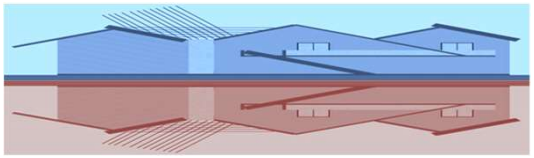
European Cooperation in the field of Scientific and Technical Research

www.cost.esf.org

Building Integration of Solar Thermal Systems – TU1205 – BISTS

Hybrid Photovoltaic/Thermal Collectors

Part B



Prof. Yiannis Tripanagnostopoulos

Univ. of Patras, Patra, Greece

COST is supported by the EU RTD Framework Programme

ESF provides the COST Office through an EC contract

European Cooperation in the field of Scientific and Technical Research

www.cost.esf.org

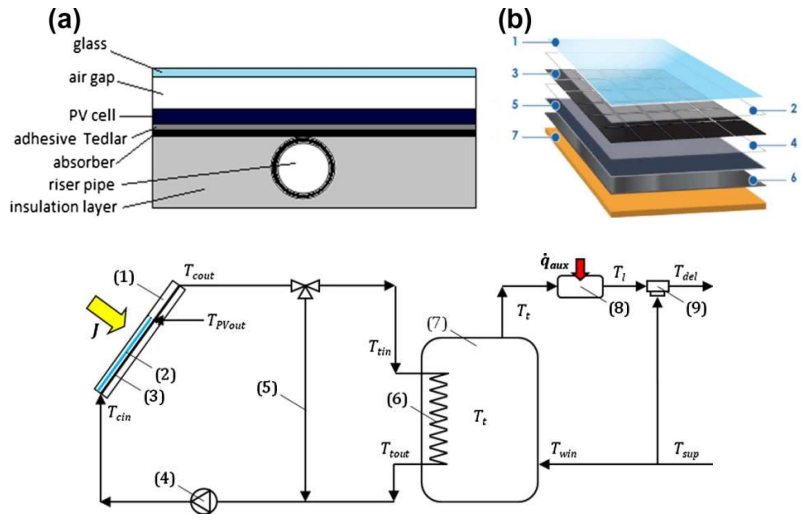
Building Integration of Solar Thermal Systems – TU1205 – BISTS

2nd part of lecture on PV/T collectors

COST is supported by the EU RTD Framework Programme

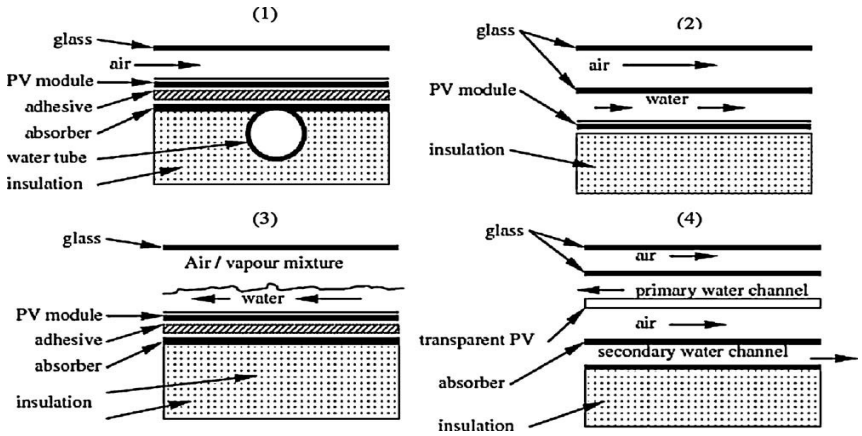
ESF provides the COST Office through an EC contract

PV/T –WATER systems



European Cooperation in the field of Scientific and Technical Research
www.cost.esf.org
Building Integration of Solar Thermal Systems – TU1205 – BISTS

PV/T –WATER systems



(Zondag, 2008)

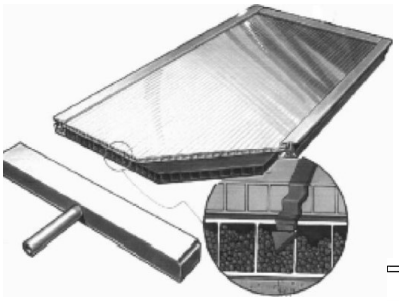
COST is supported by
the EU RTD Framework Programme
ESF provides the COST Office
through an EC contract

European Cooperation in the field of Scientific and Technical Research

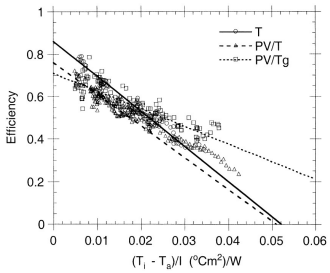
www.cost.esf.org

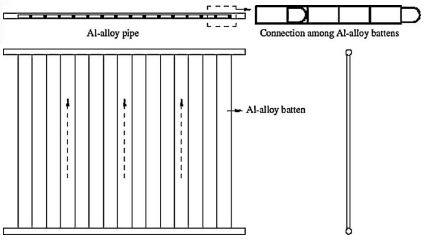
Building Integration of Solar Thermal Systems – TU1205 – BISTS

PV/T –WATER systems



(Sadnes and Rekstadt, 2002)





COST is supported by the EU RTD Framework Programme

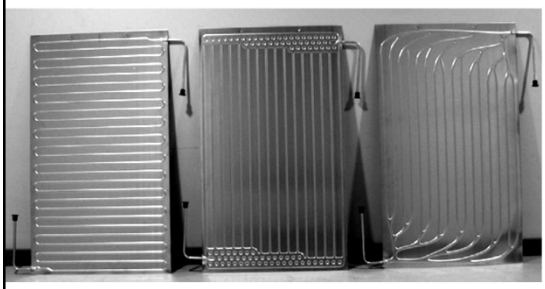
ESF provides the COST Office through an EC contract

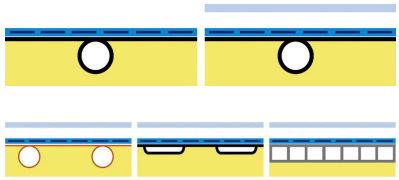
European Cooperation in the field of Scientific and Technical Research

www.cost.esf.org

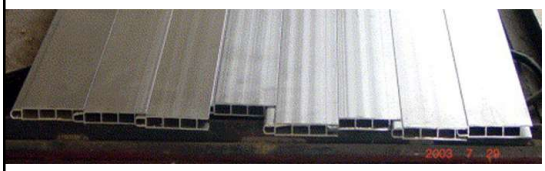
Building Integration of Solar Thermal Systems – TU1205 – BISTS

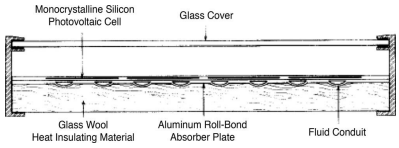
PV/T –WATER systems





(Aste et al, 2014)

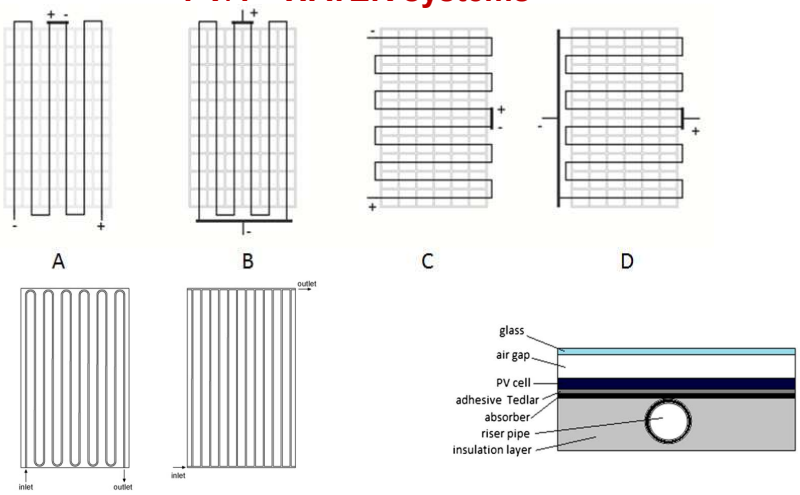




COST is supported by the EU RTD Framework Programme

ESF provides the COST Office through an EC contract

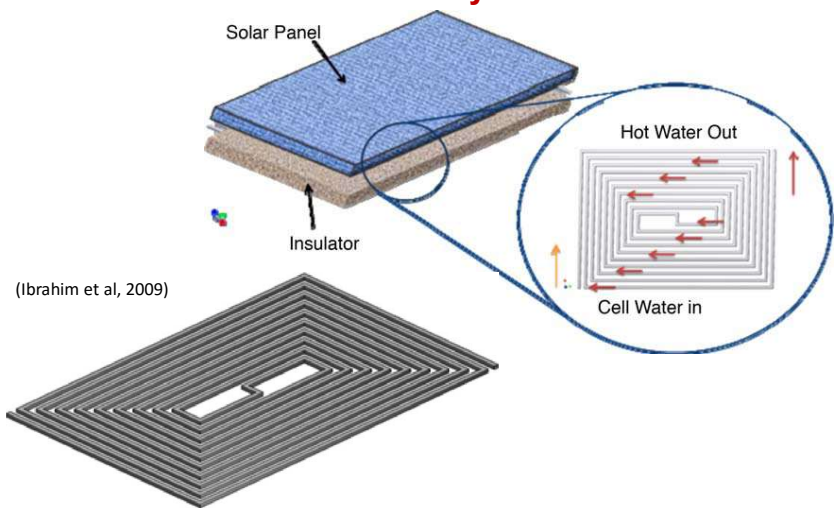
PV/T –WATER systems



(Aste et al, 2014)

