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Building Integration of Solar Thermal Systems

Title: **Review on modelling and simulation of building-integrated solar thermal systems**

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Participants: Chr. Cappel, C. Christofi, A. Coronas, R. Mateus, M. Mckeever, Chr. Maurer, M. Kilic.

Contributors: Chr. Lamnatou, J. Mondol, A. Ghosh, D. Nikolic, M. Bojic, S. Kalogirou, D. Chemisana (WG2 leader).

Contents:

Abstract

In the present study, a literature review focusing on Building-Integrated (BI) solar systems is conducted. The review refers to systems which produce thermal, electrical or both thermal/electrical energy. Emphasis is given on the BI solar thermal systems while the solar electrical and solar thermal/electrical systems are also included in order to have a more complete picture of the current literature. The results of the review show that in the literature the greatest part of the models are thermal and/or energetic simulations of BI Photovoltaic-Thermal (PVT) (or BI PV) and skin façades. Thus, there is a need for thermal and/or energetic modelling works about BI solar thermal systems, especially for models which give emphasis to the building (since the greatest part of the investigations give emphasis to the system itself). On the other hand, the optical-models are very few and certainly, more optical-modelling studies are needed since they could provide useful information for the behaviour of the BI solar thermal systems from the optical point of view.

1. Introduction

The building sector is an energy-demand sector and the use of renewable energy technologies could provide considerable benefits. Among renewable energy systems, solar energy technologies are promising especially for countries with high solar radiation. In the frame of this concept, several solar systems have been already tested and applied in buildings. Nevertheless, there is a potential for further development and this could be achieved by adopting solar systems which are integrated into the building envelope. This specific type of systems in the literature is known as Building Integrated (BI) solar systems. BI configurations are a new tendency in the building sector and they provide several advantages given the fact that they replace a part of the building (façade, roof, etc.). Among the BI systems, solar thermal are a recent development; thereby, there is a potential for further development and this could be achieved by investigating this type of installations e.g. by means of modelling.

The present work provides an overview in terms of modelling works about BI solar thermal systems. References from the literature about BI solar thermal configurations along with other systems (which produce electrical and thermal or only electrical energy) are cited, separated into groups, based on the type of the model (thermal, energetic simulation, etc.) and based on the specific characteristics of each system (skin façade, solar thermal collector, Photovoltaic-Thermal (PVT), etc.). In this way, a complete picture of the studies available in literature is provided while the gaps in literature are identified. It should be noted that few works about systems which are Building-Added (BA) (and not real BI) are also cited for certain cases when the system/or the model is of great interest. Moreover, in some categories, some general studies (e.g. about modelling of building components) are also cited.

In the literature there are no review works about the modelling studies in the field of BI solar thermal systems and thus, the present work is an innovative study. The results of the present investigation reveal which types of models/systems are available in the current literature and which types need further development. In this way, the present work provides useful information for example for academic/research purposes while models/systems which would be interesting for future investigation are also proposed.

2. Studies of Energetic Simulation (emphasis: building)

2.1. BI, Skin Façade

1. Ciampi M., Leccese F. and Tuoni G., Ventilated facades energy performance in summer cooling of buildings, 2003: Solar Energy 75(6), 491–502.

http://dx.doi.org/10.1016/j.solener.2003.09.010

Contexts	Outcomes
An analytical, simple method for design applications → evaluation of electrical energy savings in buildings Forced (with fan) and natural ventilation cases (stack effect) were examined Reference climatic conditions: outdoor air temperature = 28^{o}C; indoor air temperature = 24^{o}C; solar radiation intensity = 400 W/m^{2}	In all cases, the energy saving increases as the air duct width increases, The positioning of the insulating material close to the inner masonry wall is more efficient than the one close to the outer facing. The energy saving increases remarkably as solar radiation intensity increases; the bigger the solar radiation is the more efficient ventilated façades turn out to be from an energy saving point of view. The energy saving increases sensibly as the difference between the outdoor and indoor temperatures decreases. The energy saving is remarkably influenced by the wall outer surface thermal resistance value and by relative roughness of the slabs delimiting the air duct.

2. Goia F., Haase M. and Perino M., Optimizing the configuration of a façade module for office buildings by means of integrated thermal and lighting simulations in a total energy perspective, 2013: Applied Energy 108, 515 – 527.

http://dx.doi.org/10.1016/j.apenergy.2013.02.063

Contexts	Outcomes
A comprehensive approach (including heating, cooling and artificial lighting energy demand) was adopted → optimization of façade configuration.	The optimal configuration of the façade module was investigated for an office building characterized by a typical

A methodology for the optimal transparent percentage in a façade module for low energy office buildings The investigation was carried out in a temperate oceanic climate (with different HVAC system efficiency) Façade module: single skin façade technology; two surfaces: a transparent part and an opaque part; the transparent surface was made of a triple glazing with low-E coatings (clear glass panes) and integrated external solar shading devices – i.e. a highly-reflective external venetian blind system (blind slate reflectivity: 80%) Aim of the search: to find the WWR (Window-to-Wall Ratio) of the façade module that minimizes the total energy demand of the building Integrated thermal-daylighting simulations The integrated thermal and daylight simulations were carried out by using the EnergyPlus software (calculations on hourly basis for the entire year).	layout, located in Frankfurt (Germany) (belongs to temperate-oceanic climate) A daylighting calculation was performed at each heat-balance time-step when the sun was up. The electric lighting control system (continuous dimming control) was simulated to determine the lighting energy needed to make up the difference between the daylighting illuminance level and the design illuminance set-point

3. Liu M., Wittchen K.B., Heiselberg P.K., Development of a simplified method for intelligent glazed façade design under different control strategies and verified by building simulation tool BSim, 2014: Building and Environment 74, 31-38.

http://dx.doi.org/10.1016/j.buildenv.2014.01.003

Contexts	Outcomes
A simplified calculation method for intelligent glazed façade under different control conditions (night shutter, solar shading and natural ventilation) was developed to simulate the energy performance and indoor environment of an office room installed with the intelligent façade. The method took into consideration the angle dependence of the solar characteristic, including the simplified hourly building model developed according to EN 13790 to evaluate the influence of the controlled façade on both the indoor environment (indoor air temperature, solar transmittance through the façade and the illuminance level on a chosen point) and the energy performance of the room.	The results were evaluated by the Danish building simulation tool BSim and they showed good correlation for indoor air temperature and solar transmittance and acceptable correlation for illuminance level, energy demands of heating, cooling, lighting and ventilation between the simplified method and BSim. The authors noted that that simplified method is a reasonable reliable tool for the early stages of an office building design process, given the fact that the model is based on hourly calculation of an office in the whole reference year.

2.2. BI, Solar Chimney

1. DeBlois J., Bilec M. and Schaefer L., Simulating home cooling load reductions for a novel opaque roof solar chimney configuration, 2013: Applied Energy 112, 142–151.

http://dx.doi.org/10.1016/j.apenergy.2013.05.084

Contexts	Outcomes
Roof solar chimney (RSC) = a low cost passive ventilation technique for reducing the energy consumption for cooling buildings This study examined the performance and the level of energy savings by simulating a detached home in four climates with RSC, cross-ventilation, and standard ventilation strategies Each case was simulated by means of ESP-r for baseline and high efficiency construction, detached homes with a single story, three bedrooms, a 189 m^2 floor plan, high thermal mass constructions PVs were integrated into the surface of the solar chimney on the South-facing roof to improve the RSC performance with their absorptive properties, and provide cooling to the reverse of the PV panels with the ventilation airflow To form the RSC, a gap under the external layer of the roof allowed airflow from the interior of the house to a plenum in the peak of the attic with vents to the outside while cross ventilation was aided with openings in the interior walls allowing flow between rooms. The ventilation gap was modelled by discretizing the RSC into 12 sections and calibrating the air-flow and convection coefficients with corresponding CFD models	The authors noted that zonal building modelling is a coarse grid numerical approach and the program ESP-r was chosen (ESP-r creates a heat flux network and an airflow network. The two are coupled by defining common zones, and solved together) Climatic conditions: four climates were chosen for the simulation. The climates ranged from Pittsburgh (relatively cool and where many houses use window air conditioners), to Phoenix (hot, arid climate and more common central air conditioning). The other two locations chosen were Albuquerque and Atlanta (with cooling requirements in between those of Pittsburgh and Phoenix). Albuquerque is a dry climate while Atlanta is a wet one. According to IECC climate zone nomenclature, Pittsburgh is 5A (moist), Albuquerque is 4B (dry), Atlanta is 3A (moist), Phoenix is 2B (dry). Typical Meteorological Year 3 (TMY3) weather data from NREL was adopted for each location

2.3. BI, Solar Shades

1. Yao J., An investigation into the impact of movable solar shades on energy, indoor thermal and visual comfort improvements, 2014: Building and Environment 71, 24 – 32.

http://dx.doi.org/10.1016/j.buildenv.2013.09.011

Contexts	Outcomes
Climatic zone: hot summer and cold winter zone of China Investigated building: a six-story residential building (2100 m^2) in Ningbo city in hot summer and cold winter zone of China which was retrofitted with external movable solar shades Modelling: a south-facing room (a typical living room in China for relaxing and socializing with a comfortable illuminance level of 100-300 lux depending on types of activity); simulation software Energyplus; building performance simulation	The building simulation study indicates that movable solar shade not only improves indoor thermal comfort in summer but also reduces dramatically extremely uncomfortable risks.

2.4. BA, Solar Cooling/heating

1. Mateus T. and Oliveira A. C., Energy and economic analysis of an integrated solar absorption cooling and heating system in different building types and climates
2009: Applied Energy 86(6), 949–957.

http://dx.doi.org/10.1016/j.apenergy.2008.09.005

Contexts	Outcomes
Integrated solar absorption cooling and heating systems for building applications. The TRNSYS software tool was used as a basis for assessment. Building types considered: residential, office, hotel TRNSYS models for a whole year in terms of combining cooling/heating and DHW applications were utilized New TRNSYS component types were created for the absorption chillers Three different locations/climates were examined: Berlin (Germany), Lisbon (Portugal), Rome (Italy)	An optimization of solar collector size and other system parameters was analysed based on the simulated results By using an integrated solar system for combined heating and cooling, it is possible to save in terms of total costs and CO_2 emissions (this is particularly true for South-European locations). The single-family house and the hotel were the cases where the solar integrated system showed a higher economic feasibility. Based on that energy costs, Rome was the only city where it was possible to achieve a break-even situation. Compared to flat-plate

	collectors, vacuum tube collectors allowed a reduction in collector area between 15 and 50%, although, due to their initial cost, flat-plate collectors had higher economic viability. In order solar cooling (and heating) to become more competitive, it is necessary the initial costs for absorption chillers and solar collectors to be lower.

2.5. General studies

1. Srebric J., Chen Q. and Glicksman L.R., A coupled airflow-and-energy simulation program for indoor thermal environment studies, 2000: ASHRAE Transactions 2000; Volume 106, Part 1, p. 929.

Contexts	Outcomes
Coupled airflow-and-energy simulation program → calculated simultaneously distributions of indoor airflow and thermal comfort and heating/cooling load Application of the program: to study thermal environment in a house and an atrium CFD and energy analysis program ACCURACY	The coupled program is capable of studying the dynamic airflow, heating/cooling load, and thermal comfort simultaneously in a space on a personal computer

2. Zhai Z., Chen Q., Haves P. and Klems J.H, On approaches to couple energy simulation and computational fluid dynamics programs, 2002: Building and Environment 37 (8–9), 857–864.

Contexts	Outcomes
Integrated energy (finite difference) and CFD (finite volume) simulation: static and dynamic coupling strategies Case studies: office in Boston; indoor auto racing complex in Pittsburgh	The coupling strategies considered were implemented by using the EnergyPlus and MIT-CFD programs

3. Studies of Energetic Simulation (emphasis: system)

3.1. BI, Skin Façade

1. J. Hensen, M. Bartak, F. Drkal, Modeling and simulation of a double-skin façade system, 2002: ASHRAE Transactions 108(2), 1251-1259.

Contexts	Outcomes
Double-Skin Façade System The airflow modeling methods considered were the mass balance network method and CFD The authors noted that network method is more suited for this type of "everyday" design support work but there are important areas where the network method in general might benefit from CFD, or vice-versa	To predict the performance of Double skin façade system constitutes a nontrivial modelling and simulation exercise that should be based on a thorough methodology and good working practice Both the network method and CFD have their own advantages and disadvantages for modelling this type of natural and hybrid ventilation systems.

2. Patania F., Gagliano A., Nocera F., Ferlito A., Galesi A., Thermofluid-dynamic analysis of ventilated facades, 2010: Energy and Buildings 42(7), 1148-1155.

http://dx.doi.org/10.1016/j.enbuild.2010.02.006

Contexts	Outcomes
Ventilated façade performance Complete thermofluid-dynamic analysis Analytical method for design applications (natural and forced convection configurations) Two-dimensional system Fluent software: finite-difference numerical solution technique based on integration over the control system Simulation for the ventilated façade considering the following climatic conditions: indoor air temperature = 297 K, temperature of the air at the inlet of the duct = outdoor air temperature = 301 K	A steady calculation method, suitable for design applications, has been illustrated to study the energy performances of ventilated façades during the summer period. The authors of that work introduced the energy saving rate ''S'' to evaluate the energetic performance of the ventilated façade. The CFD results showed: - The energy saving S augments if the solar radiation increases and thus, for constant value of the absorption coefficient and the outdoor temperature, the choice of the ventilated façade was recommended in site with high values of solar radiation. - The increase of the external air temperature resulted in decrease of the energy saving rate S due to the reduction of the effects of ventilation of the structures. - The increase of the inlet velocity caused reduction of the air temperature inside the duct and increase of the energy saving rate S.

3.2. BI, Solar Chimney

1. DeBlois J. C., Bilec M. M. and Schaefer L. L., Design and zonal building energy modeling of a roof integrated solar chimney, 2013: Renewable Energy 52, 241–250.

http://dx.doi.org/10.1016/j.renene.2012.10.023

Contexts	Outcomes
Roof integrated solar chimneys use solar radiation to heat air and induce natural ventilation through a house → they can improve the performance of roof integrated PVs by removing heat absorbed by the panels and enhance buoyant free cooling at night Unobtrusive, integrated solar chimney design in a detached single family home A method for modeling it in the zonal building energy modeling program ESP-r was proposed to assist in evaluating the design and predicting the thermal dynamics in changing ambient conditions. The model discretizes the solar chimney by dividing it into several zones CFD is used to calibrate key model inputs A sensitivity analysis evaluates model sensitivity to several inputs and assumptions The mathematical model consisted of a heat balance for nodes at each surface and in each zone and a pressure-based airflow balance. The airflow network included buoyancy forces and losses in the channel, at the inlet and at the outlet, balanced over all of the nodes The CFD model was 2D, created in ANSYS Fluent (CFD model was 2 dimensional, because the air channel was symmetric with an aspect ratio of over 30) The CFD model was more physically accurate model of heat transfer and fluid flow than the heat transfer correlation and pressure-based network used in ESP-r The model adopted a steady-state assumption and temporally constant temperature boundary conditions for the walls	The natural convection correlation selected for the walls of the channel worked well for flow driven by natural convection, but poorly for other flow modes The RSC concept shows promise as a way of providing free cooling in a house throughout the day and night, without requiring major changes in the form of the house.

3.3. BI, Trombe Wall

1. Zalewski L., Lassue S., Duthoit B. and Butez M., Study of solar walls - validating a simulation model, 2002: Building and Environment 37(1),109 –121.

http://dx.doi.org/10.1016/S0360-1323(00)00072-X

Contexts	Outcomes
Four solar wall configurations were examined: composite solar wall, Trombe wall, Insulated Trombe wall, Non-ventilated solar wall Experimental installation → measurements about thermal transfer for model validation Model: finite difference method, heat transfer was considered to be one dimensional	The model can be used to study the effect of design parameters or new materials (important for the future development of solar walls) and to compare different types of solar walls. The model is also used to study the energy efficiency of solar walls for different locations/climatic conditions

3.4. BI, PVT

1. Matuska T., Simulation Study of Building Integrated Solar Liquid PV-T Collectors, 2012: International Journal of Photoenergy 2012, 8 pages.

http://dx.doi.org/10.1155/2012/686393

Contexts	Outcomes
Simulation study on combined heat/electricity production from given BIPV-T collectors for three typical applications (5°C: primary circuits of heat pumps; 15°C: cold water preheating; 25°C: pool water preheating) was conducted Climatic conditions examined: two different European climates (warm: Athens; moderate: Prague) Mathematical model of unglazed solar flat-plate hybrid PV-T liquid collector (PVT-NEZ) based on principle theory for energy balance of solar thermal collectors expanded for photovoltaic conversion Input parameters of the model: thermal, optical, electrical, geometrical properties of PVT collector parts, climatic conditions, operation conditions Output parameters of the model: usable electric and	Main factors defining the quality of PV-T thermal performance are cooling fin quality (conductivity, thickness, and length) and bond conductance between riser pipe and cooling fin. Building integration brings a large improvement especially to low-tech PV-T collectors. While high-tech BIPV-T collector configuration shows negligible temperature difference between PV and liquid at nominal conditions A huge potential for roof applications of BIPV-T collectors instead of BIPV with 15% to 25% increase of electricity production in warm climate (Athens) and 8% to 15% increase in moderate climate (Prague). Associated heat

thermal power, output temperature of liquid, temperature of absorber surface (PV cell) Building envelope integrated installations were modelled with added adjacent envelope insulation layer of given heat resistance at the back side of PV or PVT collector with constant temperature behind considered (as interior temperature) The calculation approach of the PVT-NEZ model used external energy balance of PVT absorber (heat transfer from PVT absorber surface to ambient) and internal energy balance of PVT absorber (electric yield, heat transfer from PVT absorber surface to liquid); both balances were solved in iteration loops to find PVT absorber temperature (PV cell) and relevant heat transfer coefficients.	production is from several times to 10 times higher than electricity production. Low-tech BIPVT collectors could contribute with reduced performance level but still with considerable improvement when compared to BIPV modules without cooling.

2. Pantic S., Candanedo L. and Athienitis A. K., Modeling of energy performance of a house with three configurations of building-integrated photovoltaic/thermal systems, 2010: Energy and Buildings 42(10), 1779–1789.

http://dx.doi.org/10.1016/j.enbuild.2010.05.014

Contexts	Outcomes
Theoretical and experimental study of energy performance of three different open loop air heating BIPVT systems that utilize recovered heat for home heating: Configuration 1: base case of unglazed BIPV with airflow under it; Configuration 2: addition of 1.5 m vertical glazed solar air collector in series with Configuration 1; Configuration 3: addition of a glazing over the PV The model developed was verified against experimental data from a solar research house for Configuration 1 A mathematical model has been implemented in MathCad 2001i for the three BIPVT configurations A control volume formulation has been applied The partial differential equation for air and rock temperatures was solved numerically by explicit finite difference method	Mathematical models have been developed for - Unglazed BIPVT roof. - Unglazed BIPVT roof connected to a glazed solar air collector - Glazed BIPVT roof The obtained relationships for the BIPVT system exiting air temperature as function of solar irradiance and air speed in PV cavity may be used for developing fan airflow control strategies to achieve desired outlet air temperature for different applications. For the case of Configuration 1, preheated air was suitable for HVAC system and domestic hot water (DHW) preheating. Higher outlet air temperatures of PV cavity suitable for DHW might be achieved by Configurations 2 or 3. With

Region of the solar house: Concordia, Canada	Configuration 2, significant outlet air temperatures were achieved in winter along with enhanced thermal efficiency making it suitable for coupling with a rockbed heat storage unit. Configuration 3 significantly reduced electricity production and may lead to excessively high PV temperatures.

