tank.

7.7 Space Heating / Cooling systems

7.7.1 Fan Coil Units

Spaces located in the "Eco-Wall" as well as the conference room, auditorium tech booth, and basement mechanical areas are conditioned with two-pipe fan coil units. Each FCU receives hot water from the solar thermal system and chilled water at 7ºC from the chilled water loop. Under design conditions, the water is returned to the CHW loop at 12ºC. Occupancy sensors tied to control valves on the IUs allow for space temperature set points to be reset to unoccupied values.

7.7.2 Active Chilled Beams

4- pipe Active Chilled Beams (Induction Units) condition the majority of the building. Each IU receives hot water from the solar thermal system at 50ºC and chilled water at 14ºC. One coil is dedicated to cooling, while another coil is dedicated to heating. Air temperature is maintained by coils via control valve. Occupancy sensors tied to control valves on the IUs allow for space temperature set points to be reset to unoccupied values.

7.7.3 Thermo-Active Slab

A radiant slab conditions the Lobby in both heating and cooling modes. The circuit consists of 12 sub loops connected to a common header. The slab is controlled to be in winter or summer mode with two-way control valves which determine which loop (heating or cooling) serves the radiant floor. Depending on mode, it will receive either 14ºC cold water or 35ºC hot water. In summer mode, Pump- P-7 which delivers warm water to the slab, is shut off. A space humidity sensor monitoring indoor relative humidity will shut off the radiant slab in cooling mode if space dew-point temperatures rise above slab surface temperature.

7.7.4 Offices and Classrooms Air Handling Unit

AHU-1-05 delivers pre-conditioned 100% OA ratio ventilation air to the entire building. Air is filtered with MERV-13 equivalent filters: a pre-filter at 30% effectiveness and final filter at 85% effectiveness. AHU-1-05, located on the roof operates an energy recovery wheel to reduce peaks loads. Effectiveness is 53% humidity and 56% temperature. In summer, this provides a 62 kW reduction in cooling load at peak design, while in winter is provides a 106 kW reduction in heating load. AHU-1 has a hot water coil as primary heating/reheat, and a chilled water coil as cooling and dehumidification. In cooling mode, air is cooled to between 10 and 14ºC and is then reheated by the solar hot water to 14ºC to avoid condensation at induction units. In heating mode, air is preconditioned to leave the unit at 22ºC. In unoccupied modes, the air handler is capable of recirculating return air via a bypass damper in front of the energy recovery wheel.

7.7.5 Lobby Air Handling Unit

This unit this unit conditions and re-circulates return air within the lobby/atrium space. AHU-2-L1, located in the basement level. It serves the lobby, including the conference room pod. AHU-2-L1 has a hot water coil (47,817) as primary heating and a chilled water coil (85,566 BTUH) as cooling. In cooling mode, air is cooled to 14ºC. In heating mode, air is heated to 21^{o}C.

7.7.6 Auditorium Air Handling Unit

This unit this unit conditions and re-circulates return air. AHU-1-L1, located in the basement level. It serves the large auditorium located in the basement. AHU-1-L1 has a hot water coil as primary heating (94,500 BTUH) and a chilled water coil (224,000 BTUH) as cooling. In cooling mode, air is cooled to 14ºC. In heating mode, air is heated to 21ºC. When operational, the building load is often above 60 tons – necessitating the operation of CH-2.

7.8 HVAC Ventilation

7.8.1 3.4.1. Air Handling Units

AHU-1-05 provides constant volume preconditioned supply / ventilation air to occupied spaces throughout the building. During unoccupied times, a bypass damper allows return air to bypass the energy recovery wheel to provide mixed return and makeup air to the building.

7.8.2 Natural and Mixed Mode Ventilation

The natural ventilation system consists of operable windows for perimeter spaces and the stack effect created by the four-story atrium equipped with 8 solar chimneys. The chimneys are capped vanned ventilators which act to further boost airflow induced via thermal stack effect. Two spaces located within the “Eco-Wall” are ventilated solely by operable windows.

During times when specific close temperature, and humidity control is not required, a natural ventilation can be used in entrance Atrium, office room and classrooms. During occupied hours, the natural ventilation system is activated when the outdoor air temperature is between 12ºC and 18ºC and/or when the outdoor enthalpy value is below 25. Chimney dampers open and mechanized actuators open low-level windows. Classroom and office windows opening to the atrium may be opened to provide outside airflow through these spaces. The Air Handling unit system serving the lobby as well as the radiant floor remain off during this time.

The climate in Tel Aviv will permit acceptable thermal conditions to be achieved for up to 35% of the year using a natural ventilation system. User involvement is a key determinant in the success of this mixed mode natural ventilation system.