European Cooperation in the field of Scientific and Technical Research
www.cost.esf.org
Building Integration of Solar Thermal Systems – TU1205 – BISTS

PV/T –WATER systems



(Ibrahim et al, 2009)

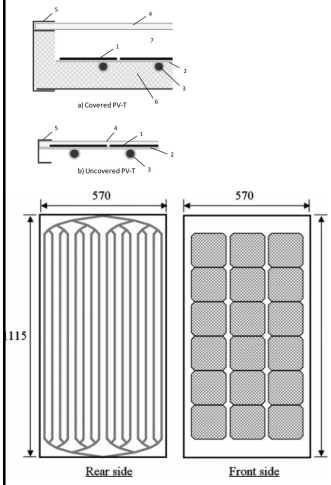
COST is supported by
the EU RTD Framework Programme
ESF provides the COST Office
through an EC contract

European Cooperation in the field of Scientific and Technical Research

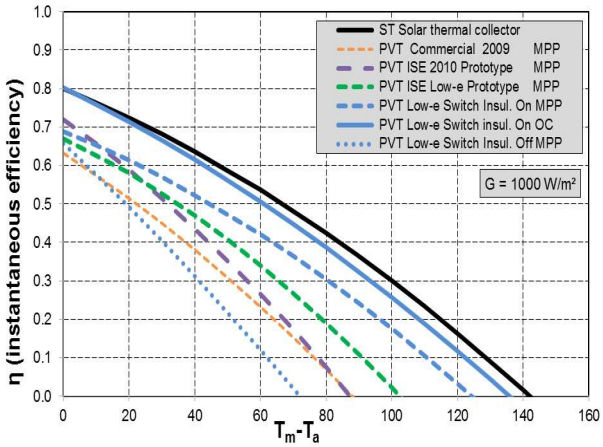
www.cost.esf.org

Building Integration of Solar Thermal Systems – TU1205 – BISTS

PV/T –WATER systems



(Dupeyrat, 2011, 2014)



(Fortuin et al, 2014)

COST is supported by the EU RTD Framework Programme

ESF provides the COST Office through an EC contract

European Cooperation in the field of Scientific and Technical Research

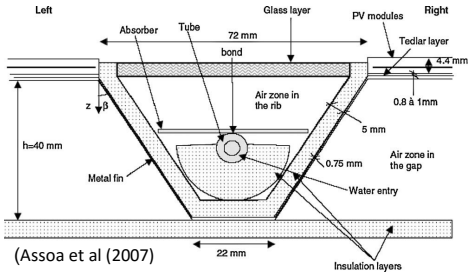
www.cost.esf.org

Building Integration of Solar Thermal Systems – TU1205 – BISTS

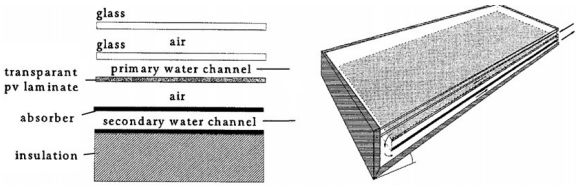
PV/T –WATER +AIR systems

One of the first commercial PV/T collectors (MSS, Millenium Electric) is based on the concept of PVT collector with heat and water heat extraction (Elazari, 1998).

Tripanagnostopoulos (2007) and Assoa et al (2007) suggest such PV/T collectors and give results from tested experimental models.



(Assoa et al (2007)



COST is supported by the EU RTD Framework Programme

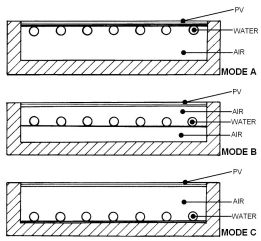
ESF provides the COST Office through an EC contract

European Cooperation in the field of Scientific and Technical Research

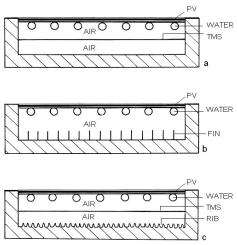
www.cost.esf.org

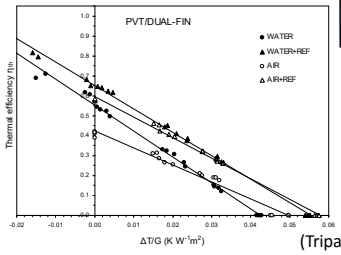
Building Integration of Solar Thermal Systems – TU1205 – BISTS

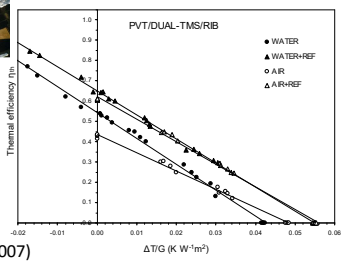
PV/T –WATER +AIR systems



The suggested systems are based on the TMS, FIN and RIB modifications , for the air heat extraction improvements







(Tripanagnostopoulos, 2007)

COST is supported by the EU RTD Framework Programme

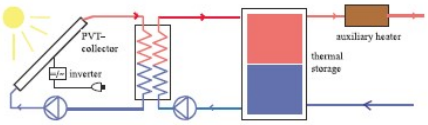
ESF provides the COST Office through an EC contract

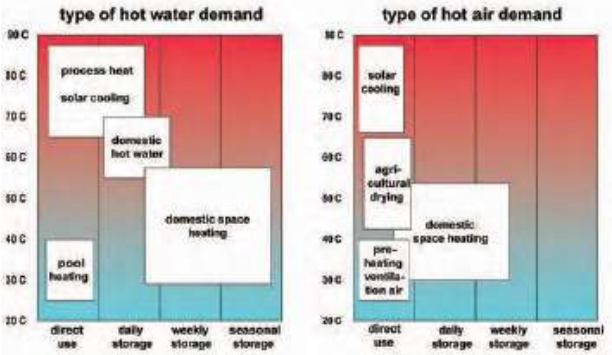
European Cooperation in the field of Scientific and Technical Research

www.cost.esf.org

Building Integration of Solar Thermal Systems – TU1205 – BISTS

Solar energy system application chart





COST is supported by the EU RTD Framework Programme

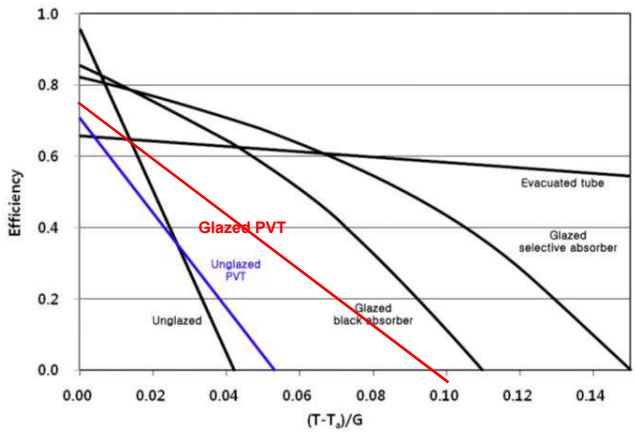
ESF provides the COST Office through an EC contract

European Cooperation in the field of Scientific and Technical Research

www.cost.esf.org

Building Integration of Solar Thermal Systems – TU1205 – BISTS

ST and PV/T system performance



Comparison of thermal efficiency curves of solar thermal and PV/T collectors

COST is supported by the EU RTD Framework Programme

ESF provides the COST Office through an EC contract

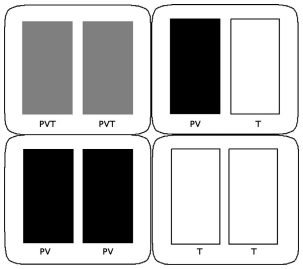
European Cooperation in the field of Scientific and Technical Research

www.cost.esf.org

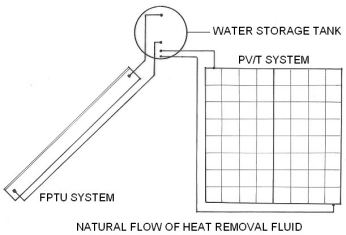
Building Integration of Solar Thermal Systems – TU1205 – BISTS

PV/T +THERMAL systems

For the optimal use of building roof and façade to obtain heat and electricity from solar energy systems, an effective combination of thermal collectors, photovoltaics and PV/T systems should be applied.



An effective system is the thermal collectors with PV/T collectors connected with the same water storage tank. The PV/T collectors preheat the water and the thermal collector s work for the main heating.

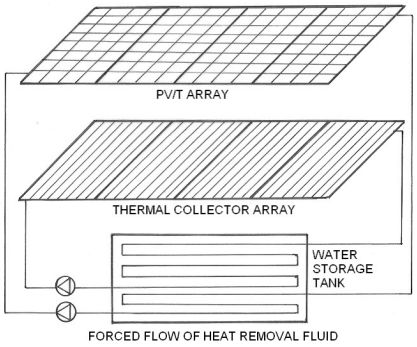


(Tripanagnostopoulos, 2006)

COST is supported by the EU RTD Framework Programme

ESF provides the COST Office through an EC contract

PV/T +THERMAL systems



(Tripanagnostopoulos, 2006)

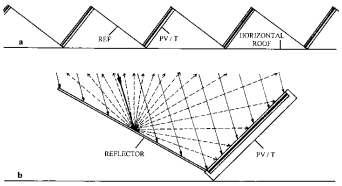
The suggested PV/T+Thermal collector system can be applied to larger solar energy arrays. Both systems (PV/T and Thermal Collectors) can be connected with the same water storage tank.