3. Davidsson H., Perers B. and Karlsson B., Performance of a multifunctional PV/T hybrid solar window, 2008: Solar Energy 84(3), 365 –372.
http://dx.doi.org/10.1016/j.solener.2009.11.006

Contexts	Outcomes
A BI multifunctional PV/T collector was developed and evaluated: the PVT solar window was constructed from PV cells laminated on solar absorbers and it was placed in a window behind the glazing → to reduce the costs of the solar electricity, reflectors were added to focus radiation onto the solar cells	A model for the simulation of the electric and hot water production was developed: the model could perform yearly energy simulations where different effects such as shading of the cells or effects of the glazing could be included or excluded The simulation program was calibrated against measurements of a prototype solar window placed in Lund in the south of Sweden and against a solar window built into a single family house, Solgården, in Älvkarleö in the middle of Sweden TRNSYS was adopted for some cases

4. Delisle V. and Kummert M., A novel approach to compare building-integrated photovoltaics/thermal air collectors to side-by-side PV modules and solar thermal collectors, 2014: Solar Energy 100, 50 –65.

http://dx.doi.org/10.1016/j.solener.2013.09.040

Contexts	Outcomes
Case study of 40 m^2 south-facing roof located in Montreal, Canada Simulation was done for BIPV/T air system and side-by-side PV modules and liquid solar thermal collectors (PV + T) using TRNSYS A new methodology was developed to deal with the	For a conversion factor of 2, the BIPV/T system was found to produce 5–29% more equivalent useful thermal energy than the PV + T system

challenge of comparing different types of energy. In this novel methodology, the two systems are operated based on criteria for thermal energy usefulness and the thermal energy collected is transferred into water using a heat exchanger. The concept of equivalent useful thermal energy production was adopted to combine the electrical and the thermal energy produced. To demonstrate the usefulness of that approach, a case study for a residence was performed by the authors.	

5. F. Ghani, M. Duke, J.K. Carson, Estimation of photovoltaic conversion efficiency of a building integrated photovoltaic/thermal (BIPV/T) collector array using an artificial neural network, 2012: Solar Energy 86, 3378–3387.

http://dx.doi.org/10.1016/j.solener.2012.09.001

Contexts	Outcomes
BIPVT dimensions are related with specific roofing and energy requirements of the customer; thus, the issue of flow distribution and its effect on both thermal and PV performance it is important. In order to quantify the effect of flow distribution on PV output of a BIPVT array, a numerical approach was developed by authors in a previous work. That study was numerical and the authors calculated PV output. However, that method was time consuming and computationally intensive. To address this issue, the authors proposed in this paper an artificial neural network which can be used to approximate the PV yield of an array of specified shape operating under parallel/reverse flow in the manifolds and also with one or two fluid channels cooling each string of cells.	By approximating the yield for each scenario, the optimal configuration can then be selected. It was found that the neural network can be successfully trained for this specific case offering a fast alternative to the original numerical approach.

3.5. BI, PV

1. Yoo S.-H., Simulation for an optimal application of BIPV through parameter variation, 2011: Solar Energy 85(7), 1291–1301.

http://dx.doi.org/10.1016/j.solener.2011.03.004

Contexts	Outcomes
The efficiency of a BIPV system as a shading device was examined at different months	The efficiency of the BIPV system as a shading device is seen to vary greatly in

Weather data: Suwon area, Korea The simulation program SOLCEL, for the calculation of a shading/sunlit area on solar cell module and façade, surface temperature of solar cell module, effective solar irradiance on solar cell module, the power generation of a BIPV as a shading device, was developed and validated.	different months. The simulation and experimental results for over surface temperature of solar cell module vary slightly under a higher solar irradiance condition.

2. Electrical/Energetic simulation (emphasis: system)
Stamenic L., Smiley E. and Karim K., Low light conditions modelling for building integrated photovoltaic (BIPV) systems, 2004: Solar Energy 77(1), 37-45

http://dx.doi.org/10.1016/j.solener.2004.03.016

Contexts	Outcomes
Low irradiance efficiency of PV modules was examined (low light level dependence of PV module efficiency is very important for accurate modeling of BIPVs, especially in northern latitudes and in climates with significant cloud cover). A new model for photovoltaic module performance was developed based on the single diode model of a solar cell, but introduced a single lumped parameter to the ideal diode equation to characterize the non-ideal characteristics of the cell. The model was first applied to the open circuit voltage data collected for a solar module operating under conditions in which low irradiance contributed a large percentage of energy to the total annual energy production. Once the validity of the model was verified for modeling open circuit voltage the model was applied to a more comprehensive model which calculated the total power production on an hourly basis over several days.	The proposed model was able to accurately predict the actual energy production of a test system (at British Columbia Institute of Technology (BCIT)). Region of the experimental set-up: BCIT, Burnaby, Canada The model is capable of modelling the performance of photovoltaic systems that produce a large percentage of their total energy at low irradiance conditions.

3. Fara L., Moraru A.G., Sterian P., Bobei A.P., Diaconu A. and Fara S., Building Integrated Photovoltaic (BIPV) systems in Romania. Monitoring, modelling and experimental validation, 2013: Journal of Optoelectronics and Advanced Materials 15(1-2), 125-130.

Contexts	Outcomes
Performance analysis of a BIPV system developed in Romania and mounted on the building of the Polytechnic University of Bucharest (PUB) The estimation of the energy production of the BIPVs, on a short term period (two days), was considered Short-term solar irradiation forecasts are elaborated in two ways, based on meteorological experimental datasets Forecasting tests were run using Autoregressive Integrated Moving Average (ARIMA) models.	Artificial neural network (ANN) techniques were also evaluated (based on meteorological variables) in order to enhance the forecasts of solar irradiation

4. Muresan C., Ménézo C., Bennacer R. and Vaillon R., Numerical Simulation of a Vertical Solar Collector Integrated in a Building Frame: Radiation and Turbulent Natural Convection Coupling, 2006: Heat Transfer Engineering, 27(2), 29-42.

DOI:10.1080/01457630500397658

Contexts	Outcomes
Vertical double skin PV façade (a tall PV module located at a fixed distance from a vertical wall of a building): elementary study During winter, fresh air is aspired by the air supply system; during the summer, supporting thermal chimney effect so as to cool PV The collector is subjected to direct and indirect sun irradiation while the space between the wall and the collector forms a channel, at the bottom of which air is admitted and buoyancy-driven convection is developed Damping functions were inserted in the kinetic energy of the turbulence dissipation (ε) equation to account for viscous and wall-damping effects A finite volume scheme with a second-order discretization method for both advection and diffusion terms was applied; pressure correction method was adopted; the resolution was performed by using the SIMPLER algorithm	Preliminary results of coupled heat transfer for the whole collector were proposed by using gray radiation properties. For that specific case, it seemed that the turbulent regime appeared very close to vertical channel outlet. From all of these results, it is was concluded that further work is needed in order to include realistic variations of radiation properties, including photoelectric effects and sun irradiation, so that a complete parametric study will allow extracting the best strategy to integrate PVs to buildings.

Coupling of radiation heat transfer with conduction in the collector cover and overall coupling with thermo-aerodynamics phenomena in the air channel	

5. Mondol J. D., Yohanis Y. G., Smyth M. and Norton B., Long-term validated simulation of a building integrated photovoltaic system, 2005: Solar Energy 78, 163–176.

http://dx.doi.org/10.1016/j.solener.2004.04.021

Contexts	Outcomes
The PV array was roof mounted facing due south at an inclination 45° and was located in Ballymena, Northern Ireland The electrical and thermal performance of the BIPV system was predicted using TRNSYS. A new component model has been developed for modeling inverter output and modifications were made to standard TRNSYS types for global-diffuse correlation and PV module temperature Statistical analysis was performed with the measured and predicted data for three global-diffuse correlations and four tilted surface radiation models to find those best for estimating the beam and diffuse components of the horizontal insolation and total, beam and diffuse components of insolation at the inclined PV surface, respectively Measured and simulated electrical PV outputs were compared on daily basis	Developed TRNSY type for inverter has been validated with measured data. The results revealed that modification of global-diffuse correlation and module temperature prediction improved the overall accuracy of the simulation model. The monthly error between measured and predicted PV output was below 16%. Over the period of simulation, the monthly average error between the measured and the predicted PV output was 6.79% while the monthly average error between measured and predicted inverter output was found to be 4.74%.

6. J.-H. Yoon, J. Song, S.-J. Lee, Practical application of building integrated photovoltaic (BIPV) system using transparent amorphous silicon thin-film PV module, 2011: Solar Energy 85(5), 723-733.

http://dx.doi.org/10.1016/j.solener.2010.12.026

Contexts	Outcomes
An analysis has been carried out on the first practical application in Korea of the design and installation of building integrated photovoltaic (BIPV) modules on the windows covering the front side of a building by using transparent thin-film amorphous silicon solar	From simulating influencing factors such as azimuth and shading, the measured energy generation efficiency in the tested condition can be improved up to 47% by changing the building location in

cells. This analysis was performed through long-term monitoring of performance for 2 years. Electrical energy generation per unit power output was estimated through the 2 year monitoring of an actual BIPV system.	terms of azimuth and shading, thus allowing better solar radiation for the PV module. From the real application of the BIPV system, the installation of a PV module associated with azimuth and shading can be said to be the essentially influencing factors on PV performance Both factors can be useful design parameters in order to optimize a PV system for an architectural BIPV application.

7. T. Dwi Atmajaa, Façade and rooftop PV installation strategy for building integrated photo voltaic application, 2013: Energy Procedia 32, 105-114.

http://dx.doi.org/10.1016/j.egypro.2013.05.014

Contexts	**Outcomes**
Building integrated photo voltaic (BIPV) is an emerged research topic to optimize building component replacement using certain types of photo voltaic (PV) module. This paper conducts a strategic review on the optimum PV module installation to generate electricity from the building envelope. The façades and rooftops would be an object of building envelope to be deposited with a specific characteristic installation of PV module.	Recent calculations of the inclination angle of attaching the PV module in the selected walls indicates that an optimum angle in horizontal and vertical inclination. The calculation also uses installation distance to module length ratio to achieve a greater solar insulation on the PV modules. Other calculation also performed to observe effective load carrying capacity (ELCC) against PV penetration level to perceive the optimum PV penetration level for high ELCC without resulting operational problems.

8. D. Masa-Bote, E. Caamaño-Martín, Methodology for estimating building integrated photovoltaics electricity production under shadowing conditions and case study, 2014: RenewableandSustainableEnergyReviews31, 492–500.

http://dx.doi.org/10.1016/j.rser.2013.12.019

Contexts	Outcomes
The electricity losses due to shadows over PV generator have an impact on the performance of BIPV systems (electricity losses). In the frame of that work a methodology to estimate electricity produced by BIPV systems which incorporated a model for shading losses, was developed. The methodology was validated by means of one-year experimental data from two similar PV systems (BI on the roof) of a building which belongs to the Technical University of Madrid. The study included several weather conditions: clear, partially overcast, fully overcast sky.	The errors by the best performing model were less than 1% and 3% in annual and daily electricity estimation. The adoption of models which account for the reduced performance at low irradiance levels also improved the estimation of generated electricity. The authors noted that the proposed methodology is simple, easy-to-use and can provide fast/accurate results at low costs. Also it could be applied for PV systems which are not BI.

3.6. BI, CPV

1. E. F. Fernández, F. Almonacid, N. Sarmah, P. Rodrigo, T.K. Mallick, P. Pérez-Higueras, A model based on artificial neuronal network for the prediction of the maximum power of a low concentration photovoltaic module for building integration, 2014: Solar Energy 100, 148 –158.

http://dx.doi.org/10.1016/j.solener.2013.11.036

Contexts	Outcomes
Low concentration photovoltaic (LCPV) modules for BI are studied. The aim of that work was the development of an accurate model based on artificial neural networks (ANNs) to predict the maximum power (P) of a LCPV module for building integration under real conditions.	The model takes into account all the main important parameters that influence the electrical output of these systems: direct irradiance, diffuse irradiance, module temperature and the transverse and longitudinal incidence angles. The proposed model can be used for estimating the maximum power of a BI LCPV module with an adequate margin of error: R2 = 0.99. The ANN model had accurate performance for days in which the maximum power was mainly given by direct irradiance (clear days) and also for days in which the maximum power was mainly given by diffuse irradiance (cloudy days). Nevertheless, the

	performance of the artificial network based model had poorer results for the diffuse irradiance component than for the direct irradiance component. Despite this fact, the ANN based model can predict the maximum power of a BI LCPV module with an adequate degree of accuracy.

3.7. BA, Solar Cooling

1. K.F. Fong, C.K. Lee, T.T. Chow, Comparative study of solar cooling systems with building-integrated solar collectors for use in sub-tropical regions like Hong Kong, 2012: Applied Energy 90, 189–195.

http://dx.doi.org/10.1016/j.apenergy.2011.06.013

Contexts	Outcomes
The performance of solar cooling systems with building-integrated (BI) solar collectors was simulated and the results compared with those having the solar collectors installed conventionally on the roof based on the weather data in Hong Kong. Two types of solar collectors and the corresponding cooling systems, namely the flat-plate collectors for absorption refrigeration and the PV panels for DC-driven vapour compression refrigeration, were used in the analysis.	It was found that in both cases, the adoption of BI solar collectors resulted in a lower solar fraction (SF) and consequently a higher primary energy consumption even though the zone loads were reduced. The reduction in SF was more pronounced in the peak load season when the solar radiation was nearly parallel to the solar collector surfaces during the daytimes, especially for those facing the south direction. It was concluded that the use of BI solar collectors in solar cooling systems should be restricted only to situations where the availability of the roof was limited or insufficient when applied in sub-tropical regions like Hong Kong.

3.8. General studies

1. Athienitis A., Modeling and Simulation of Passive and Active Solar Thermal Systems, 2012: Reference Module in Earth Systems and Environmental Sciences
Comprehensive Renewable Energy, 357–417, Volume 3: Solar Thermal Systems: Components and Applications.

http://dx.doi.org/10.1016/B978-0-08-087872-0.00311-5

Contexts	Outcomes
That chapter presented major passive solar technologies and systems, followed by in-depth sections on their modeling (using both analytical and numerical models) More recent developments were described with a focus on BIPVs and net-zero energy solar homes	Various design methods were presented as well as an overview of the simulation techniques and programs suitable for active solar heating as well as cooling systems The software programs described briefly in that chapter included F-chart, TRNSYS and WATSUN

2. T. Hwang, S. Kang, J. T. Kim, Optimization of the building integrated photovoltaic system in office Buildings - Focus on the orientation, inclined angle and installed area, 2012: Energy and Buildings 46, 92-104.

http://dx.doi.org/10.1016/j.enbuild.2011.10.041

Contexts	Outcomes
This study aims to analyze the maximum electric energy production according to the inclination and direction of photovoltaic (PV) installations and the effects of the installation distance to the module length ratio. The annual solar insolation on PV panels was calculated for various façades of two buildings, and an analysis of different horizontal and vertical inclinations of PV panels was also conducted in consideration of the effects of panel shading from other panels and surrounding buildings.	As a result, the electric energy production due to the use of the PV system can cover approximately 1–5% of the electric energy consumption of a typical office building in Korea in terms of proper combinations of the following installation factors: inclination, module type, installation distance to module length ratio, and direction. The research estimated the proportion of power generation by BIPV systems according to different types of PV modules and installation methods. The data could serve as a useful reference for the application of BIPV systems in buildings.

3. S. Sharples, H. Radhi, Assessing the technical and economic performance of building integrated photovoltaics and their value to the GCC society, 2013: Renewable Energy 55, 150-159.

http://dx.doi.org/10.1016/j.renene.2012.11.034

Contexts	Outcomes
This paper assesses the technical and economic performance of PV technology integrated into residential buildings in the Gulf Cooperation Council (GCC) countries.	Through a systematic modelling analysis it is shown that the efficiency of PV system drops by 4-6% due to high range of module temperature and also a change in power output due to high ambient temperatures. Consequently, the outputs of horizontal and vertical PV modules are found to be less than estimates based on standard test conditions. Economically, this study shows that building integrated photovoltaic (BIPV) systems are not viable in GCC countries and cannot compete with conventional electricity sources on a unit cost basis.

4. W. Zhou, H. Yang, Z. Fan, A novel model for photovoltaic array performance prediction, 2007: Applied Energy 84, 1187–1198.

http://dx.doi.org/10.1016/j.apenergy.2007.04.006

Contexts	Outcomes
Based on the I–V curves, a novel and simple model was proposed. In order to validate the model, field measured data from one existing BIPV in Hong Kong was adopted and good agreements between simulated results/field data was found.	Five parameters were introduced to take account of all the non-linear effect of the environmental factors on PV module performance Model accuracy was demonstrated by comparing the predictions with the field data. The model was verified for several meteorological conditions (sunny, cloudy, four seasons). The results demonstrate acceptable accuracy of the model for modeling PV array outputs over various environmental conditions.

5. Kim J., Adaptive façade design for the daylighting performance in an office building: the investigation of an opening design strategy with cellular automata, 2013, International Journal of Low-Carbon Technologies 1-8.

doi: 10.1093/ijlct/ctt015

Contexts	Outcomes
The objective was the development of an innovative façade design strategy that comes from the development of digital technology and dynamic daylight performance measuring methods. The parameters were studied through the computational process of cellular automata (CA) to generate the several alternative opening patterns on building façade.	Each CA design value was tested under static and dynamic sky condition in order to analyze the quality and quantity of daylight and visual comfort over the year. The proposed CA system allowed changing the average opacity of building façade and tool advantage from the generative behavior for esthetics. The visualized daylight analysis maps with numeric data helped for the searching of the adaptive façade design.

6. T. Hong, C. Koo, J. Park, H. S. Park, A GIS (geographic information system)-based optimization model for estimating the electricity generation of the rooftop PV (photovoltaic) system, 2013: Energy, 1-10.

http://dx.doi.org/10.1016/j.energy.2013.11.082

Contexts	Outcomes
A sensitivity analysis on how the impact factors of the rooftop PV system affect its electricity generation was conducted. That study aimed to ultimately develop a GIS-based optimization model for estimating the electricity generation of a rooftop PV system.	Several impact factors were adopted in the sensitivity analysis. The result of this study showed that there were 1.12-, 1.62- and 1.37-fold differences in the annual electricity generation of the rooftop PV in South Korea due to the regional factor, the azimuth of the installed panel and the slope of the installed panel, respectively.

7. Lin Lu and Yang H. X., A study on simulations of the power output and practical models for Building Integrated Photovoltaic systems, 2004: Journal of Solar Energy Engineering 126(3), 929-935.

doi:10.1115/1.1701883

Contexts	Outcomes
A simple, practical, accurate model for describing the characteristics of PV power output was developed (describing I-V characteristics of PV modules according to the equivalent circuits of solar cells, by which an accurate but complicated model of the maximum power output (MPO) can be achieved).	Taking that MPO model as benchmark, two other application models from other studies were evaluated and examined. A simplified application model for describing the maximum PV power output was then derived from the results of the simulation. Once solar radiation on PVs and ambient

	temperature are known, the power output of BIPV systems or PV systems can be calculated accurately and easily.

8. S. Karthikeyan, G. Ravikumar Solomon, V. Kumaresan, R. Velraj, Parametric studies on packed bed storage unit filled with PCM encapsulated spherical containers for low temperature solar air heating applications, 2014: Energy Conversion and Management 78, 74 –80.

http://dx.doi.org/10.1016/j.enconman.2013.10.042

Contexts	Outcomes
(PCM) encapsulated spherical containers for low temperature solar air heating applications. Parametric analysis was performed using validated enthalpy based numerical model that considers the thermal gradient inside the PCM container.	The results of the simulations showed that the size of the PCM ball, fluid inlet temperature and mass flow rate of the heat transfer fluid (HTF) influenced respectively the heat transfer area in the packed bed, temperature difference between the HTF and PCM and the surface convective heat transfer coefficient between HTF and PCM balls. The poor thermal conductivity of the PCM had only negligible effect on heat transfer because of high surface convective resistance provided by the air. The influence of various parameters for the selected range of values were analyzed using the charging time, instantaneous heat stored and cumulative heat stored during the charging process.

4. Studies of Energetic Simulation (emphasis: building/system)

4.1. BI, Skin Façade

1. Saelens D., Roels S. and Hens H., The inlet temperature as a boundary condition for multiple-skin façade modeling, 2004: Energy and Buildings 36 (8), 825–835.

http://dx.doi.org/10.1016/j.enbuild.2004.01.005

Contexts	Outcomes
The results of numerical models for multiple-skin façades (MSFs) are very sensitive to inlet temperature	By analysing the influence of the inlet temperature, this work showed that a

→ to illustrate this, a sensitivity study on mechanically and naturally ventilated façade was conducted by means of a numerical model (cell-centred finite volume method) - MSF model was also coupled to TRNSYS → energy performance analysis - MSF model and building model - Climatic conditions: Belgium, February	reliable energy assessment needs a correct implementation of the boundary conditions and modelling parameters. Measurements showed that the assumption of an inlet temperature equal to the interior or exterior air temperature was usually not valid. A sensitivity study revealed the significance of the inlet temperature as a boundary condition for numerical multiple-skin façade models. Models to estimate the inlet temperature should take the heating and cooling because of contact with the bounding surfaces and heating due to solar radiation. In addition, the effects of a change of the airflow rate have to be considered.

2. R. Høseggen, B.J. Wachenfeldt, S.O. Hanssen, Building simulation as an assisting tool in decision making Case study: With or without a double-skin façade?, 2008: Energy and Buildings 40, 821–827.

http://dx.doi.org/10.1016/j.enbuild.2007.05.015

Contexts	Outcomes
A planned office building in the city-centre of Trondheim, Norway, was adopted as case for considering whether a double-skin should be applied to the east façade in order to reduce the heating demand, thus making the double-skin façade a profitable investment. The building was modeled both with and without a double-skin façade (building energy simulation program ESP-r). That work described how a double-skin façade with controllable windows and hatches for natural ventilation can be implemented in the simulation program.	Simulation results showed that the energy demand for heating was about 20% higher for the single-skin façade with the basic window solution compared to the double-skin alternative. Nevertheless, by switching to windows with an improved U-value in the single-skin alternative, the difference in energy demand was almost evened out. The number of hours with excessive temperatures was not significantly higher for the double-skin alternative. However, the predicted energy savings were not sufficient in order to make the application of a double-skin façade profitable.

4.2. BI, Trombe Wall

1. Bojic M., Johannes K. and Kuznik F., Optimizing energy and environmental performance of passive Trombe wall, 2013, Energy and Buildings 70, 279 – 286.

http://dx.doi.org/10.1016/j.enbuild.2013.11.062

Contexts	Outcomes
Energy and environmental performance: buildings with and without Trombe walls Two Trombe walls were adopted at the south side of a "Mozart" house located in Lyon, France. The house satisfied the French thermal regulation The simulation was conducted by using EnergyPlus, Genopt and parametric algorithm	The results showed that the building with Trombe walls in Lyon, France, by using solar energy may save around 20% operating energy during heating compared to that used by the building without Trombe walls. The environmental impact of the buildings was also examined.

4.3. BI, PVT

1. Kim J.H., Kim J.T., A simulation study of air-type building-integrated photovoltaic-thermal system2012: Energy Procedia 30, 1016 – 1024

http://dx.doi.org/10.1016/j.egypro.2012.11.114

Contexts	Outcomes
TRNSYS simulation was performed The electrical and thermal performance of air type BIPVT system was evaluated The energy performance of a building was calculated considering air type BIPVT as a building envelop.	It was concluded from the simulation result that BIPVT system was more efficient compared to BIPV system without ventilation.

4.4. BI, PV

1. Chow T. T., Fong K. F., He W., Lin Z. and Chan A. L. S., Performance evaluation of a PV ventilated window applying to office building of Hong Kong, 2007: Energy and Buildings 39, 643–650.

http://dx.doi.org/10.1016/j.enbuild.2006.09.014

Contexts	Outcomes
An energy model of a PV ventilated window system was developed, based on TMY weather data for Hong Kong	The energy model of the PV ventilated window system was first introduced. Based on that together with TMY

Energy model of the PV ventilated window: 2D computer model Performance analysis of application: small office: 3 m × 3 m × 3 m cubicle office within the perimeter zone of an office building; indoor temperature set points = 22°C in winter (from November to April next year) and 25°C in summer (from May to October) The simulation results on daylight saving were obtained by using EnergyPlus simulation software	weather data for Hong Kong and the daylight simulation capability of the EnergyPlus program, the overall performance analysis was executed for different window orientations. It was found that a solar cell transmittance from 0.45 to 0.55 could achieve the best electricity saving.

2. J. Pérez-Alonso, M. Pérez-García, M. Pasamontes-Romera, A.J. Callejón-Ferre, Performance analysis and neural modelling of a greenhouse integrated photovoltaic system, 2012: Renewable and Sustainable Energy Reviews 16(7), 4675-4685.

http://dx.doi.org/10.1016/j.rser.2012.04.002

Contexts	**Outcomes**
Greenhouses can include added capabilities for the energy generation by the integration of photovoltaic solar modules in their cladding provided that the blocking effect of photo-synthetically active radiation is not significant for plants growing. This work describes the results of an experience carried out at Almería (South Eastern Spain), where it has been built and monitored a 1.024 m^2 pilot photovoltaic green house. The experimental setup has consisted of a green house roof 9.79% coverage ratio by means of 24 flexible thin film modules, installed in two different checker board configurations.	The obtained results indicate that, for the conditions of the undertaken experiment, they early electricity production normalised to the green house ground surface is 8.25 kWh/m^2, concordant to previous findings for the used type of modules. An artificial neural network model has been elaborated to predict the electricity instantaneous production of the system, showing the suitability of this modelling technique for complex and non linear systems, as it is the case of the constructively integrated PV plants, either in green houses and buildings, where both impinging radiation and system configuration are highly constrained by the pre-existing structures.

3. T.T. Chow, J.W. Hand, P.A. Strachan, Building-integrated photovoltaic and thermal applications in a subtropical hotel building, 2003: Applied Thermal Engineering 23, 2035–2049.

http://dx.doi.org/10.1016/S1359-4311(03)00183-2

Contexts	Outcomes
Comparative study of three different options in applying large-scale BIPVs in a coastal city at the South China Sea. The computational model was based on a 260 m^2, mono-crystalline Si PV wall of a 30-storey hotel. The numerical analysis was conducted by ESP-r building energy simulation software.	The results revealed that the different design options exhibit short-term electrical performance differences, but they have similar long-term electricity yields. Nevertheless, some configurations performed much better in terms of reducing building air-conditioning loads.

4. C. Hachem, A. Athienitis, P. Fazio, Energy performance enhancement in multistory residential buildings, 2014: Applied Energy 116, 9–19.

http://dx.doi.org/10.1016/j.apenergy.2013.11.018

Contexts	Outcomes
The effect of increasing residential density in multistory buildings on the overall solar potential and energy use of these buildings was examined. Hourly direct solar radiation was computed by EnergyPlus (ASHRAE model of clear sky applied to Montreal) The Equivalent One-Diode Model (or ‘‘TRNSYS PV’’ model, EnergyPlus) was adopted to perform electricity generation	Apartment buildings/passive solar configurations were adopted: low, mid-, high- rise. All integration of PV systems in façades, in addition to roof surfaces was considered. The study revealed that investment in advanced design of façades (such as folded-plate curtain walls) can substantially increase the production of electricity and it can achieve net zero and surplus energy status in building over eight stories high.

4.5. General Studies

1. Clarke J.A, Johnstone C., Kelly N. and Strachan P. A., The simulation of Photovoltaic-Integrated building facades, 1997: 5th IBPSA Conference: Sept. 8-10, Prague, Czech

Contexts	Outcomes
Extension to the ESPr system: simulation of façade and roof-integrated PVs The algorithms were for predicting electrical power output as a function of module characteristics, incident solar radiation and module temperature. The integration of the algorithm within ESP-r air and power flow network models, to facilitate hybrid photovoltaic system studies was described	Integration with within the ESP-r → aspects of coupling: assignment of special behavior to multilayered construction nodes in order to transform some part of their absorbed solar energy to electricity; use of an air flow network to transport heat from nodes designated as PV cells and deliver this heat to intra-building locations via

Building: initially located within the UK and then, in a warmer European climate corresponding to northern Italy	heat exchangers or directly; use of an electrical power flow network for modeling of local electricity use and co-operative switching with the grid

2. Kelly N. J., Towards a design environment for building integrated energy systems: the integration of electrical power flow modelling with building simulation, 1998: MSc thesis, Department of Mechanical Engineering. Energy Systems Research Unit University of Strathclyde, Glasgow, UK

Contexts	Outcomes
Power flow modeling: coupling the electrical network to the rest of the building model could be conducted by using 'hybrid' components that also exist in other energy subsystems of the building model. These hybrid components can supply the power flows necessary for the solution of the electrical network → integration of the electrical network solver into ESP-r flexible, modular simultaneous solution process	Component models for BI energy systems simulation: various component types could be added to ESP-r for use in the integrated simulation of the electrical network and BI energy systems: the electrical conductors and transformers which couple the control volumes in the electrical network; the hybrid load and the plant components which draw power from the electrical network, while simultaneously affecting thermophysical conditions in other parts of building network; the hybrid and the plant components could be used in the modeling of BI energy systems Verification of the electrical network solver and hybrid model calibration

3. Kim K. H. and Han S. H., Integrated Towers: High Performance Facades, 2012: Conference WREF 2012, CO, US, 13-17 May.

Contexts	Outcomes
The analysis was based on the case study of high-rise integrated towers located in two different climate zones: Aurora Tower in Kuala Lumpur, Malaysia located in Climate Zone 1A; New York Times building in New York City located in Climate Zone 4A That research adopted the integration of BIM (building information modeling) and energy simulation tool to facilitate workflow of 3D modeling and energy performance verification of building façades	The authors noted that integration of BIM and energy simulation tool provides timely efficient energy verification and offers a powerful framework toward solving many problems in contemporary building sustainability

The work focused on three areas: heat gain, daylighting control benefits and solar energy potentials from building façades	

4. M. Bojić, M. Miletić, D. Cvetković, Optimization of size of overhangs with and without solar collectors, 2013: 26 th International Conference ECOS, Guilin, Guangxi, China, 2013, 16-19 July.

http://is.mfkg.kg.ac.rs/podaci/Dragan_Cvetkovic/106/D069final.pdf

Contexts	Outcomes
This paper presents the results of the optimization of the size of overhangs with and without solar collectors for two summer houses that operate during a cooling season in Serbia. The first house only has overhangs. The second house has overhangs covered by solar collectors. They are simulated and optimized by using EnergyPlus and Hooke Jeeves algorithm for their cooling season operation. Then, optimal depths of the overhangs are found.	The objective function serves to minimize the primary energy consumption needed for sanitary water heating and space cooling of the house, and amount of embodied energy in overhangs and solar collectors. Results show that overhangs depth depends on the use of solar collectors. Their depths also depend on their orientation.

5. N. Aste, R. S. Adhikari, L. C. Tagliabue , Solar integrated roof: Electrical and thermal production for a building renovation, 2012: Energy Procedia 30, 1042-1051.

http://dx.doi.org/10.1016/j.egypro.2012.11.117

Contexts	Outcomes
Solar renovation of a training Centre at Casargo, Lecco, Italy. The technology used for the roof refurbishment is an innovative system called TIS (Tetto Integrale Solarizzato); which means solar integrated roof. TIS is a modular covering system with the option to insert the various types of solar energy modules, providing most suitable dimension and configuration for a specific application.	The prototype of TIS system was presented. This paper presents the design details, energy performance and economic evaluation of solar integration roof of Casargo. The building is under monitoring phase. A comparison has been made between the monitored and simulated energy performance data.

6. S. A. Kalogirou, M. Bojic, Artificial neural networks for the prediction of the energy consumption of a passive solar building, 2000: Energy 25, 479–491.

http://dx.doi.org/10.1016/S0360-5442(99)00086-9

Contexts	Outcomes
Artificial neural networks (ANNs) were adopted for the prediction of the energy consumption of a passive solar building. Building thermal behavior was evaluated by using a dynamic thermal building (finite volumes and time marching).	The ANN modeling was able to predict the energy consumption of a building with acceptable accuracy. The application of ANNs revealed that it is possible to model such systems with a minimum amount of input data, thus providing the designer of such systems with the flexibility to test a number of systems quickly.

7. L. F. Sim, Numerical modelling of a solar thermal cooling system under arid weather conditions, 2013: Renewable Energy, In press.

http://dx.doi.org/10.1016/j.renene.2013.11.032

Contexts	Outcomes
A study about thermal cooling for an office (weather conditions: Doha, Qatar). The simulations were performed by using TRNSYS. Studied parameters: solar collector area, collector slope, tank volume, water flow rate, heat exchanger effectiveness.	The results revealed that the optimum system for 4.5 kW adsorption cooling required 23.4 m^2 evacuated tube collector titled at 24^o from horizontal with a water storage tank of 0.3 m^3. The adsorption cooling system can reduce the electricity consumption by 47% in comparison with a compression cooling system.

8. A. Colmenar-Santos, J. Vale-Vale, D. Borge-Diez, R. Requena-Pérez, Solar thermal systems for high rise buildings with high consumption demand: Case study for a 5 star hotel in Sao Paulo, Brazil, 2014: Energy and Buildings 69, 481–489.

http://dx.doi.org/10.1016/j.enbuild.2013.11.036

Contexts	Outcomes
Solutions for solar water installations in high rise buildings were studied. The integration of solar collectors into the building, hot water distribution installation and solutions to minimize the risk of exposure to Legionella, were examined. The requirements of solar thermal in developing countries were examined: solar hot water standards in Brazil (Sao Paulo). Software adopted: RETScreen	The proposed solutions for solar hot water systems for the case of high rise building applications minimize the issues with the pressure distribution due to the height of the building. A case study about a 5-star hotel clearly justified the installation of solar thermal systems in buildings with a high demand for hot water.

5. Studies of Thermal Simulation (emphasis: building)

5.1. BI, Skin Façade

1. Gratia E. and De Hendre A., Greenhouse effect in double-skin façade, 2007: Energy and Buildings 39(2), 199–211.

http://dx.doi.org/10.1016/j.enbuild.2006.06.004

Contexts	Outcomes
TAS software for building thermal analysis was used Identification of the factors that influence greenhouse effect → impact of these parameters on cavity temperature evolution Identified parameters: solar radiation level, cavity depth of the double-skin, glazing type, etc. A middle-size office building was examined Climatic data assumptions: Belgian standard days	The factors that influence the greenhouse effect are solar radiation level, orientation and shading devices use, opaque wall/window proportion of the interior façade, wind speed, colour of shading devices and of interior façade, depth of the cavity of the double-skin, glazing type in the interior façade and openings in the double-skin.

2. Chan Y. C and Tzempelikos A., A Simulation and Experimental Study of the Impact of Passive and Active Façade Systems on the Energy performance of Building Perimeter Zones, 2012: ASHRAE Transactions 118(2), p. 149.

Contexts	Outcomes
A method for assessing the integrated energy performance of passive and active multi-section façade systems combined with lighting and thermal controls of perimeter building zones by using an open source language A thermal network approach was adopted to predict indoor thermal environmental conditions and annual energy consumption of perimeter zones equipped with combinations of passive and active façade systems such as selective glazings, translucent panels, motorized shades and blinds, in conjunction with daylight-linked lighting controls The model utilized anisotropic sky models for an accurate prediction of solar gains, variable angular glazing properties and non-linear interior and exterior convection and radiation heat transfer coefficients together with transient internal gains obtained from transient lighting simulation	A simple private office with one exterior window was adopted as an initial case study Experimental measurements (in full-scale laboratories with and without shading) were utilized to compare to simulation results in order to validate the model The model was expanded and generalized to include the impact of multi-sectional façades in order to evaluate the combined impact of glazing and shading configurations on energy demand/thermal comfort

5.2. General studies

1. Alemu A. T, Saman W. and Belusko M., A model for integrating passive and low energy airflow components into low rise buildings, 2012: Energy and Buildings 49, 148–157.

http://dx.doi.org/10.1016/j.enbuild.2012.02.002

Contexts	Outcomes
Passive airflow components which require simultaneous prediction of air temperature and flow rate were integrated into a coupled building ventilation and thermal model That model allowed the assessment of a combination of passive features such as solar chimney and wind induced earth-air tunnel for both natural and hybrid ventilation systems at the design stage → the model could facilitate the design of buildings with passive cooling features thus, minimizing the need for conventional cooling Mathematical model: a multi zone building ventilation and thermal model with integrated passive cooling features. The model was quasi steady state for each simulation hour. Separate wind and buoyancy driven airflow components (including solar chimney and wind induced earth-air tunnel were added into the multizone ventilation model The thermal model was a quasi-steady model applied to lightweight structure and thermal capacitance was ignored. The internal heat load, solar load and the heat transfer through walls, windows, roof, ground and openings were taken into consideration	The output of the model was compared with well validated TRNSYS-COMIS software for a naturally ventilated single zone building with a low and a high level large openings (space dimensions: 5 m x 5 m x 3 m height) A simulation was conducted for a single day (the first day of January using the TRNSYS weather database for Adelaide, Australia)

6. Studies of Thermal Simulation (emphasis: system)

6.1. BI, Solar Thermal Collectors

1. Motte F., Notton G., Cristofari C. and Canaletti J. L., A building integrated solar collector: Performances characterization and first stage of numerical calculation, 2013: Renewable Energy 49, 1–5

http://dx.doi.org/10.1016/j.renene.2012.04.049

Contexts	Outcomes
A new concept of a solar collector for water heating, patented, with high building integration, without any visual impact was presented Numerical calculations in Matlab by using a finite difference model and an electrical analogy were performed Thermal model: a nearly bi-dimensional model with the thermal transfers was developed; it was composed of a serial assembling of one-dimensional elementary models. Each model was based on a nodal discretization of the solar collector.	Good agreement between numerical and experimental results was found At low reduced temperature values, the thermal performances were found to be close to the conventional ones. However, the authors noted that it is necessary to optimize the shape of that collector in order to improve thermal insulation. This will be conducted by using the developed thermal model. The next step will be to include in that model a differentiation between direct and diffuse radiation and to develop correlations between the thermal coefficients and the environmental parameters (e.g. sky temperature correlated to the clearness index).