In this system the heat from PV/T collectors is transmitted to water storage tank through Heat Exchanger . The HE is placed at the lower part of storage tank to have thermal contact with the cooler water in the tank .

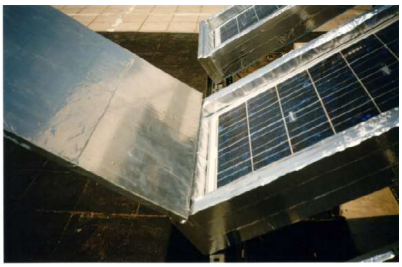
The thermal collectors provide storage tank with heat of higher temperature than PV/T system, as they can operate efficiently at higher temperatures without the existing PV/T thermal limitations.

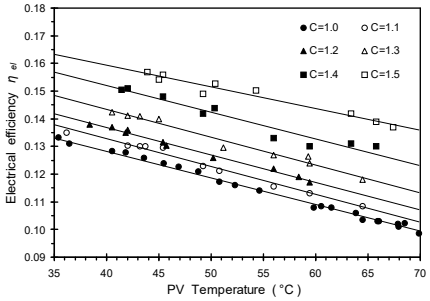
European Cooperation in the field of Scientific and Technical Research
www.cost.esf.org
Building Integration of Solar Thermal Systems – TU1205 – BISTS

LOW CONCENTRATING PV/T systems



(Tripanagnostopoulos et al, 2002)





Effective use of diffuse booster reflectors to PV and PV/T systems to improve performance (Tripanagnostopoulos et al, 2005, 2006, 2007, Robles-Ocampo et al. 2007, Kostic et al, 2010)

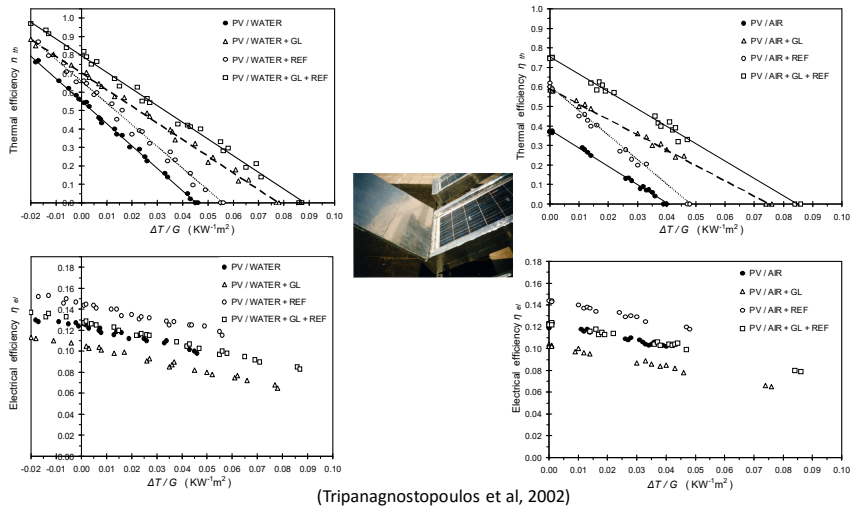
COST is supported by the EU RTD Framework Programme
ESF provides the COST Office through an EC contract

European Cooperation in the field of Scientific and Technical Research

www.cost.esf.org

Building Integration of Solar Thermal Systems – TU1205 – BISTS

LOW CONCENTRATING PV/T systems



(Tripanagnostopoulos et al, 2002)

COST is supported by the EU RTD Framework Programme

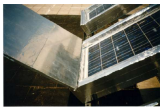
ESF provides the COST Office through an EC contract

European Cooperation in the field of Scientific and Technical Research

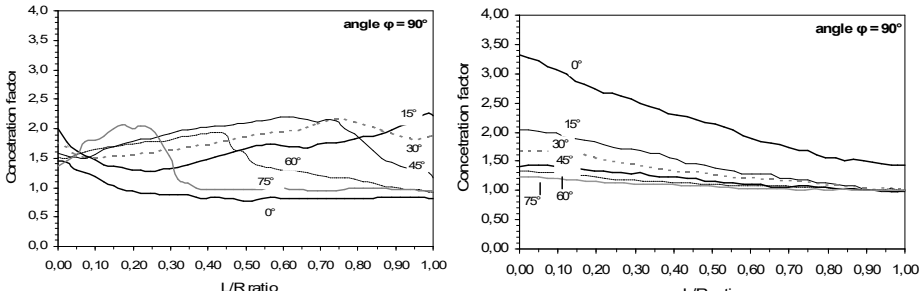
www.cost.esf.org

Building Integration of Solar Thermal Systems – TU1205 – BISTS

LOW CONCENTRATING PV/T systems



The system concentration ratio factor along PV module, for different reflectors: flat aluminum sheets (left) and white painted sheets (right), as low cost diffuse reflectors.



(Tripanagnostopoulos et al, 2002)

COST is supported by the EU RTD Framework Programme

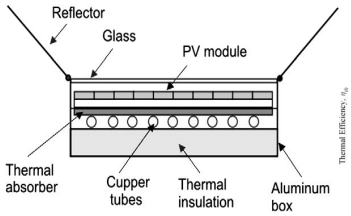
ESF provides the COST Office through an EC contract

European Cooperation in the field of Scientific and Technical Research

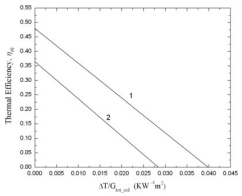
www.cost.esf.org

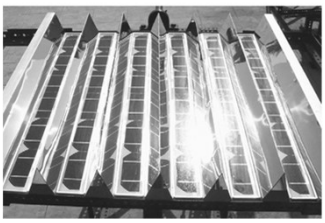
Building Integration of Solar Thermal Systems – TU1205 – BISTS

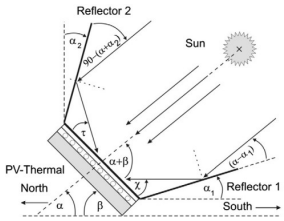
LOW CONCENTRATING PV/T systems

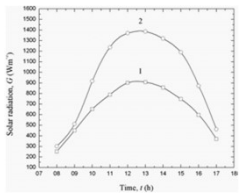


(Kostic et al, 2010)









COST is supported by the EU RTD Framework Programme

ESF provides the COST Office through an EC contract

European Cooperation in the field of Scientific and Technical Research

www.cost.esf.org

Building Integration of Solar Thermal Systems – TU1205 – BISTS

LOW CONCENTRATING PV/T systems

COST is supported by the EU RTD Framework Programme

ESF provides the COST Office through an EC contract

European Cooperation in the field of Scientific and Technical Research

www.cost.esf.org

Building Integration of Solar Thermal Systems – TU1205 – BISTS

LOW CONCENTRATING PV/T systems

Low concentrating trough CPVT collector

(Coventry, 2006)

High concentrating dish CPVT collector

(Helmers and Kramer, 2013)

COST is supported by the EU RTD Framework Programme

ESF provides the COST Office through an EC contract

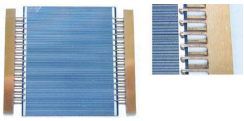
European Cooperation in the field of Scientific and Technical Research

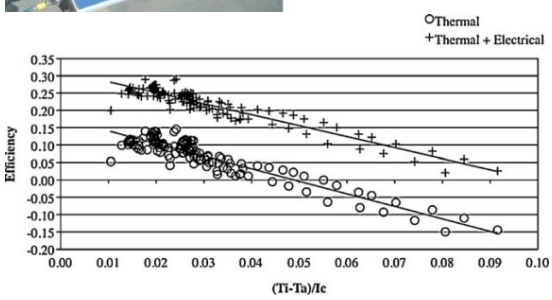
www.cost.esf.org

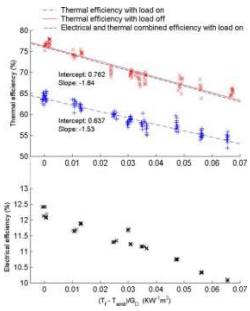
Building Integration of Solar Thermal Systems – TU1205 – BISTS

LOW CONCENTRATING PV/T systems

(Coventry, 2006)







COST is supported by the EU RTD Framework Programme

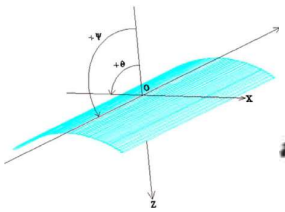
ESF provides the COST Office through an EC contract

European Cooperation in the field of Scientific and Technical Research

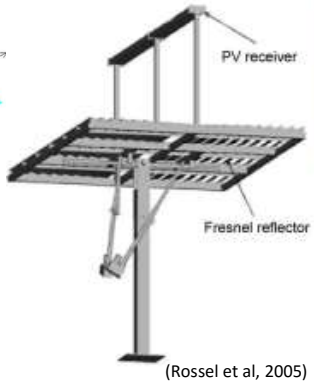
www.cost.esf.org

Building Integration of Solar Thermal Systems – TU1205 – BISTS

LOW CONCENTRATING PV/T systems



(Chemisana and Ibanez, 2010)



(Rossel et al, 2005)