2. F. Motte, G. Notton, Chr. Cristofari, J.-L. Canaletti, Design and modelling of a new patented thermal solar collector with high building integration, 2013: Applied Energy 102, 631-639.

http://dx.doi.org/10.1016/j.apenergy.2012.08.012

Contexts	Outcomes
A new concept of flat plate solar collector is presented: its originality comes from its remarkable shape and from its integration into a rainwater gutter. The complete solar collector consists in several short modules connected serially.	A numerical model is developed in Matlab environment using a finite difference model and an electrical analogy. At last, the thermal model is validated from experimental data under various meteorological situations. The adequacy of the model with the experimental data is shown for various temperatures inside the solar collector and for the water temperatures.

3. Anderson T. N., Duke M., Carson J. K., The effect of colour on the thermal performance of building integrated solar collectors, 2010: Solar Energy Materials and Solar Cells 94(2), 350–354.

http://dx.doi.org/10.1016/j.solmat.2009.10.012

Contexts	Outcomes
Experimental and theoretical work One-dimensional steady- state thermal model based on the Hottel–Whillier–Bliss equations Region/climatic conditions: Auckland, New Zealand	The theoretical thermal efficiency of colored collectors was determined Having demonstrated and validated the design model of the colored solar collectors, it was examined the fraction of a typical domestic water-heating load that could be provided by the various theoretical colored collectors. An F-chart was constructed for the operation of the collectors in Auckland, New Zealand Low-cost coloured mild steel collectors could potentially provide noticeable contributions to domestic water heating loads. The performance of coloured solar collectors can be accurately modelled using a combination of experimental and numerical techniques. The use of coloured solar collectors will start to be an area that receives more attention than it has to date.

6.2. BI, Skin Façades

1. von Grabe J., A prediction tool for the temperature field of double facades, 2002: Energy and Buildings 34(9), 891–899.

http://dx.doi.org/10.1016/S0378-7788(02)00065-8

Contexts	Outcomes
Development and validation of a simulation algorithm for the temperature behaviour and the flow characteristics of double façades	It has been developed in order to obtain a tool which enables the energy consultant to make quick design decisions

2. Park C. S., Augenbroe G., Messadi T., Thitisawat M. and Sadegh N., Calibration of a lumped simulation model for double-skin façade systems, 2004: Energy and Buildings 36(11), 1117–1130.

http://dx.doi.org/10.1016/j.enbuild.2004.04.003

Contexts	Outcomes
Calibration of a simulation model of double-skin façade systems with controlled rotating louvers and ventilation openings The approach of the investigation was based on a parameter estimation technique and in situ monitoring of a full-scale element mounted on the south facing façade of an existing building The new approach was based on a postulated "minimalistic" lumped model which was calibrated on in-situ measurements	The lumped models for double-skin façade systems can be easily constructed based on a "grey box" approach, i.e., partly based on the lumped descriptions of dominant physical processes, and augmented by calibration parameters to make up for the simplifications. The model is very accurate in the prediction of the most relevant state variables, reliable for performance studies, and computationally light enough for model based optimal control.

3. Balocco C. and Colombari M., Thermal behaviour of interactive mechanically ventilated double glazed façade: Non-dimensional analysis, 2006: Energy and Buildings 38(1), 1–7.

http://dx.doi.org/10.1016/j.enbuild.2005.02.006

Contexts	Outcomes
Non-dimensional analysis is proposed as a method to analyze mechanically ventilated double glazed façade energy performance. The 12 non-dimensional numbers defined can be used to describe thermal and energy performance of interactive façade designs. A comparison between Nusselt number solved by experimental data and Nusselt calculated by the validated multivariable correlation function is reported in the present paper. Due to its wide validity field the proposed method can be used to analyze thermodynamic performances of glass double-skin façades with mechanical ventilation	Applying non-dimensional analysis to a mechanically ventilated double glass façade, a correlation between 12 nondimensional numbers has been obtained. Model has been validated using experimental data. The proposed method is useful to study thermal energy performances of mechanically ventilated double-skin façades for different climatic conditions, aspect ratio, shading device systems and also different thermo-physical characteristics of two glasses.

4. Coussirat M., Guardo A., Jou E., Egusquiza E., Cuerva E. Alavedra P., Performance and influence of numerical sub-models on the CFD simulation of free and forced convection in double-glazed ventilated façades, 2008: Energy and Buildings 40 (10), 1781–1789.

http://dx.doi.org/10.1016/j.enbuild.2008.03.009

Contexts	Outcomes
Double-glazed façades CFD Fluent software: flow and heat transfer modeling Undesirable building oveheating → Mediterranean climates	In this work, several modeling tests were carried out on a well-documented experimental test case taken from the open literature in order to obtain a suitable model of the aforementioned thermo-fluid-dynamics effects.

5. Pérez-Grande I., Meseguer J. and Alonso G., Influence of glass properties on the performance of double-glazed facades, 2005: Applied Thermal Engineering 25 (17-18), 3163-3175.

http://dx.doi.org/10.1016/j.applthermaleng.2005.04.004

Contexts	Outcomes
Glass properties influence on the performance of double-glazed façades Continental climate areas with warm summers (these façades increase dramatically the cooling requirements over summer months) → selection of appropriate glass	The thermo-fluid dynamics problem was solved by finite-volume commercial code, FLUENT, with a standard k–ε turbulence model By giving emphasis on the thermal balance, it was showed that an appropriate selection of the glasses forming the channel can reduce the thermal load into the building by almost an order of magnitude. It was also demonstrated that an appropriate use of the air stream flowing between the glass surfaces can improve global thermal balance.

6. Guardo A., Coussirat M., Egusquiza E., Alavedra P. and Castilla R., A CFD approach to evaluate the influence of construction and operation parameters on the performance of Active Transparent Façades in Mediterranean climates, 2009: Energy and Buildings 41(5), 534 –542.

http://dx.doi.org/10.1016/j.enbuild.2008.11.019

Contexts	Outcomes
Active Transparent Façades (ATF) Mediterranean climate → overheating Influence of construction/operation parameters of the ATF (such as optical properties of the materials, geometrical relations of the façade or flow stream conditions) in terms of energy savings, measured as a	The parameters that affect the most the reduction on solar load gain are related with the optical properties of the glass. An increase of the length-to-depth ratio causes a decrease on the ATF efficiency in terms of solar load gains.

reduction of the solar load entering the building. Climatic conditions: Barcelona, Spain. CFD simulations: RNG k-epsilon turbulence model (when needed) and P1 radiation model; Fluent software; 3D geometries.	

7. Nassim Safer N., Woloszyn M. and Roux J. J., Three-dimensional simulation with a CFD tool of the airflow phenomena in single floor double-skin façade equipped with a Venetian blind, 2005: Solar Energy 79(2), 193-203.

http://dx.doi.org/10.1016/j.solener.2004.09.016

Contexts	Outcomes
Modelling of a compact double-skin façade equipped with a venetian blind and forced ventilation The modelling was conducted by using CFD approach to assess the air movement within the ventilated façade channel. Three-dimensional airflow was modelled by using a homogeneous porous media representation, in order to reduce the size of the mathematical model. A parametric study was proposed, analyzing the impact of three parameters on the airflow development: slat tilt angle, blind position, air outlet position The commercial CFD tool FLUENT 6.0.20 was utilized, based on the finite-volume method and the SIMPLE solving algorithm	The CFD approach enables accurate computations of the velocity–pressure fields inside the channel of ventilated double-skin façades The global double skin façade model using the velocity averages and the airflow rates inside the channel of the double-skin façades will be derived from these CFD results

8. Pasut W. and De Carli M., Evaluation of various CFD modelling strategies in predicting air flow and temperature in a naturally ventilated double skin façade, 2012: Applied Thermal Engineering 37, 267–274.

http://dx.doi.org/10.1016/j.applthermaleng.2011.11.028

Contexts	Outcomes
This paper showed, through a sensitivity analysis, a good strategy for carrying out CFD simulation of double skin façades. The validation of the results was based on experimental data from the literature	A CFD model for the natural ventilated double skin façade was developed. The model can be used to predict the airflow patterns, air temperature and air velocity distributions, and heat flux from gap into the room.

The paper provides a discussion about factors which are important in the simulation.	The model was validated using experimental data collected in a full-scale double skin module test facility by Mai et al.

9. Jiru T. E. and Haghighat F., Modeling ventilated double skin façade - A zonal approach, 2008: Energy and Buildings 40(8), 1567-1576.

http://dx.doi.org/10.1016/j.enbuild.2008.02.017

Contexts	Outcomes
In the zonal approach, the DSF can be divided into a number of control volumes, using two or three-dimensional cells, which are usually larger than the cells normally used in CFD. The advantage of using the zonal approach is that the resulting systems of algebraic equations are smaller and much easier to solve than the CFD. The zonal models can provide information on airflow and temperature distribution in a ventilated space faster than CFD, but with more accuracy and detail than lumped and control-volume models. Application of zonal approach for modeling of airflow and temperature in a ventilated double skin façades (DSF). The zonal airflow equation, power-law, was employed to calculate the airflow through the shading device and cavities. The zonal energy equation was adopted to evaluate the temperature distribution in the DSF system. The predicted temperature distributions were verified by using measured values and parametric studies were conducted in order to identify the influence of height, flow rate and presence of venetian blinds on the inlet–outlet temperature difference. The case used for the development and the verification of the DSF models: experimental test cell at the Dipartimento di Energetica, Politecnico di Torino, Italy.	The zonal models can be used to assess the performance of the DSF system with venetian blinds. The results revealed that the zonal models can be used to assess the performance of the DSF system with venetian blinds. The zonal models provided more detailed information (which is not possible for the lumped and the control-volume models). Parametric study was also conducted in order to assess the influence of cavity height; inlet mass flow rate; and presence of venetian blinds on the outlet-inlet temperature difference. The result demonstrated that the influence of changing the values of each parameter was more apparent during the day than during the night. The DSF model developed can further be integrated into Building Simulation tool that includes HVAC plant and allows the evaluation of the use of control mechanisms in the DSF and their influence on the energy consumption of the HVAC system.

10. W.J. Stec, A.H.C. van Paassen, A. Maziarz, Modelling the double skin façade with plants, 2005: Energy and Buildings 37, 419–427.

http://dx.doi.org/10.1016/j.enbuild.2004.08.008

Contexts	Outcomes
Plants in office buildings can provide several advantages. These are mostly related with thermal, aesthetic, psychological, comfort level and sound attenuation. That research at TU Delft aimed in defining the thermal performance of the double skin façade with plants. A simulation model was developed and validated. After validating, the simulation model could analyze the influence of plants on the performance of the double skin façade. The simulation model was built by SimulinkTM. The thermal model was represented by the heat exchange between the layers of the façade.	The results revealed that In general plants created more effective shading system than blinds providing advantages such as: for the same solar radiation, the temperature raise of the plants was about twice lower than that for the blinds; the temperature of the plants never exceeded the temperature of 35^{o}C, when blinds could exceed 55^{o}C; plants in the double skin façade reduced cooling capacity by almost 20%.

6.3. BI, Pipes

1. Albanese M. V., Robinson B. S., Brehob E. G. and Sharp M. K., Simulated and experimental performance of a heat pipe assisted solar wall, 2012: Solar Energy 86 (5), 1552–1562.

http://dx.doi.org/10.1016/j.solener.2012.02.017

Contexts	Outcomes
Simplified, thermal resistance-based computer models were developed to simulate the performance of direct gain, indirect gain and integrated heat pipe passive solar systems A computer model was developed to further investigate the feasibility of heat pipe integrated walls in a range of climates; a parametric study was conducted to determine the design features that have a significant effect on performance, a prototype heat pipe wall was constructed and tested to provide validation data MatLab codes were created to simulate hourly performance of the heat pipe system, as well as direct gain and concrete and water wall indirect gain systems; thermal network approach was adopted - An anisotropic model was utilized (three components: diffuse radiation – uniform, circumsolar, horizon brightening).	The heat pipe system provided substantial gains in performance relative to conventional direct and indirect gain passive solar systems and, thus, presents a promising alternative for reducing building energy use. Economic performance depends on the climate and the load to collector ratio, as well as a number of factors related to the costs of the system and of conventional heating.

Four cities were chosen to provide a range of insolation and temperatures: Albuquerque (New Mexico, the warmest and clearest of the four climates), Rock Springs (Wyoming, USA), Louisville (Kentucky, USA), Madison (Wisconsin, USA).	

2. Hassan M. M. and Beliveau Y., Design, construction and performance prediction of integrated solar roof collectors using finite element analysis, 2007: Construction and Building Materials 21(5), 1069-1078.

http://dx.doi.org/10.1016/j.conbuildmat.2006.01.001

Contexts	Outcomes
An integrated roof solar collector was designed The integrated roof solar collector consisted of a 6.35 mm single glass panel with a selective surface, followed by a 1-mm air-gap. The thermal collecting medium was a fluid (water with antifreeze) enclosed copper pipes. The pipes were laid within concrete cavities to minimize construction cost and time as well as to reduce convection losses. The copper pipes were connected together by means of a 1 mm copper plate absorber. 3D finite element models were developed to evaluate the thermal performance of the integrated roof solar collector.	The models were used to predict the optimum set of variables that can be used in buildings in order to achieve adequate thermal comfort. Coupled conduction, forced convection, long wave thermal radiation modes of heat transfer were considered in the developed models. A specific location (Blacksburg, Virginia, USA) was modelled. ABAQUS software version 5.8 was used for finite element modelling of the solar roof panel.

3. Zhu Q., Xu X., Wang J. and Xiao F., Development of dynamic simplified thermal models of active pipe-embedded building envelopes using genetic algorithm, 2014: International Journal of Thermal Sciences 76, 258–272.

http://dx.doi.org/10.1016/j.ijthermalsci.2013.09.008

Contexts	Outcomes
New building envelope: active pipe-embedded building envelope → external wall (or roof) with pipes embedded in it (may include PCM) → advantages: utilizes directly low-grade energy sources for reducing building cooling/heating load and improving indoor thermal comfort.	The optimal simplified model provides reasonable and accurate performance prediction whatever for the pipe-embedded light weight building wall, the pipe-embedded medium weight building wall, the pipe-embedded heavy

Dynamic, simplified thermal model of this structure with the thermal network structure of lumped thermal mass and the parameter identification of the simplified model based on frequency characteristic analysis. These resistances and capacitances are identified in frequency domain by using generic algorithm (GA) by comparing the frequency characteristics of the simplified model with the theoretical frequency characteristics of this structure obtained with Frequency-Domain Finite Difference (FDFD) method - Firstly, the FDFD model of this structure was established and the theoretical frequency characteristics under various disturbances were calculated for the reference of parameter identification. Then, an equivalent dynamic simplified thermal model with lump thermal network structure was developed and its frequency characteristics were also deduced and calculated. Finally, the GA estimator was adopted to identify these parameters of the simplified model for allowing the frequency responses of the simplified model to match the theoretical frequency responses by using the FDFD method. Performance prediction of this structure under realistic weather conditions, indoor air condition and circulating water temperature condition for practical applications (China).	weight building wall. The model accuracy may differ depending on the wall physical properties. The optimal model of the pipe-embedded light weighted wall may represent the theoretical frequency characteristics the best while the optimal models of the pipe-embedded medium weighted wall and the pipe-embedded heavy weighted wall present similar accuracy. In general, the simplified RC model is a good model for predicting the heat transfer performance of this structure.

6.4. BI, Solar Chimney

1. Ong K. S., A mathematical model of a solar chimney, 2003: Renewable Energy 28(7), 1047–1060.

http://dx.doi.org/10.1016/S0960-1481(02)00057-5

Contexts	Outcomes
Analytical, physical model / thermal resistance network. A wall-type solar chimney was examined (a glass cover which with the other three solid walls of the chimney form a channel through which the heated air could	The thermal performance of the solar chimney as determined from the glass, wall and air temperatures, air mass flow rate and instantaneous heat collection efficiency of the chimney are presented. Satisfactory correlation obtained.

rise and flow by natural convection). Steady-state heat transfer equations → matrix-inversion solution procedure.	

6.5. BI, Trombe Wall

1. Jubran B. A., Hamdan M. A. and Manfalouti W., Modelling free convection in a Trombe wall, 1991: Renewable Energy 1 (3–4), 351–360.

http://dx.doi.org/10.1016/0960-1481(91)90044-P

Contexts	Outcomes
Numerical model for laminar, free convection flow in Trombe wall and a modified version of the conventional Trombe wall. Finite difference method.	The variation of fluid velocity, temperature and the average Nusselt number have been determined numerically for selected tilt angles of the glass wall for the modified version of the Trombe wall. It was found that there is a significant effect of the glass wall inclination on the average Nusselt number.

2. Ben Yedder R., Du Z.-G. and Bilgen E., Numerical study of laminar natural convection in composite Trombe wall systems, 1990: Solar & Wind Technology7(6), 675–683.

http://dx.doi.org/10.1016/0741-983X(90)90042-Z

Contexts	Outcomes
Natural convection problem in a composite Trombe wall solar collector. SIMPLER method was used (control volumes). Model for natural convention in cavities. Flow: steady, laminar, 2D.	The aspect ratio A has a small influence on the heat transfer and that other geometric parameters such as orifice position, channel size and width have important effects on the useful energy transmitted to the dwelling.

3. Koyunbabaa B. K., Yilmaz Z. and Ulgen K., An approach for energy modeling of a building integrated photovoltaic (BIPV) Trombe wall system, 2013: Energy and Buildings 67, 680–688.

http://dx.doi.org/10.1016/j.enbuild.2011.06.031

Contexts	Outcomes
A two-dimensional simulation model of a naturally ventilated BIPV Trombe wall system for winter period to be → applied to different locations with different climatic conditions, PV types, thermal mass samples, etc. The commercial CFD code Ansys CFX was adopted to model air flow and heat transfer with the Navier–Stokes equations. Ansys CFX based on finite volume technique. Validation of the model with experimental results of a BIPV Trombe wall built in Izmir, Turkey. An energy analysis for determining the performance of a BIPV Trombe wall integrated to the façade of a room was carried out (based on transient condition). CFD was used to predict temperature and velocity distribution in the test room model. The simulations for two-dimensional model of BIPV Trombe wall system were carried out for February 4–7th, 2008. Experimental set-up at Solar Energy Institute, Ege University Campus, Izmir, Turkey.	This study has shown the capability of a CFD code to predict the radiation, conduction and natural convection in a BIPV Trombe wall system. The k-epsilon turbulence model was used to conduct the CFD simulations on the meshed structure. Radiation heat transfer was modeled using Monte Carlo model.