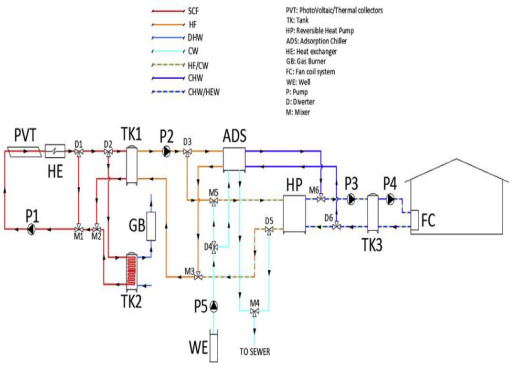
European Cooperation in the field of Scientific and Technical Research

Università degli Studi di Napoli Federico II

Building Integration of Solar Thermal Systems – TU1205 – BISTS

Example of application of PVT

PVT field area 20 [m2]
Reference temperature for PV efficiency 25 [C]
PVT slope 30°
PVT azimuth 0 °
PVT set point temperature (when TK1 is supplied) 30/70 [C]
PVT set point temperature (when TK2 is supplied) 55 [C]
TK1 volume/PVT area 100 [l/m2]
TK1 set point temperature 25/65 [C]
TK2 volume/PVT area 50 [l/m2]
TK2 set point temperature 50 [C]
TK3 volume 1 [m3]
TK3 set point temperature winter 47 [C]
TK3 set point temperature summer 6 [C]
TK1, TK2, TK3 los coefficient 0.278 [W/(m2 C)]
P3 flow 2400 [kg/h]
P4 flow 1500 [kg/h]
P5 flow 3600 [kg/h]
HP rated heating capacity 8 [kW]
HP rated cooling capacity 7 [kW]
Space heating set point temperature 20 [C]
Space cooling set point temperature 26 [C]



From: A novel solar-assisted heat pump driven by photovoltaic/thermal collectors: Dynamic simulation and thermoeconomic optimization.
Francesco Calise , Massimo Dentice d'Accadia , Rafal Damian Figaj , Laura Vanoli

COST is supported by the EU RTD Framework Programme

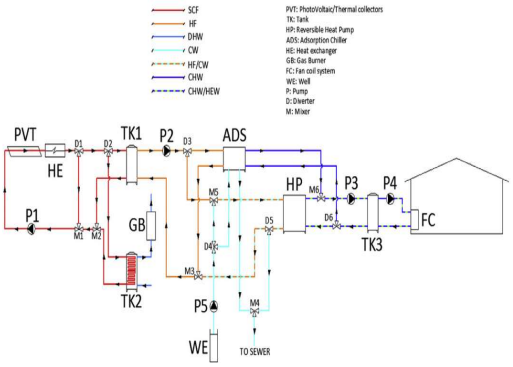
ESF provides the COST Office through an EC contract

Example of application of PVT

Operation functioning

In winter time the PVT provides the heat to Tank 1(TK1) and Tank 2(TK2). TK1 provides the heat for the evaporator of the heat pump whereas from TK2 comes the heat for the DHW (Domestic hot Water).
The heat Pump heats tank 3 (TK3) that feeds the Fan coil for the space heating.

In summer time the PVT provides the heat to Tank 1(TK1) and Tank 2(TK2). From TK1 comes the heat for the adsorption chiller.
When the power of the adsorption chiller is not enough we can use the heat pump like auxiliary.
All of this two system cool TK3 that feeds the Fan coil for the space cooling.



From: A novel solar-asisted heat pump driven by photovoltaic/thermal collectors: Dynamic simulation and thermoeconomic optimization. Francesco Calise , Massimo Dentice d'Accadia , Rafal Damian Figaj , Laura Vanoli

Study for PV/T and STC application

Suitable application for the use of PV/T systems is a Hotel. We are realizing a solution for an existing hotel in Patras (GR), that already uses the thermal panels for producing DHW.

Total surface of the roof [m2]: 431
Hotel 3* [l/day*person]: 60
Total liters for day of DOMESTIC HOT WATER: 6120
Heat Pump data middle cop= 5,00

PV data
average solar radiation [kWh/day]=5,69
B.O.P. factor balance of system=0,8
η PV=0,12
η th = 0,7
Optimum panel inclination: 33°

European Cooperation in the field of Scientific and Technical Research

Building Integration of Solar Thermal Systems – TU1205 – BISTS

Study for PV/T and STC application

Our idea is to cuple PVT with solar Thermal panels in order to cover all the DHW consumption and to provides a tiny amount of electrical energy to reduce the required from the net.

The balance point between PVT and Thermal panels

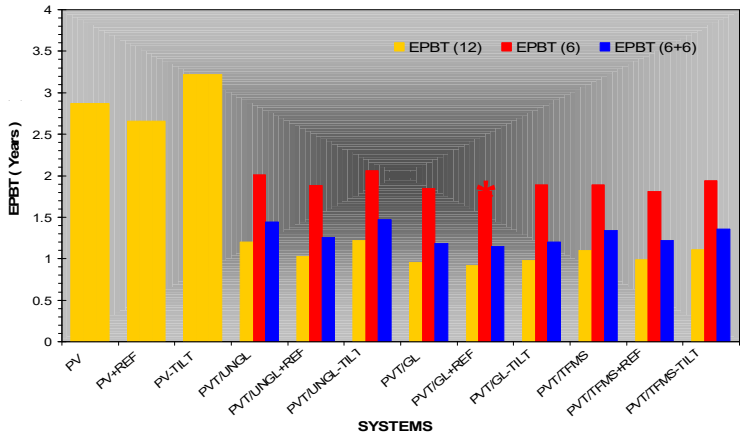
(1) to use a heat pump to provide the heat to DHW and to use, in the winter, the heat from the PVT to have an higher COP of the HP;

(2) to use the heat from the PVT for pre-heating the water and thus to use the solar thermal panels to achieve the higher temperatures

European Cooperation in the field of Scientific and Technical Research

Building Integration of Solar Thermal Systems – TU1205 – BISTS

PV/T and PV Energy Pay Back Times



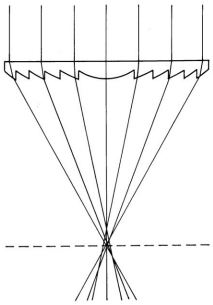
(Tripanagnosatopoulos et al, 2006)

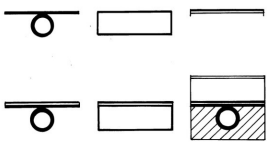
COST is supported by the EU RTD Framework Programme

ESF provides the COST Office through an EC contract

PV/T systems combined with Fresnel lenses

The direct incident solar radiation can be concentrated on an absorber strip, located at the focal position and can be taken away to achieve lower illumination level and also to avoid the overheating of the space.



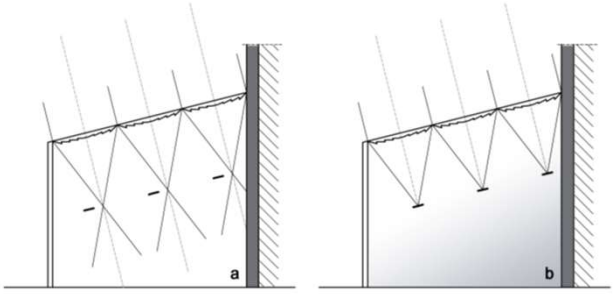


In low intensity irradiance, the absorber can be out of focus leaving the light to come in the interior space and keep the illumination at an acceptable level.

(Tripanagnostopoulos et al, 2006)

European Cooperation in the field of Scientific and Technical Research
www.cost.esf.org
Building Integration of Solar Thermal Systems – TU1205 – BISTS

PV/T systems combined with Fresnel lenses

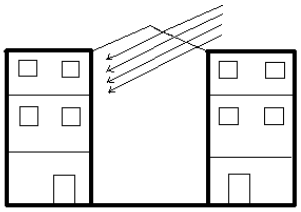


Absorbers out of focus Absorbers at focus

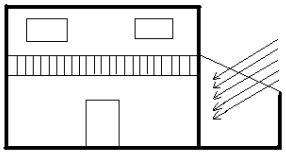
The combination of Fresnel lenses with linear PV/T absorbers can control the illumination and the temperature of the transparently covered internal spaces of buildings (atria, sunspaces). (Tripanagnostopoulos et al, 2006)

COST is supported by the EU RTD Framework Programme
ESF provides the COST Office through an EC contract

PV/T systems combined with Fresnel lenses

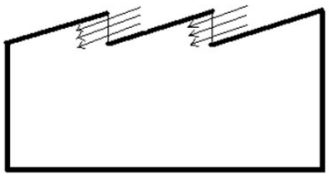


atrium



sunspace

room

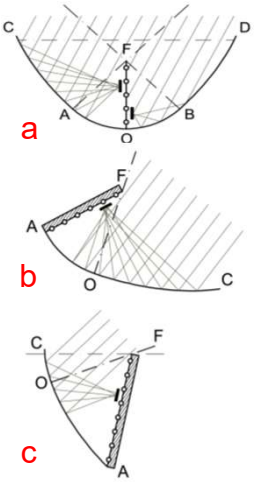


industry

(Tripanagnostopoulos et al, 2006)

European Cooperation in the field of Scientific and Technical Research
www.cost.esf.org
Building Integration of Solar Thermal Systems – TU1205 – BISTS

CPC reflectors combined with PVT absorbers



Stationary CPC reflectors with flat bifacial absorber is combined with PV strips that track the converged solar radiation and absorb the concentrated solar radiation.

The non-absorbed beam solar radiation and the diffuse solar radiation are absorbed by the secondary flat bifacial thermal absorber.

In asymmetric CPC reflector, the PV strip is moving in front of the thermal absorber, tracking the converged solar radiation.

The parabola axis is directed to: (b) the higher altitude of sun (summer) or to (c) the lower sun altitude (winter).

(Tripanagnostopoulos , 2008)

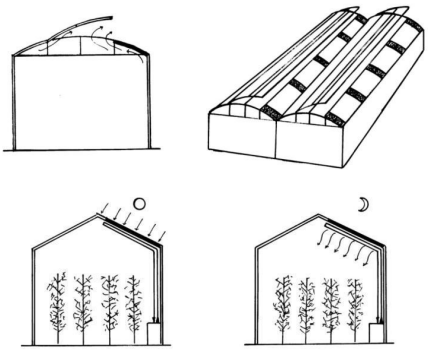
COST is supported by the EU RTD Framework Programme
ESF provides the COST Office through an EC contract
EUROPEAN SCIENCE FOUNDATION

Greenhouse with PV and PVT systems

Greenhouse roof can be used to install PV modules and provide electricity.

PV modules should be arranged in a suitable way, to avoid permanent plant shading and to contribute to natural ventilation of greenhouse.

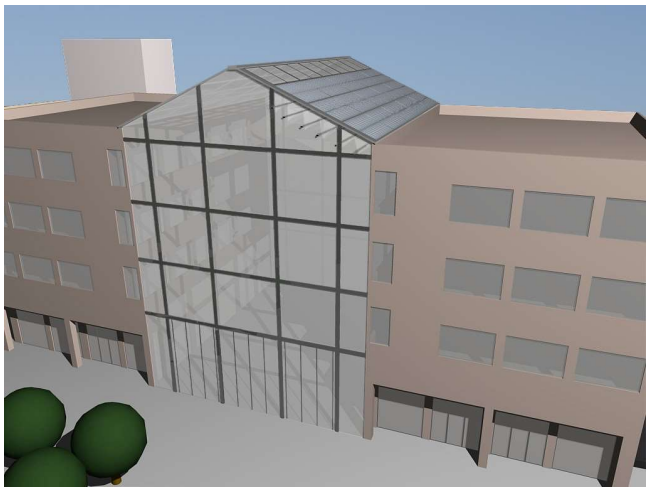
The PV modules can carry water heat exchangers at their rear surface and be combined with thermal storage to operate as cooling (during day)-heating (during night) system of the greenhouse.



(Rocamora and Tripanagnostopoulos, 2006)

European Cooperation in the field of Scientific and Technical Research
www.cost.esf.org
Building Integration of Solar Thermal Systems – TU1205 – BISTS

Suggested applications of improved PVT systems



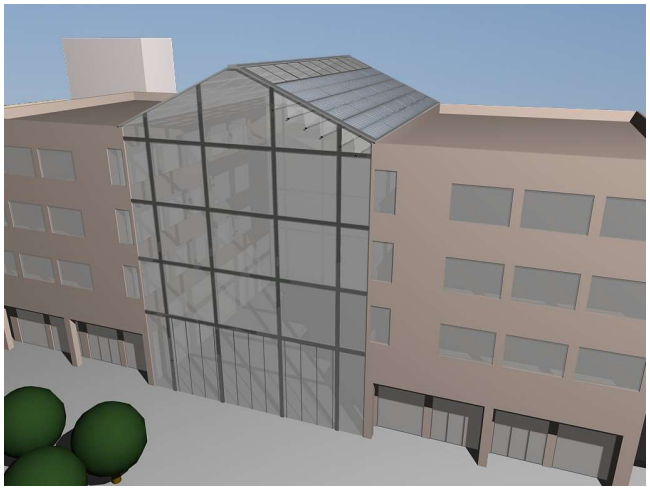
COST is supported by the EU RTD Framework Programme
ESF provides the COST Office through an EC contract

European Cooperation in the field of Scientific and Technical Research

www.cost.esf.org

Building Integration of Solar Thermal Systems – TU1205 – BISTS

Suggested applications of improved PVT systems



COST is supported by the EU RTD Framework Programme

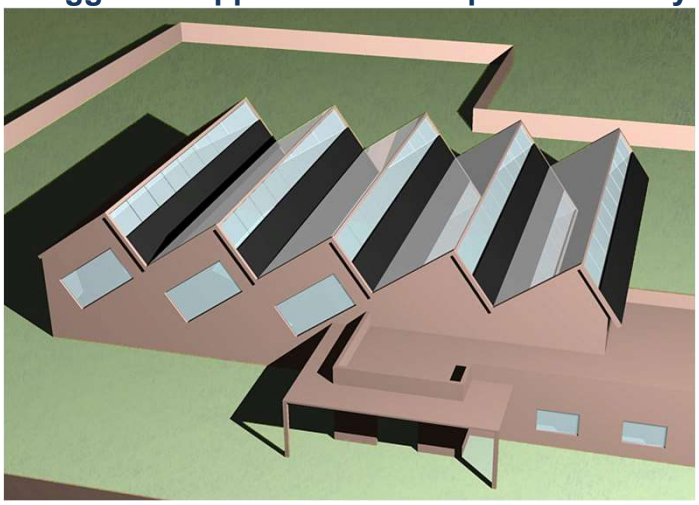
ESF provides the COST Office through an EC contract

European Cooperation in the field of Scientific and Technical Research

www.cost.esf.org

Building Integration of Solar Thermal Systems – TU1205 – BISTS

Suggested applications of improved PVT systems



COST is supported by the EU RTD Framework Programme

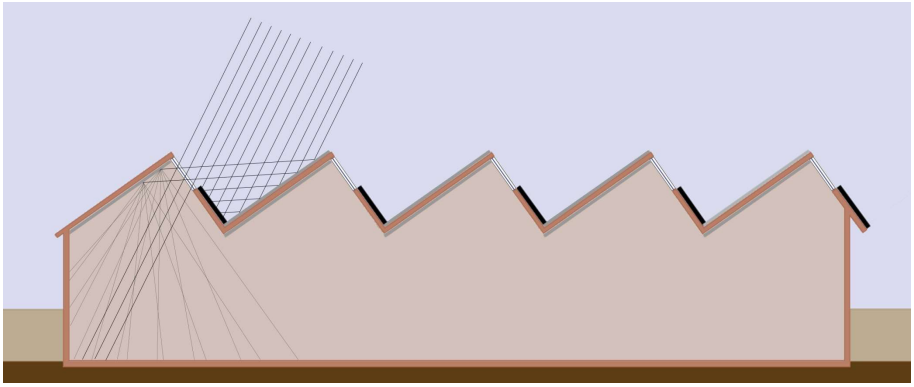
ESF provides the COST Office through an EC contract

European Cooperation in the field of Scientific and Technical Research

www.cost.esf.org

Building Integration of Solar Thermal Systems – TU1205 – BISTS

Suggested applications of improved PVT systems

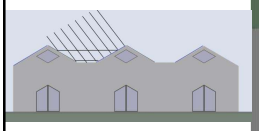


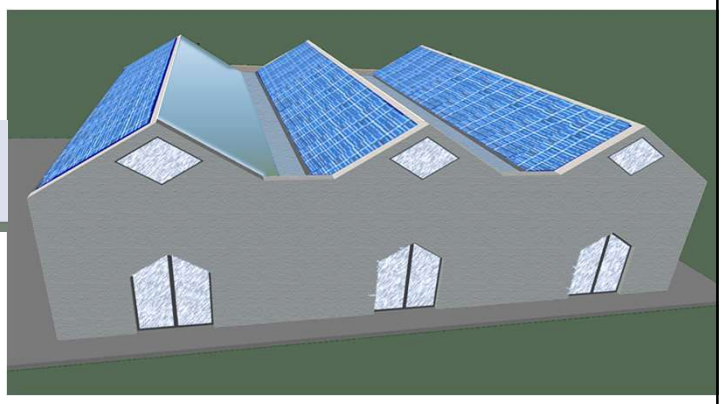
European Cooperation in the field of Scientific and Technical Research

www.cost.esf.org

Building Integration of Solar Thermal Systems – TU1205 – BISTS

Suggested applications of improved PVT systems





Building roofs can be effectively used to install PV modules, filling the opposite roof surface with diffuse reflectors, to provide additional solar energy and increasing system's electrical output

COST is supported by
the EU RTD Framework Programme

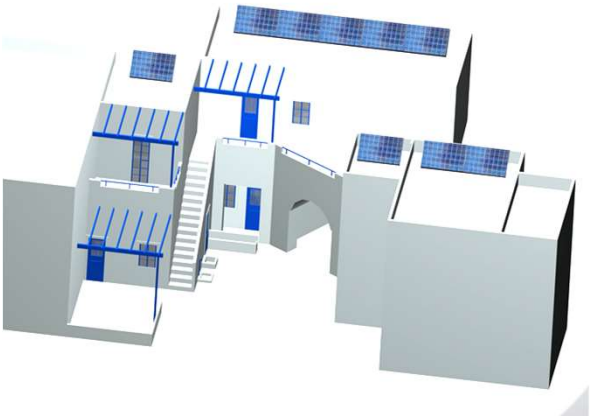
ESF provides the COST Office
through an EC contract

European Cooperation in the field of Scientific and Technical Research

www.cost.esf.org

Building Integration of Solar Thermal Systems – TU1205 – BISTS

Suggested applications of improved PVT systems



HYBRID PV/T COLLECTORS ON CYCLADIC HOUSE ROOF

European Cooperation in the field of Scientific and Technical Research

www.cost.esf.org

Building Integration of Solar Thermal Systems – TU1205 – BISTS

Suggested applications of improved PVT systems

Example of aesthetic integration of solar and wind energy systems on a building of Cycladic islands, for effective operation of sun and wind

COST is supported by the EU RTD Framework Programme

ESF provides the COST Office through an EC contract

EPILOGE (1)

The hybrid Photovoltaic/Thermal (PV/T or PVT) collectors convert solar radiation simultaneously to electricity and heat, increasing the total energy output of PVs.