6.6. BI, PVT

1. Anderson T.N., Duke M., Morrison G.L. and Carson J.K., Performance of a building integrated photovoltaic/thermal (BIPVT) solar collector, 2009: Solar Energy 83(4), 445–455.

http://dx.doi.org/10.1016/j.solener.2008.08.013

Contexts	Outcomes
A novel building integrated photovoltaic/thermal (BIPVT) solar collector was theoretically analyzed through a modified Hottel–Whillier model The model was validated with experimental data from testing on a prototype BIPVT collector. One dimensional steady state thermal model	The collector base material made little difference to the thermal efficiency of the BIPVT suggests that lower cost materials, such as steel, could be utilised for these systems. The disadvantage of using steel is that the electrical efficiency would be

The electrical efficiency was calculated based on the difference between mean BIPVT temperature and Nominal Operating Cell Temperature (NOCT) (298 K).	decreased marginally. Good thermal contact between the PV cells and the absorber needs to be made; this could be achieved using thermally conductive adhesives and will improve both the electrical and thermal efficiencies of the system. Increase in the transmittance/ absorptance product results in the greatest increase in thermal efficiency of all the parameters assessed, without greatly reducing the electrical efficiency. The use of unglazed BIPVT systems in conjunction with heat pumps could present interesting possibilities. Significant potential exists to utilise the low natural convection heat transfer in the attic at the rear of the BIPVT to act as an insulating layer rather than using additional insulation material. The use of this air layer would allow the material cost of such a system to be significantly reduced.

2. Ji J., Chow T. T. and He W., Dynamic performance of hybrid photovoltaic/thermal collector wall in Hong Kong, 2003: Building and Environment 38 (11), 1327–1334.

http://dx.doi.org/10.1016/S0360-1323(03)00115-X

Contexts	Outcomes
Based on the heat transfer analysis on a west-facing PVT collector wall with typical weather data of Hong Kong, a computational thermal model was developed. Based on the thermal model described above, a simulation program HYBRIDPV-1.0 (in FORTRAN) was developed.	The simulation program could determine the energy performance of PV/hot water collector system with any performance characteristic of PV panel, any climatic region and for any orientation of the collector wall → hourly TRY weather data in Hong Kong was used as a data input for the simulation program.

3. Ji J., Han J., Chow T. T., Yi H., Lu J., He W. and Sun W., Effect of fluid flow and packing factor on energy performance of a wall-mounted hybrid photovoltaic/water-heating collector system, 2006: Energy and Buildings 38(12), 1380-1387.

http://dx.doi.org/10.1016/j.enbuild.2006.02.010

Contexts	Outcomes
Façade-integrated BiPVT A numerical model was developed by modifying the Hottel–Whillier model, which was originally for the thermal analysis of flat-plate solar thermal collectors. Computer simulations were performed to analyze system performance. The combined effects of the solar cell packing factor and the water mass flow rate on the thermal and electrical efficiencies were examined.	The increase of working fluid mass flow rate is beneficial for PV cooling. System operation at the optimum mass flow rate improves the thermal performance of the system and meets the PV cooling requirement so that a better electrical performance can also be achieved.

4. Chen Y., Galal K. and Athienitis A. K., Modeling, design and thermal performance of a BIPV/T system thermally coupled with a ventilated concrete slab in a low energy solar house: Part 2, ventilated concrete slab, 2010: Solar Energy 84 (11), 1908–1919.

http://dx.doi.org/10.1016/j.solener.2010.06.012

Contexts	Outcomes
Modeling and design of a BIPVT system thermally coupled with a ventilated concrete slab (VCS) adopted in a prefabricated, two-storey detached, low energy solar house and their performance assessment based on monitored data. Climatic conditions: Canada (cold climate regions with cold but sunny winters).	A simplified three-dimensional, control volume, explicit finite difference thermal model was developed to simulate the thermal performance of the constructed VCS. The modelling approach can be applied to other types of VCS. The developed model is showed to be appropriate for design purposes and for study of control strategies.

5. Aelenei L. and Pereira R., Innovative Solutions for Net Zero-Energy Building: BIPV-PCM System – Modeling, Design and Thermal Performance, 2013: IEEE, IYCE 2013 Conference, 6-8 June, Siofok, Hungary.

http://dx.doi.org/10.1109/IYCE.2013.6604162

Contexts	Outcomes
Numerical thermal analysis of two different systems for integrating on building façade: BIPVT and BIPVT-PCM (Phase Change Material). A dynamic model was simulated using the real climatic data of winter time measured on the building site (Lisbon, Portugal). 1D numerical dynamic simulation model inside the control volume; fully finite difference scheme; programming MATLAB/SIMULINK® with SIMSCAPE® library.	The results revealed that the system using PCM decreased the temperature inside the air cavity and thus, the system was more stable due to the storage of solar gains as latent heat in the PCM wall. The thermal efficiency of the ventilated BIPVT was higher than the ventilated BIPVT-PCM because of the airflow at elevated temperature into the room. Nevertheless, after few hours, the two systems efficiencies appeared to be close to each other. That made PCM a reasonable option.

6. Ghani F., Duke M. and Carson J. K., Effect of flow distribution on the photovoltaic performance of a building integrated photovoltaic/thermal (BIPV/T) collector, 2012: Solar Energy 86(5), 1518-1530.

http://dx.doi.org/10.1016/j.solener.2012.02.013

Contexts	Outcomes
BIPVT: effect of flow distribution on PV performance A three step numerical analysis was conducted to model flow distribution, temperature variation, PV yield for a PVT collector of various design (manifold sizes), geometric shape (aspect ratio), operating characteristics in order to vary flow uniformity within the collector. CFD; FEA analysis → Heat transfer analysis → PV modelling. All simulations were conducted by using Autodesk Simulation Multi-physics 2012 software.	The results showed that the flow distribution within the collector will have a significant influence on the photovoltaic performance of a hybrid PVT collector. For the case where the flow distribution was most uniform, PV performance was improved by over 9% in comparison to a traditional PV collector operating under the same conditions. However, for poor flow the performance was only improved by approximately 2%. It was found that several parameters influence flow distribution: e.g. manifold to riser pipe ratio (a ratio of 4:1 was found to be ideal and that increasing to a 6:1 ratio offered negligible improvement). It was also found that array geometry (characterised by its aspect ratio in this study) is important for both flow distribution and PV yield. That study identified that optimal mass flow rate

	was dependent on array shape or aspect ratio.

7. Liao L., Athienitis A., Park K.-W., Collins M. and Poissant Y., Numerical study of conjugate heat transfer in a bipv-thermal system, 2005: ASME 2005, Orlando, Florida, USA, August 6–12.

Contexts	Outcomes
CFD study of a BIPVT system which generated both electricity and thermal energy. The conjugate heat transfer in the BIPVT system cavity was studied with a 2-D CFD model while the k-ε model was used to simulate the turbulent flow and convective heat transfer in the cavity, in addition to buoyancy effect. The longwave radiation between boundary surfaces was also modelled.	Experimental measurements: full scale outdoor test facility at Concordia University (Canada) showed good agreement with the CFD model. Average and local convective heat transfer coefficients were generated and PV panel average temperature and local cell temperatures were calculated and compared with the data from the experiments.

6.7. BI, PV

1. Fung T. Y. Y. and Yang H., Study on thermal performance of semi-transparent building-integrated photovoltaic glazings, 2008: Energy and Buildings 40(3), 341–350.

http://dx.doi.org/10.1016/j.enbuild.2007.03.002

Contexts	Outcomes
A one-dimensional transient simulation model, the Semi-transparent Photovoltaic module Heat Gain (SPVHG) model, for the thermal performance of the semi-transparent photovoltaic (PV) modules was developed and experimentally validated.	The SPVHG model can be applied for simulating various scenarios. Annual total heat gains through the semi-transparent BIPVs under different scenarios were simulated by means of the SPVHG model . Annual thermal performance (using the SPVHG model): climatic data for Hong Kong. The total heat gain follows the variation of solar radiation. The total heat gain through the PV module is dominated by solar heat gain.

	The effects of different parameters of the PV modules were also studied.

2. Charron R. and Athienitis A. K., Optimization of the performance of double-façades with integrated photovoltaic panels and motorized blinds, 2006: Solar Energy 80(5), 482–491.

http://dx.doi.org/10.1016/j.solener.2005.05.004

Contexts	Outcomes
Double-façades with integrated photovoltaics (PV) and motorized blinds. One-dimensional finite-difference thermal model is developed, with an algorithm that iteratively determines which convective heat transfer coefficient correlation to use for each surface inside the cavity using expressions that consider system characteristics and temperature distribution. Environmental conditions used in the model: representative of what would be experienced in Montreal, Canada.	A theoretical investigation of the performance of double façades with integrated photovoltaics and motorized blinds was presented for the case of forced ventilation. When the PVs were installed in the middle of the cavity, air flows on both sides, increasing PV section overall (thermal-electric) efficiency by about 25%, but lowered electricity generation by 21%. Integrating 0.015 m long, 0.002 m wide fins to the PV back plate resulted to a similar increase in efficiency without compromising electricity generation. The placing of the blind in the middle of the cavity increased the vision section efficiency by 5%. By adopting that approach to optimize performance can lead to combined thermal-electric efficiencies of over 60%.

3. Gan G., Numerical determination of adequate air gaps for building-integrated photovoltaics, 2009: Solar Energy 83(8), 1253-1273.

http://dx.doi.org/10.1016/j.solener.2009.02.008

Contexts	Outcomes
CFD software FLUENT (2005) was adopted for modeling of fluid flow and heat transfer around PV modules mounted on pitched roofs and in front of a vertical façade.	CFD has been used to predict the effect of air gap size on the PV performance in terms of cell temperature for a range of roof pitches and PV panel lengths at

Modelling was performed for realistic PV modules (type BP 485) and for a range of roof pitches and gap sizes. The modelling was two-dimensional for heat and fluid flow. In order to ascertain the reliability of CFD modelling, the model was validated for buoyancy-induced fluid flow and heat transfer in a tall open air cavity. The RNG k-e turbulence model was utilized for modelling turbulent air flow and heat transfer. Ambient air temperature was fixed at 20°C while the incident solar radiation was first fixed at 1000 W/m^2 and then varied with inclination of roof mounted PV modules for an example location. A discrete transfer radiation model was adopted for modelling the radiation heat transfer from the modules to surroundings.	different solar heat gain levels. The CFD technique can be used to predict the required air gap for a given type of module and method of building integration.

4. N. Friling, M. J. Jiménez, H. Bloem, H. Madsen, Modelling the heat dynamics of building integrated and ventilated photovoltaic modules, 2009: Energy and Buildings 41(10), 1051-1057.

http://dx.doi.org/10.1016/j.enbuild.2009.05.018

Contexts	Outcomes
This paper deals with mathematical modelling of the heat transfer of building integrated photovoltaic (BIPV) modules. The experiment and data originate from a test reference module the EC-JRC Ispra. The set-up provides the opportunity of changing physical parameters, the ventilation speed and the type of air flow, and this makes it possible to determine the preferable set-up. The models are first order stochastic state space models.	The analysis has revealed that it is necessary to use non-linear state space models in order to obtain a satisfactory description of the PV module temperature, and in order to be able to distinguish the variations in the set-up. The heat transfer is increased when the forced ventilation velocity is increased, while the change in type of air flow does not have as striking influence. The residual analysis show that the best description of the PV module temperature is obtained when fins, disturbing the laminar flow and making it turbulent, are applied in the set-up

	combined with high level of air flow. The improved description by the model is mainly seen in periods with high solar radiation.

6.8. BI, Several systems

1. Sanjuan C., Suárez M.J., González M., Pistono J. and Blanco E., Energy performance of an open-joint ventilated façade compared with a conventional sealed cavity façade, 2011: Solar Energy 85(9), 1851–1863.

http://dx.doi.org/10.1016/j.solener.2011.04.028

Contexts	Outcomes
Open-joint ventilated façade (OJVF): a building system in which coating material (metallic, ceramic, stone or composite) is hanged by means of a metallic-frame structure to the exterior face of the wall, creating an air cavity between wall and slab → buoyancy effect and thus, ability to reduce cooling thermal loads. Phenomena produced on a typical open joint ventilated façade and comparison of its energy performance with that of a conventional sealed air cavity façade. The thermo fluid-dynamic behavior of both systems was analyzed with CFD. The numerical model employed a CFD code (FLUENT 6.3) to analyze the thermal and fluid dynamic phenomena taking place in OJVF. CFD software solved Navier–Stokes equations (including energy conservation equation) using finite volume method. 3D simulations were conducted. Climatic data: Madrid, Spain (Continental Mediterranean climate).	The three-dimensional CFD model developed to simulate a typical Open Joint Ventilated Façade has enabled a better understanding of the ventilation effect induced by the solar radiation in the air gap of the façade. Velocity profiles, together with temperature and heat flux distributions have been compared with those obtained in a conventional sealed cavity façade. The model has been also used to compare the thermal performance of both façades for the specific climatic conditions of Madrid (Spain).

2. Chen Y., Athienitis A. K. and Galal K. E., Frequency domain and finite difference modeling of ventilated concrete slabs and comparison with field measurements: Part 2. Application, 2013: International Journal of Heat and Mass Transfer 66, 957–966.

http://dx.doi.org/10.1016/j.ijheatmasstransfer.2013.07.086

Contexts	Outcomes
Frequency response (FR) and lumped-parameter finite difference (LPFD) approaches for the thermal modeling of building-integrated thermal energy storage (BITES) systems. The results are compared to each other and with field-measured data from a solar demonstration house with a ventilated concrete slab (VCS).	The modelling techniques are applied to two kinds of VCS – one has air channel at the bottom of the mass (VCS-b) while the other kind has hollow cores as air channel (VCS-c). The explicit LPFD and FR models generate almost identical outcomes under periodic conditions. The accuracies of different discretization configurations and choices of time step were quantified. Time step of half an hour for FR models typically resulted in less than 3% error in the thermal performance. For LPFD models, discretization with Biot number less than 0.5 can reduce error to about 5%. Larger Biot number tended to overestimate the heat flow from air to the slab over time. For practical slab thickness (0.1-0.2 m), simulation results from 2-layer VCS-b and 3-layer VCS-c models with time step of half an hour showed errors less than 9%. LPFD simulation results under non-periodic conditions were presented for VCS-b and they were compared with field-measured data from a near net-zero energy solar house.

3. Palmero-Marrero A. I. and Oliveira A. C., Evaluation of a solar thermal system using building louvre shading devices, 2006: Solar Energy 80(5), 545 – 554.

http://dx.doi.org/10.1016/j.solener.2005.04.003

Contexts	Outcomes
Modification of existing louvre designs to integrate a solar collector in the shading device was performed → evaluation of a thermal solar system for water heating. A numerical model for the integrated solar collector	In the models, steady state heat transfer was assumed (negligible thermal inertia) while the models consisted of 4–6 heat balance equations, depending on the configuration, stating that the sum of all

was developed for different configurations and the collector efficiency was evaluated for each configuration. System thermal performance was obtained for the climatic conditions of: Lisbon (Portugal), Tenerife (Spain). The different configurations which were considered for the integrated collector were: collector with tubes; collector with larger channels; collector with smaller channels and transparent cover area.	incoming fluxes is equal to the sum of all outgoing fluxes.

4. Z. Wang, Z. Duan, X. Zhao, M. Chen, Dynamic performance of a façade-based solar loop heat pipe water heating system, 2012: Solar Energy 86, 1632–1647.

http://dx.doi.org/10.1016/j.solener.2012.02.031

Contexts	Outcomes
Study of a novel façade-based solar loop heat pipe (LHP) water heating system: theoretically and experimentally.	Two types of glass covers, i.e., double glazed/evacuated tubes and single-glazing plate, were adopted. The double-glazed/evacuated-tube system showed better performance than the single-glazing one.

5. Manz H., Numerical simulation of heat transfer by natural convection in cavities of facade elements, 2003: Energy and Buildings 35, 305 –311.

http://dx.doi.org/10.1016/S0378-7788(02)00088-9

Contexts	Outcomes
Heat transfer by the natural convection of air layers within vertical, rectangular cavities was examined for applications in building façade elements, such as insulating glazing units, double-skin façades, doors, etc. by using a CFD code (commercial CFD code FLOVENT, Version 3.1; finite volume method).	The presented method can be considered suitable for calculating convective heat transfer in tall, vertical cavities in different types of façade elements. That work included combination of an optical model for determining absorbed solar radiation in layers of façade elements such as glass panes, roller blinds, etc. with CFD modeling in order to increase the reliability of predictions

	of these elements thermal transmission and total solar energy transmission.

6.9. BA, Several systems

1. D. A.G. Redpath, P. Dalzell, P. W. Griffiths and N. J. Hewitt, Investigation of concentrating and nonconcentrating evacuated tube solar water heaters using 2D particle imaging velocimetry, 2014: International Journal of Low-Carbon Technologies.

doi:10.1093/ijlct/ctu004

Contexts	Outcomes
Under transient climatic conditions, solar water heaters with heat pipes are more effective in terms of capturing incident solar radiation (in comparison with other types of water heaters). Two configurations were studied: thermosiphon fluid flow and reflective concentrators.	A model manifold simulated the manifold of a heat-pipe evacuated tube solar water heater was presented. 2D-PIV revealed significant differences in flow patterns between the two manifold configurations which were confirmed by comparing Nusselt number. The five pin-fin system had Nusselt 2.1 times greater than that calculated at the same location in the 10 pin-fin configuration. The results showed that the incorporation of concentrators would have a small effect on the overall system efficiency but would reduce the frictional losses internally. The authors noted that further work is needed for the improvement of similar heat exchangers.

2. Sultana T., Morrison G.L. and Rosengarten G., Thermal performance of a roof integrated solar microconcentrating collector, 2011: ISES 5, 3494-3505, 30th ISES Congress, SWC 2011; Kassel; Germany; 28 Aug.- 2 Sept.

Contexts	Outcomes
Concentrating solar thermal systems for rooftop applications. Thermal performance of a new low-cost solar thermal micro-concentrating collector (MCT) which used linear Fresnel reflectors and it was designed to operate at temperatures up to 220°C.	A computational model for the prototype collector was developed by using ANSYS-CFX. The numerical results were compared with experimental measurements. The efficiency of the collector was

The modules of that collector were approximately 3 meters long by 1 meter wide and 0.3 meters high. Objective of the study: to optimize the design to maximize the overall thermal efficiency. Computational investigation of radiation and convection heat transfer in order to understand the heat loss mechanisms.	established on the basis of ray tracing and heat loss analysis.

6.10. General studies

1. Moshfegh B., Sandberg M., Investigation of fluid flow and heat transfer in a vertical channel heated from one side by PV elements, Part I – numerical study, WREC 1996, 248-253.

http://dx.doi.org/10.1016/0960-1481(96)88856-2

Contexts	Outcomes
Numerical study about fluid flow and heat transfer of buoyancy-driven convection between two vertical parallel walls, heated from one side. Both convection and radiation heat exchanges were taken into account as the heat transfer mechanisms by which the thermal energy is transferred into the air. A steady-state 2D model was adopted (finite element code).	Numerical results were derived for a channel (6.5 m height; different widths of the channel). The results showed the importance of radiation heat exchangers to the heat transfer mechanisms between channel walls.

2. G. Gan, S. B. Riffat, CFD modelling of air flow and thermal performance of an atrium integrated with photovoltaics, 2004: Building and Environment 39, 735- 748.

http://dx.doi.org/10.1016/j.buildenv.2004.01.027

Contexts	Outcomes
The thermal performance of an atrium integrated with PVs was evaluated. CFD was adopted for the prediction of air flow and temperature distribution in the atrium. CFD was then used to investigate the effect of ventilation strategies on PV performance. CFD package FLUENT was utilized.	The work showed that CFD is useful for optimising building ventilation systems to provide a comfortable indoor environment and effective cooling of BI PVs. For effective cooling of roof PVs, cool outdoor air should be supplied through an opening close to the roof or an air channel under the PVs. Increasing the ventilation rate can also reduce temperature and thus, improve PV

	performance, in particular if cool outdoor air is supplied via an opening close to the PVs.

3. G. Gan, Effect of air gap on the performance of building-integrated photovoltaics, 2009: Energy 34, 913–921.

http://dx.doi.org/10.1016/j.energy.2009.04.003

Contexts	Outcomes
Ventilation of PVs installed over or beside a building envelope can reduce module temperature and increase electrical conversion efficiency. A CFD method was adopted to assess the effect of the size of air gap between PV modules and building envelope on PV performance in terms of cell temperature for a range of roof pitches and panel lengths and to determine the minimum air gap that is required to minimise PV overheating. CFD software FLUENT was adopted.	It was found that PV mean PV temperature and maximum PV temperature associated with hot spots decreased with the increase in pitch angle and air gap. Mean PV temperature also decreased with increasing panel length for air gaps greater than or equal to 0.08 m whereas maximum PV temperature generally increased with panel length. In order to reduce possible overheating of PVs and hot spots near the top of the modules requires minimum air gap 0.12–0.15 m for multiple module installation and 0.14–0.16 m for single module installation depending on roof pitches.

7. Studies about Thermal Simulation (emphasis: building/system)

7.1. BI, Solar Thermal

1. Maurer C. , Baumann T., Hermann M., Di Lauro P., Pavan S., Michel L. and Kuhn T.E., Heating and cooling in high-rise buildings using facade-integrated transparent solar thermal collector systems, 2013: Journal of Building Performance Simulation 6(6), 449-457.

10.1080/19401493.2013.766263

Contexts	Outcomes
Transparent solar thermal collectors (TSTCs) were studied Modelling challenges that arise when considering building façades and especially integrated TSTC systems were examined.	New transient systems simulation (TRNSYS) types were developed A simplified model was presented for comparison purposes.

	The overall performance of a building with façade-integrated TSTC was examined by considering a complete simulation model coupling the TSTC, building and heating, ventilation and air conditioning operation of the building. Possibilities for primary energy savings were investigated by using building mass as an additional thermal storage.

2. M. M. Hassan, Y. Beliveau, Design, construction and performance prediction of integrated solar roof collectors using finite element analysis, 2007: Construction and Building Materials 21, 1069–1078.

http://dx.doi.org/10.1016/j.conbuildmat.2006.01.001

Contexts	Outcomes
An integrated roof solar collector was designed to achieve ease of construction, energy efficiency, functional integration, composite behaviour, sustainability, reliability, flexibility, and cost effectiveness. Three-dimensional (3D) finite element models were then developed to evaluate the thermal performance of the integrated roof solar collector. Coupled conduction, forced convection, and long wave thermal radiation modes of heat transfer were considered in the developed models. A specific location (Blacksburg, VA) was modelled.	Results showed that the integrated roof collector provides acceptable thermal performance by supplying approximately 85% of the building space heating and hot water requirements.

7.2. BI, Trombe Wall

1. Nowzari R. and Atikol U., Transient Performance Analysis of a Model Building Integrated with a Trombe-Wall, 2009: Conference HTE'09, 20-22 August 2009, Moscow, Russia.

Contexts	Outcomes
Investigation of temperature behaviour of a hypothetical two-story building with a total floor area of 120 m^2 by modelling and simulation with TRNSYS program. A vented Trombe wall was adopted for the south	The simulation results obtained by TRNSYS for the hypothetical building integrated with a thermal storage wall: for January because it is one of the coldest months of the year.

façade of the ground floor and a direct gain window of area 6.5 m^2 was placed on the south façade of the First floor. It was assumed that the model building was located in Larnaca, Cyprus.	

7.3. BI, PVT

1. Chen Y., Athienitis A. K. and Galal K., Modeling, design and thermal performance of a BIPV/T system thermally coupled with a ventilated concrete slab in a low energy solar house: Part 1, BIPV/T system and house energy concept, 2010: Solar Energy 84(11), 1892–1907.

http://dx.doi.org/10.1016/j.solener.2010.06.013

Contexts	Outcomes
A quasi-two dimensional, control volume, steady state model for the simulation of the thermal performance of a BIPVT system, as well as a linear equation for predicting the temperature of the PVs and air at the outlet was developed based on measured data (the model and the equation could be applied to other BIPVT systems with similar configurations and they are useful in preliminary design and for control of air flow in the BIPVT system). During the initial design stage, the house was first analyzed without renewable energy use: based on HOT 2000 simulations, the annual gross space heating load (without solar gains) was evaluated Climatic conditions: Eastman, Quebec, Canada (a cold climate area).	A thermal model of the BIPV/T system suitable for preliminary design and control of the airflow is developed.

7.4. BI, PV

1. Mei L., Infield D., Eicker U. and Fux V., Thermal modelling of a building with an integrated ventilated PV façade, 2003: Energy and Buildings 35(6), 605–617.

http://dx.doi.org/10.1016/S0378-7788(02)00168-8

Contexts	Outcomes
Dynamic, finite element thermal model for ventilated PV façades combined with TRNSYS → complete	A thermal building model is developed that include submodels of the

thermal building model incorporating a ventilated PV façade and solar air collectors. Building with an integrated ventilated PV façade/solar air collector system. Building model validated with experimental data from a 6.5-m high PV façade on the Mataro Library near Barcelona.	ventilated PV façade and the additional solar air collectors. The modelled and the measured air temperatures were found to be in good agreement. The heating and cooling loads for the building with and without that ventilated façade were calculated and the impact of climatic variations on the performance such buildings was also investigated. The results showed that the cooling loads were marginally higher with the PV façade for all locations considered, while the impact of the façade on the heating load depended on the location.

7.5. BI, Several systems

1. Kuhn T.E., Herkel S., Frontini F., Strachan P. and Kokogiannakis G., Solar control: A general method for modelling of solar gains through complex facades in building simulation programs, 2011: Energy and Buildings 43(1), 19 – 27.

http://dx.doi.org/10.1016/j.enbuild.2010.07.015

Contexts	Outcomes
A new method (¨black box¨ model) for integrating complex façades in building simulation programs was developed. The method was designed to be used for complex façade components with nontrivial angular dependence. Complex façades: façades with prismatic layers, light re-directing surfaces, etc. → façade properties with complex angular dependence, façades with non-airtight layers, non-flat surfaces, etc. The method was implemented in ESP-r and the implementation was validated; the authors noted that the method could be implemented also in other detailed simulation programs such as DOE-2, EnergyPlus, TRNSYS or TAS thermal analysis software.	Advantage of the new method: only uses measurable quantities of the transparent or translucent part of the façade as a whole. General idea of the model: to describe every complex façade with a two-layer model → each of the two virtual layers has an effective solar absorptance with the desired angular dependence, between the two layers, there is a temperature-dependent thermal resistance.

7.6. BA, Space heating/water heating

1. Ji J., Luo C., Chow T.-T., Sun W. and He W., Thermal characteristics of a building-integrated dual-function solar collector in water heating mode with natural circulation, 2011a: Energy 36 (1), 566–574.

http://dx.doi.org/10.1016/j.energy.2010.10.004

Contexts	Outcomes
Building-integrated (added on the façade) dual-function solar collector in water heating mode with natural circulation was studied (modified collector). Dual function: passive space heating during cold winter; water heating over warm seasons (two independent modes). Dynamic numerical model for water heating performance and solar transmission though building façade / experimental validation (experimental set-up: collector prototype mounted on the exterior wall of a testing hot-box). Finite difference model. Heat flow through the front glazing: considered as one-dimensional. Water heating model for the collector; building façade model (coupling: collector model with building wall); space thermal load computations. Region/climatic conditions: Hefei, China. Based on practical air-conditioned room design conditions, numerical analysis was conducted to study water heating performance and to compare the solar transmission through building façade in different seasons with or without its presence.	A coupled numerical model has been developed for this building-integrated dual-function solar collector system. Through experimental validation, the numerical model was demonstrated, which is able to give accurate predictions. Over typical summer days, with the modified collector the daily cooling load of the room was reduced by 2%. The modified design did not lead to summer overheating (common in most of the traditional passive space heating systems). In addition, over typical summer days, water temperature in storage tank may exceed 40^{o}C (good for most of the hot water applications). During typical autumn days, the modified collector in water heating mode with natural circulation resulted in an increase of space cooling load but a reduction of space heating load. Furthermore, during typical autumn days, the water temperature can reach 48^{o}C with a thermal efficiency of 48.4% and a corresponding water heat gain at 6.57 MJ/m^{2}.

2. Ji J., Luo C-L, Chow T-T, Sun W. and He W., Modelling and validation of a building-integrated dual-function solar collector, 2011b: Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy, 225-259.

DOI: 10.1177/2041296710394243

Contexts	Outcomes
Two dynamic numerical models based on the finite-difference method. Region/climatic conditions: Hefei, China. A novel BI solar thermal system (BI dual-function solar collector) was proposed. The system had two independent operating modes: passive space heating mode and water heating mode (it used criteria to select the operating mode: during cold days it works in passive space heating and during warm season it works in the water heating mode). A testing system was established and it performed in thermosiphon water heating mode for heating of water. Two dynamic numerical models were presented for the two operating modes of the testing system. The experimental data were used to validate the two models.	For the thermosiphon water heating mode, it was proved by comparison of the experimental and simulated results that during the experimental periods, the prediction of the daily thermal efficiencies only had a maximal relative absolute deviation of 2.6% and the RMSD of the simulated result of the indoor temperature was around 0.4^{o}C. For the case of the space heating mode, the numerical model can also give accurate predictions but with higher deviation compared to the model for the system in the thermosiphon water heating mode.

7.7. General studies

1. Charvát P., Klimeš L. and Ostrý M., Numerical and experimental investigation of a PCM-based thermal storage unit for solar air systems, 2014: Energy and Buildings 68, 488–497.

http://dx.doi.org/10.1016/j.enbuild.2013.10.011

Contexts	Outcomes
Phase Change Materials (PCMs) for thermal energy storage in air-based solar thermal systems. Climatic conditions: Czech Republic. Model and experimental validation (paraffin-based PCM). Numerical model of the heat storage unit was implemented as a 1D transient heat transfer problem; TRNSYS 17 simulation tool was used for the numerical investigations; coupling between TRNSYS and MATLAB was adopted for the development of the numerical model of the heat storage unit; the numerical model developed in MATLAB was consequently recompiled with the use of C++ programming language to the form of the build-in TRNSYS module.	The results of the simulations demonstrated a good agreement with the experimental results. The model was adopted for a parametric study analysing the influence of certain parameters. The performed investigations revealed a potential of the use of latent heat thermal storage in air-based thermal systems with a narrow temperature operation range.

8. Studies of Energetic/Thermal Simulation (emphasis: building)

No available studies

9. Studies of Energetic/Thermal Simulation (emphasis: system)

9.1. BI, Solar Thermal

1. G. Notton, F. Motte, Chr. Cristofari, J.-L. Canaletti, New patented solar thermal concept for high building integration: Test and modeling, 2013: Energy Procedia 42, 43-52.

http://dx.doi.org/10.1016/j.egypro.2013.11.004

Contexts	Outcomes
A new concept of flat plate solar collector is presented: it has a remarkable shape and is integrated into a rainwater gutter. Several solar modules are connected serially or in parallel. A numerical model is developed in Matlab environment using a finite difference model and an electrical analogy. The thermal model is validated from experimental data under various meteorological situations. The adequacy of this model with the experimental data is shown for the water temperatures and for various temperatures inside the solar collector.	The developed model has a good accuracy with the measured data: the relative root mean square errors are around 5% for the water temperatures and from 4.6 % to 10% for the internal ones. The main advantage of this model is to be able to modify easily the characteristics and the form of the used materials.

9.2. BI, Skin Façades

1. D. Faggembauu, M. Costa, M. Soria, A. Oliva, Numerical analysis of the thermal behaviour of ventilated glazed facades in Mediterranean climates.
Part I: development and validation of a numerical model, 2003: Solar Energy 75, 217–228.

http://dx.doi.org/10.1016/j.solener.2003.07.013

Contexts	Outcomes
Despite the architectural interest of the glazed façades, in Mediterranean climate these systems are responsible for the overheating of the building. In these zones, double-skin envelopes made up of two layers of glass separated by an air channel in order to collect or evacuate the solar energy absorbed by the façade are a design option that could resolve this issue.	A specific numerical code (for time-accurate simulations of the thermal and fluid-dynamic behaviour of ventilated and conventional façades) was developed. It was based on 1D-discretizations and allowed the evaluation of the performance of the façades over the course of a year. The

	numerical results of each submodel were compared with the results of analytical models; both with reference situations and with experimental measures obtained in real-site test façade facilities (in different climatic conditions). The numerical code is a useful tool for the evaluation of the performance of different building façades. Different materials, orientations, geometries and climates can be tested in order to optimise designs/recommendations.

9.3. BI, PVT

1. Agrawal B. and Tiwari G. N., Optimizing the energy and exergy of building integrated photovoltaic thermal (BIPVT) systems under cold climatic conditions, 2010: Applied Energy 87(2), 417 – 426.

http://dx.doi.org/10.1016/j.apenergy.2009.06.011

Contexts	Outcomes
One-dimensional transient model was developed by using basic heat transfer equations. An analysis was carried in order to select an appropriate BIPVT system suitable for the cold climatic conditions of India. Climatic conditions: data for Srinagar city. Software "Matlab 7" to evaluate the performance and compute the useful exergy for all combinations of the BIPVT systems.	Performance analysis of a BIPVT system has been evaluated for four different parallel and series combinations under the cold climatic conditions of India. It is concluded that for a constant mass flow rate of air, the series combination is more suitable for the buildings fitted with BIPVT systems as rooftop.

2. Yang T., Athienitis A.K., A study of design options for a building integrated photovoltaic/thermal (BIPV/T) system with glazed air collector and multiple inlets,

2012: Energy Procedia 30, 177 – 186.

http://dx.doi.org/10.1016/j.egypro.2012.11.022

Contexts	Outcomes
Open loop air based BIPVT system having single inlet. Experiment was performed inside the lab under indoor simulator at Concordia University, Canada. A control volume model was developed to validate the experimental results. Improved designs of the BIPV/T system with multiple inlets and other means of heat transfer enhancement are examined by means of the simulations.	The simulation results showed that the application of two inlets on a BIPVT collector increased thermal efficiency by around 5% and increase electrical efficiency marginally. An added vertical glazed solar air collector improved thermal efficiency significantly while the improvement was more significant with wire mesh packing in the collector.

3. Corbin C.D., Zhai Z.J., Experimental and numerical investigation on thermal and electrical performance of a building integrated photovoltaic–thermal collector system, 2010: Energy and Buildings 42, 76–82.

http://dx.doi.org/10.1016/j.enbuild.2009.07.013

Contexts	Outcomes
An experimentally validated CFD model of a new BIPVT collector was investigated to examine the effect of active heat recovery on cell efficiency and to determine the effectiveness of that device as a solar hot water heater. A parametric analysis indicated that cell efficiency can be raised by 5.3% and water temperatures suitable for domestic hot water use are possible. Thermal and combined (thermal plus electrical) efficiencies were found to be 19% and 34.9%, respectively. A new correlation was developed for relating electrical efficiency to collector inlet water temperature, ambient air temperature and insolation that allowed cell efficiency to be calculated directly. In terms of the experimental set-up: the novel experimental collector was originally designed and constructed for the 2007 U.S. Solar Decathlon by the University of Colorado Solar Decathlon Team while the collector had 41 PV panels suspended above an array of tube-fin absorbers. Two models were developed to evaluate the performance of the BIPV/T collector under different operating conditions. A collector cooled by natural convection was the base case for cell temperature comparison. That model represented a standard BIPV where PVs are mounted close to the roof surface. The second, a collector with a liquid-cooled tube-fin	The proposed BIPVT collector demonstrated potential for providing increased electrical efficiency of up to 5.3% over a naturally ventilated BIPV roof, reducing negative effects of integration into building façade. This collector provided hot water for domestic use or hydronic space heating with no additional roof space requirements. The total efficiency of the collector was predicted to be 34.9%. A new correlation was developed for relating PV cell efficiency to collector water inlet temperature, ambient air temperature and insolation. That correlation allowed cell efficiency to be predicted based on readily available and easily measured quantities. Standard methods for characterizing solar hot water collectors were also applied to determine the important collector properties from which thermal efficiency can be calculated. The numerical model was well validated and demonstrated good agreement with the experimental data from a full-scale test collector.

absorber into the cavity, simulated active heat recovery. The collector geometry simulated in both models matched with the physical characteristics of components in the physical test array. A CFD package was adopted for the simulations.	

4. H.M. Yin, D.J. Yang, G. Kelly, J. Garant, Design and performance of a novel building integrated PV/thermal system for energy efficiency of buildings, 2013: Solar Energy 87, 184–195.

http://dx.doi.org/10.1016/j.solener.2012.10.022

Contexts	Outcomes
A building integrated multifunctional roofing system has been designed to harvest solar energy through photovoltaics (PVs) and heat utilization while minimizing PV efficiency loss and eliminating the material and labor redundancies of conventional PV systems.	The performance analysis indicates that the proposed solar roofing system provides significant advantages over the traditional asphalt shingle roof and PV systems without cooling.

5. T.T. Chow, A.L.S. Chan, K.F. Fong, Z. Lin, W. He, J. Ji, Annual performance of building-integrated photovoltaic/water-heating system for warm climate application, 2009: Applied Energy 86(5), 689-696.

http://dx.doi.org/10.1016/j.apenergy.2008.09.014

Contexts	Outcomes
Through computer simulation with energy models developed for this integrative solar system in Hong Kong, the results showed that the photovoltaic/water-heating (PVW) system is having much economical advantages over the conventional photovoltaic (PV) installation. The system thermal performance under natural water circulation was found better than the pump-circulation mode.	Through computer simulation with energy models developed for this integrative solar system in Hong Kong, the results showed that the photovoltaic/water-heating (PVW) system is having much economical advantages over the conventional photovoltaic (PV) installation. The system thermal performance under natural water circulation was found better than the pump-circulation mode.

6. L. Liao, Y. Poissant, M. Collins, A. K. Athienitis, L. Candanedo and K.-W. Park, Numerical and experimental study of heat transfer in a BIPV-thermal system, 2007: Journal of Solar Energy Engineering 129(4), 423-430.

Contexts	Outcomes
A CFD study was conducted for a BIPVT. The heat transfer in the BIPVT cavity was studied with a 2D CFD model. The realizable k-ε model was adopted to simulate turbulent flow and convective heat transfer in the cavity, including buoyancy effect and long-wave radiation between boundary surfaces was also modeled. A particle image velocimetry (PIV) system was employed to examine fluid flow in BIPVT cavity and provide partial validation for the CFD model. Average and local convective heat transfer coefficients were generated with the CFD model using measured temperature profile as boundary condition.	Cavity temperature profiles were calculated and compared to the experimental data for different conditions. A good agreement was observed. Correlations of convective heat transfer coefficients were generated for the cavity surfaces. Local heat transfer coefficients, such as those presented, are necessary for the prediction of temperature distributions in BIPVs.