PV/T collectors are distinguished in PV/T-water and PV/T-air collectors, depending on the heating medium used. In PV/T-air collectors the contact of air with PV panels is direct, while in PV/T-water collectors the water heating is usually through a heat exchanger.

Apart from the use of the flat type PV/T collectors, there have been developed concentrating PV/T collectors (CPVT) using reflectors or lenses and concentrating type cells, aiming to cost effective conversion of solar energy.

The work on PV/T collectors has started before forty years and still they are not yet applied enough. New PV/T collector designs are promising for a wider application next years, mainly to adapt zero energy building requirements.

European Cooperation in the field of Scientific and Technical Research
www.cost.esf.org
Building Integration of Solar Thermal Systems – TU1205 – BISTS

EPILOGE (2)

Among the interesting suggested improvements to PV/T collectors for the achievement of higher performance and longer durability, there can be referred the following:

- The placement of TMS and FIN in the air duct of PV/T-AIR collectors
- The combination of PV/T collectors with booster diffuse reflectors
- The installation of both PV/T and Thermal collectors to building roofs and facades
- The use of temperature resistant PV modules to PV/T collectors
- The high performance attachment of PV modules and heat extraction units
- The thermal insulation switching to control PV/T system operating temperature
- The effective combination of concentrators with PV/T solar radiation receivers

COST is supported by the EU RTD Framework Programme
ESF provides the COST Office through an EC contract

European Cooperation in the field of Scientific and Technical Research

www.cost.esf.org

Building Integration of Solar Thermal Systems – TU1205 – BISTS

REFERENCES

Aelenei L. and Goncalves H. 2013. From solar building design to Net Zero Energy Buildings: performance insights of an office building. Energy Procedia 48, 1236-1243.
Aelenei L., Pereira R., Goncalves H., Athienitis A. 2014. Thermal performance of a hyrid BIPV-PCM: modelling, design and experimental investigation. Energy Procedia 48, 474-483.
Agrawal B., Tiwari G.N. 2010. Life cycle cost assessment of building integrated photovoltaic thermal (BIPVT) systems. Energy and Buildings 42, 1472-1481.
Anderson T.N., Duke M., Morrison G.L., Carson J.K. 2009. Performance of a building integrated photovoltaic/thermal (BIPVT) solar collector. Solar Energy 83, 445-455.
Assoa Y.B., Menezo C., Fraisse G., Yezou R., Brau J. 2007. Study of a new concept of photovoltaic-thermal hybrid collector. Solar Energy 81, 1132-1143.
Aste N., Beccali M., Solaini G. 2003. Experimental validation of a simulation model for a PV/T collector. ISES solar world congress, June 14-19, Goteborg, Sweden, CD-ROM.
Aste N., Del Pero C., Leonforte F., 2012. Thermal-electrical optimization of the configuration a liquid PVT collector. Energy Procedia 30, 1-7.
Aste N., Del Pero C., Leonforte F., 2014. Water flat plate PV-thermal collectors: A review. Solar Energy 102, 98-115.
Bakker M., Zondag H.A., Elswijk M.J., Strootman K.J., Jong M.J.M. 2005. Performance and costs of a roof-sized PV/thermal array combined with a ground coupled heat pump. Solar Energy 78, 331-339.
Battisti R. Tripanagnostopoulos Y. 2005. PV/Thermal systems for application in industry. In Proc. (CD-ROM) of 20th European Photovoltaic Solar Energy Conference, 6-10 June 2005, Barcelona, Spain, paper 6CV.2.3.
Bazilian M., Leeders F., van der Ree B.G.C. and Prasad D. 2001. Photovoltaic cogeneration in the built environment. Solar Energy 71, 57-69.
Beccali M., Finocchiaro P. Nocke B. 2009. Energy and economic assessment of desiccant cooling systems coupled with single glazed air and hybrid PV/thermal solar collectors for applications in hot and humid climate. Solar Energy 83, 1828-1846.
Bergene T. and Lovvik O.M. 1995. Model calculations on a flat-plate solar heat collector with integrated solar cells. Solar Energy 55, 453-462.
Bhargava A.K., Garg H.P. and Agarwal R.K. 1991. Study of a hybrid solar system – solar air heater combined with solar cells. Energy Convers. Mgmt. 31, 471-479.
Bottenberg W. R., N. Kaminar, T. Alexander, P. Carrie, K. Chen, D. Gilbert, P. Hobden, A. Kalaita, J. Zimmerman, Manufacturing technology improvements for the PVI SUNFOCUS™ concentrator. 16th European PV Solar Energy Conference 2000, 1–5 May, Glasgow, UK, 2233-2236.
Brinkworth B.J., Cross B.M., Marshall R.H. and Hongxing Yang. 1997. Thermal regulation of photovoltaic cladding. Solar Energy 61, 169-179.
Brinkworth B.J., Marshall R.H., Ibarahim Z. 2000. A validad model of naturally ventilated PV cladding. Solar Energy 69, 67-81.
Brinkworth B. J. 2000a. A procedure for routine calculation of laminar free and mixed convection in inclined ducts. Int. J. Heat Fluid Flow, 21, 456-255.
Brinkworth B.J. 2000b. Estimation of flow and heat transfer for the design of PV cooling ducts. Solar Energy 69, 413-320.
Brinkworth B.J., Sandberg M. 2006. Design procedure for cooling ducts to minimise efficiency loss due to temperature rise in PV arrays. Solar Energy 80, 89-103.
Brogren M., Ronnelid M., Karlsson B., Proc. 16th Europ. PV Solar Energy Conf. Vol. III, pp. 2121-2124, 1-5 May, Glasgow, U.K. (2000).
Brogren M., Nostell P. and Karlsson B. 2000. Optical efficiency of a PV-Thermal hybrid CPC module for high latitudes. Solar Energy 69, 173-185.
Brogren M., Karlsson B., Werner A. and Roos A. 2002. Design and evaluation of low-concentrating, stationary, parabolic reflectors for wall-integration of water-cooled photovoltaic-thermal hybrid modules. In Proc. Int. Conf. PV in Europe 7-11 Oct. Rome, 551-555.
Busato F., Lazzarin R., Noro M. 2008. Experimental analysis of photovoltaic cogeneration modules. International Journal of Low Carbon Technologies 3-4, 221-244.
Charalambous P.G., Maidment G.G., Kalogirou S.A., Yiakoumetti K. 2007. Photovoltaic thermal (PV/T) collectors: A review. Applied Thermal Engineering 27, 275-286.
Charron R., Athienitis A.K. 2006. Optimization of the performance of double-facades with integrated photovoltaic panels and motorized blinds. Solar Energy 80, 482-491.
Chemisana D., Ibanez M. 2010. Linear Fresnel concentrators for building integrated applications. Energy Conversion and Mngmnt. 51, 1476-1480.
Chow T.T. 2010. A review on photovoltaic/thermal hybrid solar technology. Applied Energy 87, 365-379.
Chow T.T. 2003. Performance analysis of photovoltaic-thermal collector by explicit dynamic model. Solar Energy 75, 143-152.
Chow T.T., He W., Ji J. 2006. Hybrid photovoltaic-thermosyphon water heating system for residential application. Solar Energy 80, 298-306.
Ciulla G., Lo Brano V., Cellura M., Franzitta V., Milone D. 2012.A finite difference model of a PV-PCM system. Energy Procedia 30, 198-206.