7. S. Li, P. Karava, S. Currie, W. E. Lin, E. Savory, Energy modeling of photovoltaic thermal systems with corrugated unglazed transpired solar collectors – Part 1: Model development and validation, 2014: Solar Energy, In press.

http://dx.doi.org/10.1016/j.solener.2013.12.040

Contexts	Outcomes
Energy models for two systems: Unglazed Transpired solar Collector (UTC) only; UTC with PVs, were developed. CFD simulations were performed. The energy models were validated with measurements (outdoor two-story test building at Purdue University, USA). Good agreement between the model prediction and the experimental data was observed.	Correlations for the average Nu related to exterior and interior convective heat transfer and the effectiveness were obtained, for the first time, for the configurations considered (UTCs with trapezoidal-shaped corrugation and small perforation suction; UTCs with PVs), through validated CFD simulations (high resolution grids; RNG k–ε turbulence closure model). The authors note that a detailed discussion of the energy performance of their system is presented in a second paper (Part 2) which is an extension of that work.

8. S. Li, P. Karava, Energy modeling of photovoltaic thermal systems with corrugated unglazed transpired solar collectors – Part 2: Performance analysis, 2014: Solar Energy, In press.

http://dx.doi.org/10.1016/j.solener.2013.12.041

Contexts	Outcomes
This paper which is an extension of the previous one (part 1) outlined all the factors that affect the thermal performance of PVTs integrated with UTCs and examined the impact of several parameters (corrugation geometry, plate orientation, incident turbulence intensity).	The findings of that study revealed that the 'vertical' installation of the plate greatly enhanced exterior and interior convective heat transfer due to the combined effects of the corrugation, wind speed, suction velocity and buoyancy, for the configuration of UTC only. Increasing the turbulence intensity increased the exterior Nu. Optimizing the geometry can greatly improve the energy performance of UTC systems. Improving the energy performance through optimizing the geometrical parameters for UTCs with PV panels was less effective.

9. Chow T. T., He W., Chan A. L. S., Fong K. F., Lin Z. and Ji J., Computer modeling and experimental validation of a building-integrated photovoltaic and water heating system, 2008: Applied Thermal Engineering 28(11–12), 1356-1364.

http://dx.doi.org/10.1016/j.applthermaleng.2007.10.007

Contexts	Outcomes
A dynamic simulation model of a BI PV and water heating system was developed. The numerical model was developed based on the finite difference control volume approach while the integrated use of energy balance and fluid flow analysis allowed the prediction of system dynamic behavior under external excitations such as changes in weather, water consumption and make-up conditions. The validity of the model was verified by comparing its predicted operating temperature changes and system daily efficiencies with the measured data acquired from an experimental rig at the City University of Hong Kong.	The use of multi-nodal scheme is considered most useful in apprehending the underlying physical processes. The integrated use of energy balance and fluid flow analysis allows the prediction of the system behavior in a comprehensive manner.

9.4. BI, PV

1. A. Kane, V. Verma, Performance Enhancement of Building Integrated Photovoltaic Module using Thermoelectric Cooling, 2013: International Journal of Renewable Energy Research 3(2).

http://www.ijrer.com/index.php/ijrer/article/view/588

Contexts	Outcomes
In order to cool BIPV, a thermoelectric system was developed. Thermoelectric module was attached at the back of PV module (cooling mode). Initially mathematical modeling of individual systems was performed. Then the dynamic model of BIPV/Thermoelectric system with consideration of temperature of PV panel temperature was developed.	The results of the simulations revealed that the proposed cooling method improved PV efficiency but at the cost of minimal power loss. The detailed analysis of the model showed that performance and life enhancement of BIPV could be achieved with 10^{o}C cooling without loss of power.

2. Mei L., Infield D., Eicker U., Fux V., Parameter estimation for ventilated photovoltaic façades, 2002: Building Services Engineering Research and Technology 23(2), 81-96.

doi: 10.1191/0143624402bt033oa

Contexts	Outcomes
The estimation of thermal parameters which describe the performance of ventilated PV façades integrated into buildings was examined.	A direct numerical approach was developed in order to identify the parameters that describe heat transfer processes. The method allowed the heat transfer coefficients to be obtained (directly) from data measured on an operational ventilated PV façade. The results were compared with values which were taken from conventional practice.

9.5. BI, PCM for passive solar walls

1. K. Darkwa, P.W. O´Callaghan, Simulation of phase change drywalls in a passive solar building, 2006: Applied Thermal Engineering 26, 853 –858.

http://dx.doi.org/10.1016/j.applthermaleng.2005.10.007

Contexts	Outcomes
Integration of phase change materials (PCMs) into building fabrics: composite PCM drywall samples (i.e. randomly-mixed and laminated PCM drywalls) were studied in a model passive solar building. Thermal simulations for a room were performed numerically by finite difference method based on the fixed mesh method.	Laminated PCM sample with a narrow phase change zone was capable of increasing minimum room temperature by about 17% more than the randomly-mixed type. Even there was some display of non-isothermal phase change process the laminated system was proved to be thermally more effective

	in terms of evolution and utilization of latent heat. Further heat transfer enhancement process was required for the development of the laminated system.

9.6. BA, PVT

1. Tonui J.K., Tripanagnostopoulos Y., Performance improvement of PV/T solar collectors with natural air flow operation, 2008: Solar Energy 82, 1–12.

http://dx.doi.org/10.1016/j.solener.2007.06.004

Contexts	Outcomes
An analytical model was developed in Fortran90 to evaluate induced airflow rate and PVT system temperature for natural airflow. Three configurations were studied: Reference; with thin metal sheet in the middle of the air channel (TMS); with fins in the middle of the air channel (FIN). These low-cost modifications in the air channel were made in order to improve heat extraction.	Model estimated the outlet air temperature within ± 2^0C for all configuration. The air mass flow rate was also calculated by this model. The air mass flow rates which were evaluated by the model for the three configurations were in agreement with the results reported for ventilated PV façades by other researchers. The model results revealed that the modified systems had better thermal efficiency for every parameter considered with the FIN system giving better performance than the TMS system but both contributed positively towards enhancing heat extraction from PV module for better electrical and thermal energy production.

2. Kalogirou S.A, Tripanagnostopoulos Y., Industrial application of PV/T solar energy systems, 2007: Applied Thermal Engineering 27, 1259–1270.

http://dx.doi.org/10.1016/j.applthermaleng.2006.11.003

Contexts	Outcomes
TRNSYS simulations were performed for hybrid PVT solar systems for domestic hot water applications both passive (thermosiphonic) and active. Prototype model was manufactured at University of	The results revealed that the electrical production of the system with polycrystalline solar cells was more than the amorphous one but the solar thermal fraction was slightly lower. A

Patras (Greece), using polycrystalline silicon (pc-Si) and amorphous silicon (a-Si) combined with water heat extraction unit. Simulations were performed using Typical Meteorological Year (TMY) data from Nicosia (35^0), Athens (38^0) and Madison (43^0). TRNSYS model calculated the energy and cost of hybrid PVT system with thermosiphon and forced water flow.	non-hybrid PV system gave about 25% more electrical energy but the present system covered also, depending on the location, a large percentage of the thermal energy of the industry considered.

3. Kalogirou S.A, Tripanagnostopoulos Y., Hybrid PV/T solar systems for domestic hot water and electricity production, 2006: Energy Conversion and Management 47, 3368–3382.

http://dx.doi.org/10.1016/j.enconman.2006.01.012

Contexts	Outcomes
TRNSYS simulation were performed for PVT systems, for three locations at different latitudes: Nicosia (35^o), Athens (38^o) and Madison (43^o). In that study, the authors considered a domestic thermosiphonic system and a larger active system suitable for a block of flats or for small office buildings.	The results revealed that a considerable amount of thermal and electrical energy was produced by the PVTs and the economic viability of the systems was improved. The electrical production of the system with polycrystalline solar cells was more than that employing the amorphous ones, but the solar thermal contribution was slightly lower. A non-hybrid PV system produced about 38% more electrical energy, but the present system covered also a large percentage of the hot water needs of the buildings considered. The TRNSYS results gave an account of the energy and cost benefits of the studied PVTs with thermosiphon and forced water flow. As a general conclusion, the overall energy production of the units was increased and the hybrid units had better chances of success. This was also strengthened by the improvement of the economic viability of these systems, especially for applications where low temperature water, like hot water production for domestic use, was also required.

4. Garg H.P., Adhikari R.S., Conventional hybrid photovoltaic/thermal (PV/T) air heating collectors: steady-state simulation, 1997: Renewable Energy 11(3), 363-385.

http://dx.doi.org/10.1016/S0960-1481(97)00007-4

Contexts	Outcomes
Performance analysis of a conventional PVT air heating collector was performed. A simulation model was developed while various performance parameters were calculated for single-glass and double-glass configurations. The results were presented to show the effect of various design and operational parameters on the performance of a system. The authors noted that these results are useful for designing such systems more scientifically; however, final selection of design and operational variables must be based on system cost-effectiveness.	The use of single- and double-glass covers in a PVT air heating system depends on the range of the temperatures for which the system is designed. The system efficiency increased with increase in collector length, mass flow rate, cell density and decreased with increase in duct depth for both configurations.

9.7. General studies

1. G. Notton, C. Cristofari, M. Mattei, P. Poggi, Modelling of a double-glass photovoltaic module using finite differences, 2005: Applied Thermal Engineering 25, 2854–2877.

http://dx.doi.org/10.1016/j.applthermaleng.2005.02.008

Contexts	Outcomes
A simulation model (finite differences) for a double-glass multi-crystalline PV module was developed and validated by using experimental data. The simulation model was based on various thermal hypotheses, particularly concerning the convective transfer coefficients and various hypotheses found in the literature were tested (the best one was accepted).	The authors considered as convective coefficient: - Only the forced convective one - The highest value between free and forced one - The sum of two coefficients: free and forced Using the developed modelling procedure, the cell temperature was estimated with a root mean square error of 1.3°C.

2. Kalogirou S.A., Use of TRNSYS for modeling and simulation of a hybrid pv–thermal solar system for Cyprus, 2001: Renewable Energy 23, 247–260.

http://dx.doi.org/10.1016/S0960-1481(00)00176-2

Contexts	Outcomes
Modelling and simulation of a PVT system was performed. The system consisted of a normal PV panel at the back of which a heat exchanger with fins was embedded. The advantage of that system was that the PV operated at a lower temperature and thus, more efficiently and also hot water was produced at the same time as electricity. The PV system consisted of a series of PV panels, a battery bank and an inverter while the thermal system consisted of a hot water storage cylinder, a pump and a differential thermostat. The system was modelled by TRNSYS, for typical meteorological year (TMY) conditions for Nicosia, Cyprus. The main component of the TRNSYS deck file constructed was Type 49, accompanied by other additional components required for the model.	The results revealed that the optimum water flow rate of the system was 25 l/h. The hybrid system increased mean annual efficiency of the PV system from 2.8% to 7.7% and in addition covered 49% of the hot water needs of a house, and thus, increased the mean annual efficiency of the system to 31.7%.

3. Bergene T., Løvvik O.M., Model calculations on a flat plate solar heat collector with integrated solar cells, 1995: Solar Energy 55(6), 453-462.

http://dx.doi.org/10.1016/0038-092X(95)00072-Y

Contexts	Outcomes
A detailed physical model of a PVT system was developed and algorithms for making quantitative predictions regarding the performance of the system were presented. The model was based on an analysis of energy transfers due to conduction, convection, radiation and predicted the amount of heat that can be drawn from the system and the (temperature-dependent) power output. Emphasis was given on the dependence of the fin width to tube diameter ratio.	In that study they showed that a PVT system was interesting with respect to system efficiency while algorithms that can be used in computer simulations were presented. The model predicted the performance of the system fairly well with system efficiencies, thermal plus electrical, about 60-80%. However, the authors mentioned that direct comparisons with relevant experiments were difficult as the system parameters relevant to the proposed model were not explicitly stated in the description of the experiments. As possible applications they proposed a domestic system for combined production of electricity and low temperature heat (for example as a pre-heater in a hot water system) and a large-scale system that it could be interesting regarding production of hydrogen and fresh water.

4. A. S. Yadav, J.L. Bhagoria, A CFD based thermo-hydraulic performance analysis of an artificially roughened solar air heater having equilateral triangular sectioned rib roughness on the absorber plate, 2014: International Journal of Heat and Mass Transfer 70, 1016–1039.

http://dx.doi.org/10.1016/j.ijheatmasstransfer.2013.11.074

Contexts	Outcomes
A numerical investigation to analyze the 2D incompressible Navier–Stokes flows through the artificially roughened solar air heater for relevant Reynolds number (from 3800 to 18,000) was conducted. Finite-volume-based numerical method was adopted. The commercial finite-volume based CFD code ANSYS FLUENT was utilized to simulate turbulent airflow through artificially roughened solar air heater. RNG k–e turbulence model was used to solve transport equations for turbulent flow energy and dissipation rate.	For a given constant value of heat flux (1000 W/m^2), the performance of the artificially roughened solar air heater was strong function of Reynolds number, relative roughness pitch and relative roughness height. The optimum configuration of the roughness element for artificially roughened solar air heater was evaluated.

5. J. Xamán, G. Álvarez, L. Lira, C. Estrada, Numerical study of heat transfer by laminar and turbulent natural convection in tall cavities of façade elements, 2005: Energy and Buildings 37, 787 –794.

http://dx.doi.org/10.1016/j.enbuild.2004.11.001

Contexts	Outcomes
Laminar and turbulent natural convection flow in a 2D tall rectangular cavity heated from the vertical side was studied numerically (finite volume method). Fluid flow and heat transfer by natural convection in a tall cavity using laminar and turbulent k–ε models was examined.	This study will help to have more accurate heat transfer parameters for several applications: façade elements, insulating units, double-skin façades, etc.

6. S. Farah, W. Saman, and M. Belusko, Chapter 79 Integrating Solar Heating and PV Cooling into the Building Envelope, 2013: A. Håkansson et al. (Eds.): Sustainability in Energy and Buildings, SIST 22, pp. 887–901, Springer-Verlag Berlin Heidelberg.

DOI: 10.1007/978-3-642-36645-1_79

Contexts	Outcomes
A new 1D, steady-state BI solar collector model was developed, incorporating PVT and thermal (PVTT) collectors connected in series. In summer, the PVT collector was air-cooled and the collected heat was discarded to the surroundings while thermal collector heated the water for domestic use. In winter, both PVT and thermal collectors were water-cooled producing domestic hot water. The presented BI collector incorporated an unglazed PVT collector and a glazed thermal collector, connected in series to form one PVTT collector. The PVTT collector was cooled by water or simultaneously by two fluids (air and water). The cooling fluid tube or channel was bounded by stiffened corrugated roof metal sheet and absorber. The roof metal sheets were available in different profiles and they were made from aluminum or coated steel. These profiles can be easily modified to allow the installation of the absorber over a trough space and the installation of the PV laminate and the glazing of the PVT and thermal sections respectively.	For the same total collector area and for the same PVT section characteristics, PVTT was found to be better than PVT by reducing the summer operating temperature. That temperature reduction avoids collector thermal stresses and provides modest electrical power output improvement; however, this small improvement is associated with a more complex collector.

10. Studies of Energetic/Thermal Simulation (emphasis: building/system)

10.1. BI, Solar Collectors

1. L. Gao, H. Bai, X. Fang, T. Wang, Experimental study of a building-integrated solar air heating system in cold climate of China, 2013: Energy and Buildings 65, 359–367.

http://dx.doi.org/10.1016/j.enbuild.2013.06.014

Contexts	Outcomes
A series of experiments were carried out under real transient outdoor conditions to investigate thermal performance, color effect and energy savings of a building-integrated solar air heating system based on unglazed transpired collectors (UTCs). The average efficiency of black UTC was 77.64% and 68.92% under high and low air flow rate respectively, which are higher than most glazed flat-plate collectors. Collector's surface color had an effect on its thermal performance.	Design heating load of a reference building in Harbin can be reduced by 6.4% due to reduced wall loss with the application of UTC. With better coordination with architectural design at early stage in a project, this building-integrated solar air heating system can be both esthetically and technically viable in cold climate of China.

10.2. BI, Skin Façade

1. A. Pappas, Z. Zhai, Numerical investigation on thermal performance and correlations of double skin facade with buoyancy-driven airflow, 2008: Energy and Buildings 40, 466–475.

http://dx.doi.org/10.1016/j.enbuild.2007.04.002

Contexts	Outcomes
The primary parameters for a double skin façade (DSF) design were examined: an integrated and iterative modeling process for analyzing the thermal performance of DSF cavities with buoyancy-driven airflow by using a building energy simulation program (BESP) along with a CFD package, were adopted. A typical DSF cavity model was established and simulated. The model was validated using measured data from Dirk Saelens (Vliet Test Cell in Leuven, Belgium).	The energy performance and potential influential factors of such DSF were investigated. The modeling was used to develop correlations for cavity airflow rate, air temperature stratification, and interior convection coefficient that can provide a more accurate energy analysis of a DSF with buoyancy-driven airflow within an annual building energy simulation program.

2. J. W. Moon, J.-H. Lee, Y. Yoon, S. Kim, Determining optimum control of double skin envelope for indoor thermal environment based on artificial neural network, 2014: Energy and Buildings 69, 175–183.

http://dx.doi.org/10.1016/j.enbuild.2013.10.016

Contexts	Outcomes
Development of an artificial neural network (ANN)-based temperature control method to keep energy efficient indoor thermal environment in buildings with double skin envelopes.	The prediction accuracy of the ANN model for indoor temperature was proved. That accuracy supported the applicability of that ANN model. The developed ANN model has the potential to be successfully applied to temperature control method for buildings with double-skin envelope systems over summer.

10.3. BI, PVT

1. Vats K., Tiwari G.N., Energy and exergy analysis of a building integrated semitransparent photovoltaic thermal (BISPVT) system, 2012: Applied Energy 96, 409–416.

http://dx.doi.org/10.1016/j.apenergy.2012.02.079

Contexts	Outcomes
Building integrated semitransparent photovoltaic thermal system was considered to the roof of a room for analytical and numerical studies. One dimensional heat conduction equation in quasi steady state was considered. No temperature stratification in the air of room and semitransparent PV module was also assumed. The room was considered as thermally insulated. The meteorological data was for Pune (India) Matlab 7.1 software was used. Six different type PV module was considered to perform comparison work on the basis of energy and exergy analysis.	Cell efficiency decreased with increase in cell temperature. The efficiency was found to be 16.0% for HIT (PV cell on top of a crystalline silicon (c-Si) cell) and 6.0% for a-Si (thin amorphous silicon). HIT produced maximum annual electrical energy (810 kW h) → suitable for generating electrical power. Si produced maximum annual thermal energy (464 kW h) → suitable for space heating applications. An annual overall thermal energy (2497 kW h) and exergy (834 kW h) was maximum for the HIT PV.

2. A. K. Athienitis, J. Bambara, B. O'Neill, J. Faille, A prototype photovoltaic/thermal system integrated with transpired collector, 2011: Solar Energy 85, 139–153.

http://dx.doi.org/10.1016/j.solener.2010.10.008

Contexts	Outcomes
Combination of BIPV/T and UTC systems for building façades is considered in this paper – specifically, the design of a prototype façade-integrated photovoltaic/thermal system with transpired collector (BIPV/T). A full scale prototype is constructed with 70% of UTC area covered with PV modules specially designed to enhance heat recovery and compared to a UTC of the same area under outdoor sunny conditions with low wind. The orientation of the corrugations in the UTC is horizontal and the black-framed modules are attached so as to facilitate flow into the UTC plenum. The BIPV/T concept is applied to a full scale office building demonstration project in Montreal, Canada	The value of the generated energy – assuming that electricity is at least four times more valuable than heat – is between 7% and 17% higher. Also, the electricity is always useful while the heat is usually utilized only in the heating season. The ratio of photovoltaic area coverage of the UTC may be selected based on the fresh air heating needs of the building, the value of the electricity generated and the available building surfaces.