European Cooperation in the field of Scientific and Technical Research

www.cost.esf.org

Building Integration of Solar Thermal Systems – TU1205 – BISTS

REFERENCES

Coventry J.S., Lovegrove K. 2003. Development of an approach to compare the 'value' of electric and thermal output from a domestic PV/thermal system. Solar Energy 75, 63-72.
Coventry J. 2005. Performance of a concentrating photovoltaic/thermal solar collector. Solar Energy 78, 211-222.
Cox C.H. III and Raghuraman P. 1985. Design considerations for flat - plate- photovoltaic/thermal collectors. Solar Energy 35, 227-241.
Duffie J. A and W. A Beckman, 1991. Solar Engineering of Thermal Processes. John Wiley & Sons, Inc. New York.
Dupeyrat P., Menezo Ch., Rommel M., Henning H.M. 2011. Efficient single glazed flat plate photovoltaic-thermalhybrid collector for domestic hot water system. Solar Energy 85, 1457-1468.
Dupeyrat P., Menezo Ch., Fortuin S. 2014. Study of the thermal and electrical performances of PVT solar hot water system. Energy and Buildings 68, 751-755.
Eicker U., Fux V., Infield D. and Mei Li. 2000. Heating and cooling of combined PV-solar air collectors facades. In Proc. Int. Conf. 16th Europ. PV solar energy. 1-5 May Glasgow, UK, 1836-1839.
Elazari A. 1998. Multi Solar System – Solar multimodule for electrical and hot water supply for residentially building. In Proc. 2nd World Conf. On Photovoltaic Solar Energy Conversion , 6-10 July, Vienna, Austria, 2430-2433.
Esposito A, 1998. Fluid Mechanics with Applications. *Prentice-Hall, INC*. New Jersey.
Fang G., Hu H., Liu X. 2010. Experimental investigation on the photovoltaic-thermal solar heat pump air-conditioning system on water-heating mode. Experimental Thermal and Fluid Science 34, 736-743.
Florschuetz L.W. 1979. Extention of the Hottel -Whillier model to the analysis of combined photovoltaic / thermal flat plate collectors. Solar Energy 22, 361-366.
Fortuin S., Hermann M., Stryi-Hipp G., Nitz P., Platzer W. 2014. Hybrid PV-Thermal collector development: conceps, experiences, results and research needs. Energy Procedia 48, 37-47.
Fraisse G., Menezo C., Johannes K. 2007. Energy performance of water hybrid PV/T collectors applied to combisystems of Direct Solar Floor type. Solar Energy 81, 1426-1438.
Frankl P. "Analisi del ciclo di vita di sistemi fotovoltaici" (LCA of Photovoltaic Systems), Ph.D. dissertation thesis, Università di Roma "La Sapienza", Roma, May 1996 - available at the Dipartimento di Meccanica e Aeronautica, Università di Roma "La Sapienza", Roma, or at the Biblioteca Nazionale, Roma, 1996.
Frankl P. Life cycle assessment (LCA) of PV systems–Overview and future outlook. In Proc. Int. Conf. PV in Europe, 7-11 Oct., Rome, Italy, 2002; 588-592.
Fujisawa T., Tani T. 1997. Annual exergy evaluation on photovoltaiv-thermal hybrid collector. Solar Energy Materials and Solar Cells 47, 135-148.
Garg H.P., P.K. Agarwal and A.K. Bhargava. 1991a. The effect of plane booster reflectors on the performance of a solar air heater with solar cells suitable for a solar dryer. Energy Convers. Mgmt. 32, 543-554.
G. Gan, "Effect of air gap on the performance of building-integrated photovoltaics," Energy, vol. 34, no. 7, pp. 913–921, 2009
Garg H.P. and Agarwal P.K. 1995. Some aspects of a PV/T collector/forced circulation flat plate solar water heater with solar cells. Energy Conv. Mgmt. 36, 87-99, 1995.
Garg H.P., and Adhikari R. S. 1997. Conventional hybrid photovoltaic / thermal (PV/T) air heating collectors: steady – state simulation. Renewable Energy 11, 363-385.
Garg H.P.,and Adhikari R.S. 1999. Performance analysis of a hybrid photovoltaic/thermal (PV/T) collector with integrated CPC troughs. Int. J. Energy Res. 23, 1295-1304.
Guiavarch A., Peuportier B. 2006. Photovoltaic collectors efficiency according to their integration in buildings. Solar Energy 80, 65-77.
Hausler T. and Rogash H. 2000. Latent heat storage of photovoltaics. In Proc. 16th Europ. PV Solar Energy Conf., 1-5 May, Glasgow, U.K. Vol III, 265-2267.
Hegazy A.A. 2000. Comparative study of the performances of four photovoltaic/thermal solar air collectors. Energy Convers. Mgmt 41, 861-881.
Helmers H., Kramer K. 2013. Multi-linear performance model for hybrid (C)PVT solar collectors. Solar Energy 92, 313-322.
Hendrie S.D. 1979. Evaluation of combined Photovoltaic/Thermal collectors. Proc. of Int. Conf. ISES, Atlanta, Georgia, USA, May 28 – June 1, Vol.3, 1865- 1869.
Hernandez M., R. Mohedano, F. Munoz, A. Sanz, P. Benitez and J. C. Minano. 16th European Photovoltaic Solar Energy Conference, 1–5 May, Glasgow, UK, 2394-2397, (2000).
Huang B.J. Lin T.H. Hung W.C. and Sun F.S. 2001. Performance evaluation of solar photovoltaic/thermal systems. Solar Energy 70, 443-448.
IEA-SHC/Task 35/PV/Thermal systems.2005. www.iea-shc.org/task35.
Ibarahim Z, Marshall R.H and Brinkworth B.J, 1999. Simplified loop analysis for naturally ventilated channel heated from one side by PV elements. Proc. UKISES Silver Jubilee Conf. Brighton, May 1999, pp. 69-74.
Ibrahim A., Othman M.Y., Ruslan M. H., Mat S., Sopian K. 2011. Recent advances in flat plate photovoltaic/thermal (PV/T) solar collectors. 2011. Renewable and Sustainable Energy Reviews 15, 352-365.

COST is supported by the EU RTD Framework Programme

ESF provides the COST Office through an EC contract

European Cooperation in the field of Scientific and Technical Research

www.cost.esf.org

Building Integration of Solar Thermal Systems – TU1205 – BISTS

REFERENCES

Infield D., Mei Li., Eicker U. 2004. Thermal performance estimation for ventilated PV facades. Solar Energy 76, 93-98.
Ito S. and Miura N. 2003. Usage of a DC fan together with photovoltaic modules in a solar air heating system. In Proc (CD-ROM) ISES World Congress Goteborg, Sweden, 14-19 June.
Jie J., Keliang L., Chow T.T., Gang P., Wei H., Hanfeng H. 2008. Performance analysis of a photovoltaic heat pump. Applied Energy 85, 680-693.
Kalogirou S.A. 2001. Use of TRNSYS for modelling and simulation of a hybrid PV-Thermal solar system for Cyprus. Renewable Energy 23, 247-260.
Kalogirou S.A. and Tripanagnostopoulos Y. 2006. Hybrid PV/T solar systems for domestic hot water and electricity production. 2006. Energy Conversion and Management 47, 3368-3382.
Kalogirou S. A. and Tripanagnostopoulos Y. Industrial application of PV/T solar energy systems. Applied Thermal Engineering 27 (8-9), pp. 1259-1270, (2007).
Karlsson B., Brogren M., Larsson S., Svensson L., Hellstrom B., Sarif Y. 2001. A large bifacial photovoltaic-thermal low-concentrating module. In Proc. 17th PV Solar Energy Conference 22-26 Oct Munich, Germany, 808-811.
Kern E.C. Jr and Russel M.C. 1978. Combined photovoltaic and thermal hybrid collector systems. Proc. of 13th IEEE Photovoltaic Specialists, Washington DC, USA, 1153 – 1157.
Kim J.H., Kim J.T. 2012. The experimental performance of an unglazed PV-thermal collector with a fully wetted absorber. Energy Procedia 30, 144-151.
Kostic Lj., Pavlovic T.M., Pavlovic Z.T. 2010. Optimal design of orientation of PV/T collector with reflectors. Applied Energy 87, 3023-3029.
Kramer K., Helmers H. 2013. The interaction of standards and innovation: Hybrid photovoltaic-thermal collectors. Solar Energy 98, 434-439.
Kritchman E.M., Friesem A.A., Yekutieli G. 1979. Efficient Fresnel lens for solar concentration. Solar Energy 1979, 22, 119-123.
Kumar S., Tiwari A. 2010. Design, fabrication and performance of a hybrid photovoltaic/thermal (PV/T) active solar still. Energy Conversion and Mngment 51, 1219-1229.
Lasnier F. and Ang T.G. 1990. *Photovoltaic Engineering Handbook*. Adam Higler, p. 258.
Leenders F. Shaap A.B, van der Helden B.G.C. 2000. Technology review on PV/Thermal concepts. In Proc. 16th European PV Solar Energy Conference, 1-5 May, Glasgow, U.K., 1976-1980.
Lorenzo E and Sala G. Hybrid silicon-glass fresnel lens as concentrator for photovoltaic applications. ISES Conf. Silver Jubilee Congress 1979, Atlanta, 536-539.
Luque A., Sala G., Arboiro J.C., Bruton T., Cunningham D., Mason N., 1998. Some results of the Eucledes photovoltaic concentrator prototype. Progress in Photovoltaics. Research and Applications 5, 195-212.
Mallick T.K., Eames P.C., Norton B. 2007. Using air flow to alleviate temperature elevation in solar cells within asymmetric compound parabolic concentrators. Solar Energy 81, 173-184.
Matuska T. 2014. Performance and economic analysis of hybrid PVT collectors in solar DHW system. Energy Procedia 48, 150-156.
Mazon R., Kaiser A.S., Zamora B., Garcia J.R., Vera F.2011. Analytical model and experimental validation of the heat transfer and the induced flow in a PV cooling duct in environmental conditions. WREC 2011, Linkoping, Sweden 8-13 May 2011, 2907-2915
Moshfegh B and Sandberg M. 1998. Flow and heat transfer in the air gap behind photovoltaic panels. Renewable & Sustainable Energy Reviews 2, 287-301.
Nayak S., Tiwari G.N. 2008. Energy and Exergy analysis of photovoltaic/thermal integrated with a solar greenhouse. Energy and Buildings 40, 2015-2021.
Nilsson J., Hakansson H., Karlsson B. 2007. Electrical and thermal characterization of a PV-CPC hybrid. Solar Energy 81, 917-928.
O'Neil M.J., Walters R.R., Perry J.L., McDanal A.J. Jackson M.C., Hess W.J. Fabrication, installation and initial operation of the 2000 sq. m. linear fresnel lens photovoltaic concentrator system at 3M/Austin (Texas). 21th IEEE PV Specialists Conference 1990, Florida, 1147 – 1152.
Notton G., Cristofari C., Mattei M., Poggi P. 2005. Modelling of a double-glass photovoltaic module using finite differences. Applied Thermal Engineering 25, 2854-2877.
Othman M.Y.H., Yatim B., Sopian K., Bakar M.N.A. 2005. Performance analysis of a double-pass photovoltaic/thermal (PV/T) solar collector with CPC and fins. Renewable Energy 30, 2005-2017.
Pantic S., Candanedo L., Athienitis A.K. 2010. Modeling of energy performance of a house with three configurations of building-integrated photovoltaic/thermal systems. Energy and Buildings 42, 1779-1789.
PVT ROADMAP, 2006. A European guide for the development and market introduction of PV-Thermal technology. www.pvtforum.org
Ries H., Gordon J.M. and Lasken M. High-flux photovoltaic solar concentrators with kaleidoscope-based optical designs. Solar Energy 1997, 60, 11-16.
Robles-Ocampo B., Ruiz-Vasquez E., Canseco_Sanchez H., Cornejo-Meza R.C., Trapaga-Martinez G., Garcia-Rodriguez F.J., Gonzalez-Hernandez J., Vorobiev Yu.Y. 2007. Photovoltaic/thermal solar hybrid system with bifacial PV module and transparent plane collector. Solar Energy Materials and Solar Cells 91, 1966-1971.
Rocamora M. C., Tripanagnostopoulos Y. 2006. Aspects of PV/T solar system application for ventilation needs in greenhouses. Acta Horticulturae 719, 239-245.