10.4. BI, PV

1. Thevenard, D., Review and recommendations for improving the modelling of building integrated Photovoltaic systems, 2005: IBPSA Conference, Montreal Canada 15-18 Aug.

Contexts	Outcomes
The models for photovoltaic (PV) systems currently in ESP-r prove very useful in estimating the electrical and thermal impact of BIPVs (they represent well the impact of PVs on the building thermal energy balance) but they may lack in accuracy in the prediction of the system energy production → To achieve both goals it is suggested to improve the PV models in ESP-r, taking into account all phenomena affecting the power output of PV modules: solar radiation intensity, cell temperature, angle of incidence, spectral distribution, uncertainty in manufacturer ratings, ageing, mismatch, soil and dirt, snow, partial shading, diodes, wiring → This would provide a more realistic estimate of the probable PV output over its lifetime. It is suggested to implement three models: a simple model based on constant efficiency, a one-diode equivalent model with explicit temperature dependency of the parameters, the Sandia model for cases when detailed modeling is required. PVs in ESP-r are modeled as an active material which can be located at any node inside a construction.	In the conclusion, the author noted that the current ESP-r PV model was adequate to predict the impact of PVs on building thermal energy balance, but may lack in accuracy to predict the energy production of the PV system. To achieve both goals at once it was suggested to improve or rewrite the PV models in ESP-r.

10.5. BA, Several systems

1. Bakker M., Zondag H.A., Performance and costs of a roof-sized PV/thermal array combined with a ground coupled heat pump, 2005: Solar Energy 78, 331–339.

http://dx.doi.org/10.1016/j.solener.2004.09.019

Contexts	Outcomes
A 25-m^2 PVT system and ground coupled heat pump was simulated with TRNSYS. The ground loop heat exchangers were modeled by using Eskilson´s model, implemented in TRNSYS type 81. This model assumed that ground thermal	This system could cover 100% total heat demand of newly built Dutch one family dwelling. Based on ten-year average energy balance of the reference system, the

properties were homogeneous, which was justified as long as the model was only used to describe long-term processes.	PVT was able to cover nearly all (96%) of its own electricity use (including pumps, electrical heater, and heat pump). The system was able to cover 100% of the heat use for space and tap water heating: the former was fully covered by the ground source heat pump by using PVT supplied heat, while the latter was partially covered by the PVTs, and partially by the heat pump.

2. F. A. Ghaith, R. Abusitta, Energy analyses of an integrated solar powered heating and cooling systems in UAE, 2014: Energy and Buildings 70 (2014) 117–126.

http://dx.doi.org/10.1016/j.enbuild.2013.11.024

Contexts	Outcomes
Viability of using the integrated Solar Heating Cooling (SHC) systems in residential buildings in UAE, by studying the thermal performance and potential energy savings, in addition to the economical and environmental aspects such as payback period and reduction in CO_2 emissions. This work involves integration of the absorption chiller with solar thermal collectors to provide a continuous cooling.	The obtained results for the fully solar powered system, showed that about 159 kWh and 126 ton/year savings were achieved in the Annual Energy Consumption (AEC) and CO_2 emissions, respectively. The maximum solar penetration of 20% was found to be optimum as it reduced AEC by 176 kWh and cut off CO_2 emissions by 140 ton/year with a payback period of 4 years.

11. Studies of Optical Simulation (emphasis: building)

No available studies

12. Studies of Optical Simulation (emphasis: system)

12.1. BI, Several systems

1. Glória Gomes M., Santos A. J., Moret Rodrigues A., Solar and visible optical properties of glazing systems with Venetian blinds: Numerical, experimental and blind control study, 2014: Building and Environment 71, 47 –59.

http://dx.doi.org/10.1016/j.buildenv.2013.09.003

Contexts	Outcomes
Both direct and diffuse fluxes of transmitted, reflected and absorbed solar and visible radiation within a multilayer glazing/shading system was presented. An algorithm or determining solar and visible optical properties of venetian blinds was also described, so that this type of system can be handled as a homogeneous layer of the fenestration system. Net radiation method for solving the radiant energy exchange within a multilayer system. Numerical, analytical, experimental results: comparison. Climatic conditions: Southern European regions (Lisbon, Portugal).	Model can be used for different sun profile angles and venetian blind geometries, suitable for comparing different glazing/venetian blind solutions and devising blind control strategies. Design charts were developed to help designers and users in enhancing the thermal and daylighting indoor conditions by adjusting the slat orientation of venetian blinds. The knowledge of the solar and visible optical properties of different glazing/shading systems is crucial in identifying the most effective sustainable strategies to improve the fenestration system performance, regarding building energy consumption and indoor comfort issues.

2. Wiegman J. W. E. and van der Kolk E, Building integrated thin film luminescent solar concentrators: Detailed efficiency characterization and light transport modeling, 2013: Solar Energy Materials and Solar Cells 103, 41–47.

http://dx.doi.org/10.1016/j.solmat.2012.04.016

Contexts	Outcomes
An inorganic thin film luminescent solar concentrator (LSC) was characterized experimentally. Application: as windows in buildings → building integrated (BI) LSCs.	The model can be used to calculate the LSC light transport efficiency as a function of window size, which only needs the easily measurable linear attenuation as input. That modelling related BI-LSC efficiency to window colour.

3. Baldinelli G., Double skin façades for warm climate regions: Analysis of a solution with an integrated movable shading system, 2009: Building and Environment 44(6), 1107–1118.

http://dx.doi.org/10.1016/j.buildenv.2008.08.005

Contexts	Outcomes
Glass double skin façade equipped with integrated movable shading devices. Three different modelling levels: optics of materials, fluid dynamics of the double skin façade and building energy balance. Aim: optimization of energy performance over winter as well as over summer. 3D CFD model made of two opaque walls with an inlet (bottom) and outlet (top) opening in the external wall; buoyancy driven flow regime. Climatic data: central Italy.	The simulation of façade performances with a CFD model for the winter configuration (shading closed) showed the instauration of a buoyancy induced flow inside the gap, producing the doubly beneficial effect of diminishing the heat dispersion through external walls and preheating the air for ventilation purposes.

4. A. Kerrouche, D.A. Hardy, D. Ross, B.S. Richards, Luminescent solar concentrators: From experimental validation of 3D ray-tracing simulations to coloured stained-glass windows for BIPV, 2014: Solar Energy Materials & Solar Cells 122, 99–106.

http://dx.doi.org/10.1016/j.solmat.2013.11.026

Contexts	Outcomes
Luminescent solar concentrators (LSC) are promising for BIPV (providing variety of colors, etc.). Ray-trace modeling: design, performance evaluation, optimization of LSCs. The study included 70 samples – both square and circular LSCs, containing five different fluorescent organic dyes.	Comparison of 3D ray-tracing modeling results with experimental data. 3D ray-trace results showed good agreement with the experimental measurements → confidence in the use of modeling for future larger LSCs for BIPVs.

5. Sellami, N., Mallick T.K., Design of nonimaging static solar concentrator for window integrated photovoltaic, 2012: 8th International Conference on Concentrating Photovoltaic Systems, CPV 2012; Toledo; Spain; 16 April 2012 through 18 April 2012.

DOI: 10.1063/1.4753845

Contexts	Outcomes
A solar concentrator for building integration (compact, static, able to collect maximum solar energy) was developed. The novel concentrator was designed for Window Integrated Concentrated PV (WICPV).	The concentrator was optically optimised (for different incident angles of the incoming light rays). Evaluating the best combination of the optical efficiency and the acceptance angle, 4x

	concentrator built from dielectric material, with total internal reflection was optimised. It was found to have a constant optical efficiency of 40% for an acceptance angle equal to 120° (-60°, +60°) and an optical concentration ratio (OCR) equal to 1.6x. This enables capture of the sun rays all day long (both direct and diffuse light). Higher OCR's were achieved for different dimensions of the solar concentrator; nevertheless, the acceptance angles were relatively low. Experimental results validated optical model results with a variation of less than 5%.

12.2. BA, Low-concentration evacuated-tube solar collector

1. G. Li, G. Pei, Y. Su, J. Ji, D. Wang and H. Zheng, Performance study of a static low concentration evacuated tube solar collector for medium-temperature applications, 2014: International Journal of Low-Carbon Technologies Advance Access, 1-7.

doi: 10.1093/ijlct/ctt083

Contexts	Outcomes
Experimental and optical analysis of a static low-concentration evacuated tube (LCET) solar collector for medium-temperature applications was performed. The LIGHTTOOL software was used for ray tracing to evaluate the LCET solar collector optical performance at different incident angles.	The ray tracing on the single LCET revealed that the overall average optical efficiency could reach 76.9% between 0 and 60^{o} incident angles, a very attractive value for medium temperature applications.

13. Studies of Optical/Thermal Simulation (emphasis: building/ system)

13.1. BI, Several systems

1. Maurer Chr. and Kuhn T. E., Variable g value of transparent façade collectors, 2012: Energy and Buildings 51, 177–184.

http://dx.doi.org/10.1016/j.enbuild.2012.05.011

Contexts	Outcomes
Transparent solar thermal collectors (TSTC) → collector model with an advanced calculation of the transmission of diffuse radiation and a connection to the building → allows analysis of collector gains and g value. The model was implemented as a TRNSYS Type and a coupled simulation between a collector and a room was presented for different façade constructions. An HVAC system was presented together → possible reductions of primary energy Frankfurt was chosen for the meteorological data.	A new Type 871 was developed which is capable of modelling transparent solar thermal collectors in a very detailed way while opening the door to coupled system simulations with a building and an HVAC system. The validation of the models has been successful.

2. D. Saelens, W. Parys, J. Roofthooft, A. Tablada de la Torre, Reprint of "Assessment of approaches for modeling louver shading devices in building energy simulation programs, 2014: Energy and Buildings 68, Part C, 799–810.

http://dx.doi.org/10.1016/j.enbuild.2013.11.031

Contexts	Outcomes
A ray-tracing method was developed to describe the global solar transmittance of louver shading devices. The developed method was integrated in the dynamic building energy simulation program TRNSYS to assess the cooling demand as well as the required peak cooling power in a south oriented office room. The proposed integrated approach allowed the calculation of the solar transmittance for each time step. For the shading device a two-dimensional angular and time dependent model was adopted. Building simulation model: simulations were conducted for a typical moderate Belgian climate.	The use of a simplified implementation of SFs is possible within acceptable margins by implementing average results from ray-tracing calculations.

3. Baruchi I., Chorin M. B., Freedman B. and Sovran I., Modeling of building integrated low concentration photovoltaic glazing windows, 2010: Proceedings of the SPIE 7785.

DOI: 10.1117/12.861524

Contexts	Outcomes
A transparent PV double glazed unit which exhibited three main features - concentrating direct solar rays on PV cells, allowing a viewer to see through the window a non-distorted image and having good thermal isolation properties, was developed.	A model which simulated seasonal and day/night variations of the optical and thermal behavior of the window as a function of installation location was presented. The outputs of the model included PV power generation and the change in the required power for heating/cooling due to the elimination of direct irradiation into the room. That outputs were utilized to optimize the optical design in order to achieve best overall energy saving performance.

4. H. Manz and Th. Frank, Thermal simulation of buildings with double-skin façades, 2005: Energy and Buildings 37, 1114–1121.

http://dx.doi.org/10.1016/j.enbuild.2005.06.014

Contexts	Outcomes
Highly glazed commercial buildings with double-skin façades may overheat during summertime; thus, in order to optimize thermal comfort and minimize cooling loads, the thermal behaviour of these buildings requires careful investigation at the design stage. Complex physical phenomena (optical, thermodynamic, fluid dynamic processes are involved).	Three level modelling, design method for the whole building with double-skin façades. Static coupling between CFD and building energy simulation. These three levels are: modelling the optics of the layer sequence of the double-skin façade by a spectral method, modelling thermodynamics and fluid dynamics of the double-skin façade by CFD, modelling building by a building energy simulation tool.

14. Studies about other types of simulation

14.1. Exergy analysis (emphasis: system)

D. Fiaschi and A. Bertolli, Design and exergy analysis of solar roofs: A viable solution with esthetic appeal to collect solar heat, 2012: Renewable Energy 46, 60-71.

http://dx.doi.org/10.1016/j.renene.2012.03.013

Contexts	Outcomes
Solar Roof (SR): ducts on the bottom side of copper roofs to collect a fraction of the absorbed solar radiation; an innovative solar collector with high aesthetic value. Basic proposed system: Unglazed Solar Roof (USR). Additional system: Glazed Solar Roof (GSR).	USR showed 30-60% efficiency. GSR performance showed significant improvement only over cold seasons; Compared with a commercial reference flat plate collector (FPC) model, the efficiency of USR was reduced by 20% over the whole operating field. The exergy efficiency curves showed optimization at temperatures well above those in flat plate collectors. Integration with a domestic hot water system showed a potential yearly solar fraction of 53% with USR and 60% with GSR.

14.2. Energetic/lighting simulation (emphasis: building/system)

M. Janak, Coupling building energy and lighting simulation, 1997: proceedings BS1997

http://www.ibpsa.org/proceedings/BS1997/BS97_P036.pdf

Contexts	Outcomes
A new method of direct run – time coupling between building energy simulation and global illuminance simulation was presented. Direct coupling at the time step level between ESP-r and RADIANCE offers building energy simulation with access to an internal illuminance calculation engine, and thereby, enabling modelling of the complex interactions between artificial lighting control and the rest of the building energy domain in a fully integrated way.	The method of direct run - time coupling between building thermal and lighting simulation was proved to be promising. It allows explicit modelling of important interactions between artificial lighting control and the rest of the building energy domain. If a short time step and sub - hourly solar irradiance or illuminance climate data are adopted, relatively realistic dynamic behaviour of the lighting control can be predicted.

14.3. Emergy analysis (emphasis: building/system)

F. Meillaud, J.-B. Gay, M.T. Brown, Evaluation of a building using the emergy method, 2005: Solar Energy 79, 204–212.

http://dx.doi.org/10.1016/j.solener.2004.11.003

Contexts	Outcomes
Emergy is the energy of one kind, usually solar energy, which is required to make a service or product. Emergy methodology was adopted and the application was a building. The LESO (Solar Energy Laboratory, Swiss Federal Institute of Technology, Lausanne) was considered. The authors noted that emergy was the most appropriate methodology to evaluate their system, because each type of flow (monetary or information) could be taken into account. The experimental LESO building is 3-stories containing faculty/students offices and a workshop. A PV installation was situated on the roof. The building was constructed in 1981 with different solar façades. A homogenous south façade, replacing these units, was built in 1999 in accordance with sustainable development strategies and a drastic reduction of the use of non-renewable energy. Units adopted: J_{em} = emergy per unit time (sej/year, solar emjoules per year).	The yearly emergy consumption/production of a building was evaluated. This building was constructed according to special environmental considerations, such as important the use of passive gains and it had low energy consumption (232 MJ/m^2 year). Considering only energy and materials inputs, electricity was the largest input to the system (2.7E16 sej/year). The total emergy of the material inflows was 1.7E16 sej/year, paper being the largest material input (5.7E15 sej/year). The specific emergy (per mass) of some common building materials was also evaluated and compared to non-renewable energy.

14.4. Sunlight simulation (emphasis: system)

A. Márquez-García, M. Varo-Martínez, R. López-Luque, Toolbox engineering software for the analysis of sunlight on buildings, 2013: International Journal of Low-Carbon Technologies.

doi: 10.1093/ijlct/ctt062

Contexts	Outcomes
Shadow, irradiance, daily radiant exposure functions were presented (created by using Visual Basic). Those functions allowed the calculation, in an easy and fast way, the daily radiant exposure in each point of a façade in an urban environment.	The developed tool can improve the method for establishing the best part on a façade to set a generation device, e.g. PV panels or solar thermal collectors.

15. Conclusions

In the frame of the present study, a literature review focusing on BI solar systems is conducted. The review includes systems which produce thermal, electrical or both thermal/electrical energy. Emphasis is given on the BI solar thermal systems while the other two types of configurations (electrical; thermal/electrical systems) are also included in order to have a more complete picture of the studies which have been done and the studies which are needed to be conducted as a future prospect.

In the field of energetic simulations of BI solar systems, there are more than 30 studies. Most of these investigations regard BI PV, BI PVT and skin façades while there are few studies about passive configurations (solar chimney and Trombe wall), BI Concentrating PV (CPV) and solar shades. Thus, it can be seen that there is a need for energetic simulations of BI solar thermal configurations, especially of active solar thermal systems which could provide hot air and/or water for building energy needs. Also it would be interesting the development of models about BI CPVT (Concentrating PV/Thermal) or BI CT (Concentrating Thermal) systems provided that low-cost and simple configurations will be selected. In general terms, most of the energetic simulations give emphasis to the system itself; thereby, there is a need for more studies which give emphasis to the building.

In the area of thermal simulations of BI solar systems, there are more than 35 studies. Most of these works are about BI PV, BI PVT and skin façades while there are few studies about BI solar thermal collectors, solar chimneys, Trombe walls and pipes integrated into the building. Thereby, there is a need for thermal simulations of BI solar thermal collectors since there are no more than 5 studies in this type of systems. As it was previously mentioned, the development of models about BI CPVT or BI CT systems could also be examined as well as systems which include heat storage solutions for example with PCM. Also in the field of thermal simulations the greatest part of the investigations gives emphasis to the system and consequently, there is need for more studies which give emphasis to the building.

Moreover, there are more than 20 studies which combine energetic and thermal simulation. In that field, there is also the same tendency: the greatest part of the works is about BI PVT while there are only few studies (no more than 2) about BI solar thermal systems. It should be noted that some of the BI PVT and BI solar thermal systems of these works include transpired collectors. Consequently, in a future prospect, energetic/thermal modelling studies about BI solar thermal configurations (with/without concentration, with/without PCM, etc.) could provide useful information. In the same way with the two previous categories, there is a need for studies which give emphasis on the building.

Concerning optical and optical/thermal simulations, there are no more than 10 studies (with emphasis on the system and on the building/system). These studies regard multiple configurations such as thin-film luminescent solar concentrators, PV windows, skin façades and systems with louver shading. Thus, it can be seen that there is a gap in the literature in the field of optical models and further developments are needed since optical simulations could provide useful information for the behaviour of the BI solar thermal systems. Also for this category, there is a need for more studies which give emphasis on the building. Finally, it should be noted that in the literature there are also some models which regard other types of simulations such as emergy and exergy.

Conclusively, in the current literature the greatest part of the models are thermal and/or energetic simulations of BI PVT (or PV) and skin façades and thereby, there is a need for thermal and/or energetic models about BI solar thermal systems (models which give emphasis to the system itself but also models which give emphasis to the building are needed). On the other hand, the optical-modelling studies are very few and certainly, more optical-modelling investigations are needed since they could provide useful information about the behaviour of the BI solar thermal systems from optical point of view.