European Cooperation in the field of Scientific and Technical Research

www.cost.esf.org

Building Integration of Solar Thermal Systems – TU1205 – BISTS

REFERENCES

Rosell J.I., Vallverdu X., Lechon M.A. and Ibanez M. 2005. Design and simulation of a low concentrating photovoltaic/thermal system. Energy Conversion and Management 46, 3034-3046.
Rumyantsev V.D., Heim M., Andreev V.M., Bett A.W., Dimroth F., Lange G., Letay G., Shvarts M.Z., Sulima O.V. Concentrator array based on GaAs cells and fresnel lens concentrators. 16th European PV Solar Energy Conf. 2000, 1–5 May, Glasgow, UK, 2312-2315.
Sandness B., Rekstad J. 2002. A photovoltaic/thermal (PV/T) collector with a polymer absorber plate-experimental study and analytical model. Solar Energy 72, 63-73.
Shaw N. C. and S. R. Wenham. 16th European Photovoltaic Solar Energy Conference, 1–5 May, Glasgow, UK, 2342-2345, (2000).
Skoplaki E. Palyvos J.A. 2009. Operating temperature of photovoltaic modules:A survey of pertinent correlations. Renewable Energy 34, 23-29.
Sopian K, Liu H.T., Yigit K.S., Kakac S. and Veziroglu T.N. 1996.Perfromance analysis of photovoltaic thermal air heaters. Energy Convers. Mgmt 37(11), 1657-1670.
Souliotis M., Tripanagnostopoulos Y., Kavga A.. 2006. The use of Fresnel Lenses to reduce the ventilation needs of greenhouses. Acta Horticulturae 719, 107–113.
Tiwari A. and Sodha M.S. 2006. Performance evaluation of solar PV/T system: An experimental validation. Solar Energy 89, 751-759.
Tonui J.K and Tripanagnostopoulos Y, 2007a. Improved PV/T solar collectors with heat extraction by natural or forced air circulation. Renewable Energy 32, 623-637.
Tonui J.K and Tripanagnostopoulos Y, 2007b. Air-cooled PV/T solar collectors with low cost performance improvement. Solar Energy 81 (4), pp. 498-511
Tonui J. K. and Tripanagnostopoulos Y. Performance Improvement of PV/T solar collectors with natural air flow operation. Solar Energy 82, pp.1-12, (2008).
Touafek K., Khelifa A., Adouane M. 2014. Theoretical and experimental study of sheet and tubes hybrid PVT collector. 2014, Energy Conversion and Management 80, 71-77.
Tripanagnostopoulos Y., Nousia Th., Souliotis M. and Yianoulis P. 2002a. Hybrid Photovoltaic/Thermal solar systems. Solar Energy 72, 217-234.
Tripanagnostopoulos Y. and Souliotis M., Battisti R. and Corrado A. 2005. Energy, cost and LCA results of PV and hybrid PV/T solar systems. Progress in Photovoltaics: Research and applications 13, 235-250.
Tripanagnostopoulos Y. and Souliotis M., Battisti R. and Corrado A. 2006a. Performance, cost and Life-cycle assessment study of hybrid PVT/AIR solar systems. Progress in Photovoltaics: Research and applications 14, 65-76.
Tripanagnostopoulos Y., Siabekou Ch. and Tonui J.K. 2006b. The Fresnel lens concept for solar control of buildings. Solar Energy 81 (5), pp. 661-675, (2007).
Tripanagnostopoulos Y. Aspects and improvements of hybrid photovoltaic/thermal solar energy systems. Solar Energy 81 (9), pp. 1117-1131, (2007).
Tripanagnostopoulos Y. 2006. Cost effective designs for building integrated PV/T solar systems. Presented in 21st European PV Solar Energy Conf. Dresden, Germany 4-6 Sep 2006.
Tripanagnostopoulos. 2008. Building Integrated Concentrating PV and PV/T Systems. Proc Int Conf Eurosun, 7-10 Oct 2008, Lisbon, Portugal.
Tripanagnostopoulos Y. and Iliopoulou A. 2007. Improved designs for low concentration photovoltaics. Int Conf. 22nd PVSEC, Milan, Italy, 3-7 Sep 2007.
Tripanagnostopoulos Y., Souliotis M., Makris Th., Chemisana D. 2010. Effective Combination of Solar and Wind Energy Systems. Proc. Int Conf. Hybrid-PV and Mini Grid, Tarragona, Spain, April 2010.
Tripanagnostopoulos. Y, 2012, Photovoltaic/Thermal Solar Collectors. Comprehensive Renewable Energy, Volume 3, Chapter 8, 255–300. Oxford: Elsevier.© 2012 Elsevier Ltd).
Tyukhov I., Simakin V., Smirnov A., Poulek V. 2009. Combined PV/T system based on concentrator with vertical p-n junctions solar cells. In website proceedings of Int Workshop on Concentrating Photovoltaic Optics and Power, Darmstadt 9-10 March 2009.
Vokas G., Christandonis N., Skittides F. 2006. Hybrid photovoltaic-thermal systems for domestic heating and cooling-A theoretical approach. Solar Energy 80, 607-615.
Wolf M. 1976. Performance analyses of combined heating and photovoltaic power systems for residences. Energy Conversion, 16, 79-90.
Yoshioka K., S. Goma, S. Hayakawa and T. Saitoh, Progress in Photovoltaics: Research and Applications, Vol. 5, pp. 139 – 145, (1997).
Young F. D, Munson B. R and Okiishi T. H, 1997. A brief introduction to fluid mechanics. John Wiley & Sons, Inc. New York.
Zacharopoulos A., P. C. Eames, D. McLarnon and B. Norton, Solar Energy, Vol. 68, pp. 439 – 452, (2000).
Zondag H.A. 2008. Flat-plate PV-Thermal collectors and systems:A review. Renewable and Sustainable Energy Reviews, 12, 891-959.
Zondag, H. A., De Vries D.W., Van Helden W.G.J., Van Zolingen R.J.C. and Van Steenhoven A.A. 2002. The thermal and electrical yield of a PV-Thermal collector. Solar Energy 72, 113-128.
Zondag, H. A., De Vries D.W., Van Helden W.G.J., Van Zolingen R.J.C. and Van Steenhoven A.A. 2003. The yield of different combined PV-thermal collector designs. Solar Energy 74, 253-269.

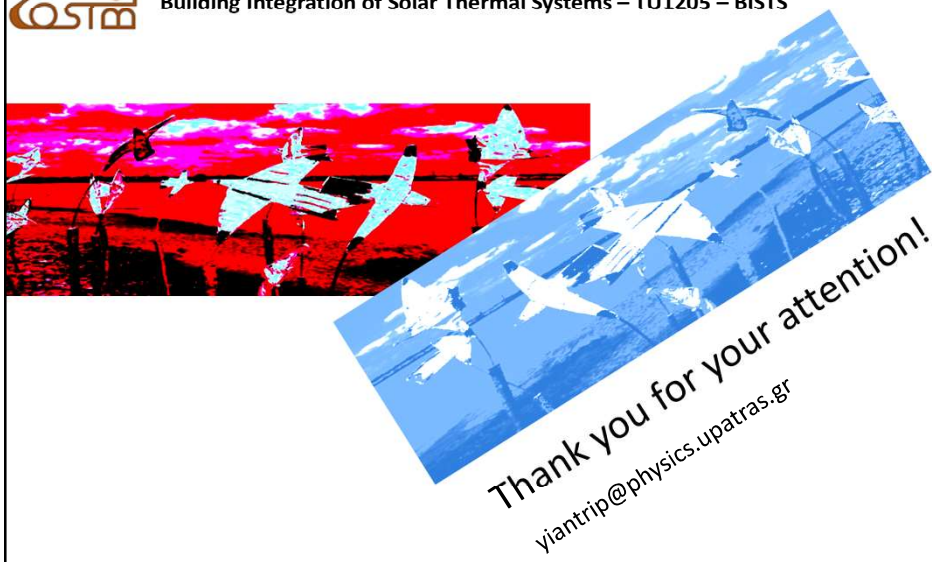
COST is supported by the EU RTD Framework Programme

ESF provides the COST Office through an EC contract

European Cooperation in the field of Scientific and Technical Research

www.cost.esf.org

Building Integration of Solar Thermal Systems – TU1205 – BISTS



COST is supported by
the EU RTD Framework Programme

ESF provides the COST Office
through an EC contract