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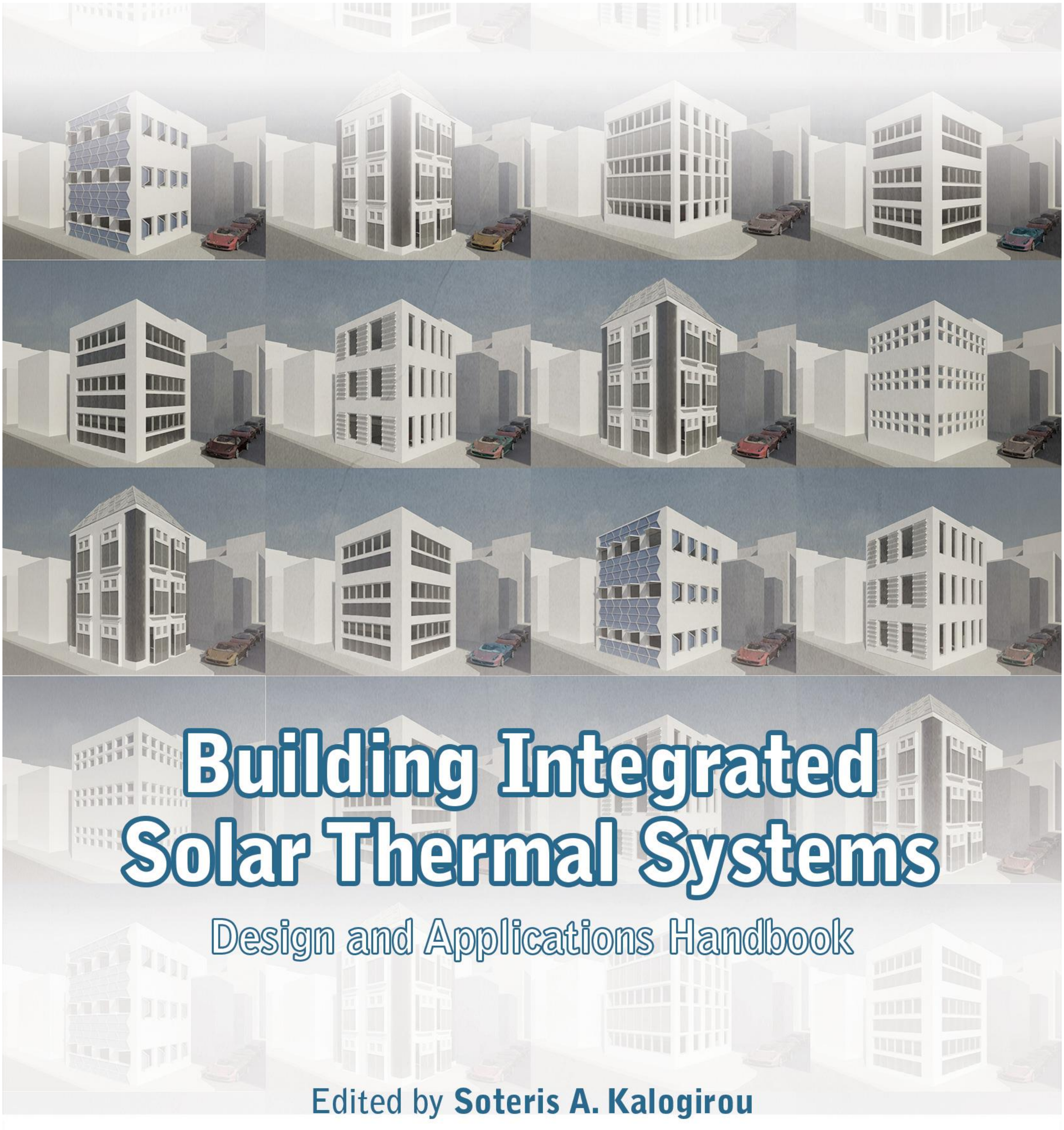
COST BISTS



Building Integrated Solar Thermal Systems

Design and Applications Handbook

Edited by **Soteris A. Kalogirou**

CYPRUS UNIVERSITY OF TECHNOLOGY 2004

COST Action TU1205 (BISTS)

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Building Integration of Solar Thermal Systems

DESIGN AND APPLICATIONS HANDBOOK

Edited by Soteris A. Kalogirou

Notice: *The compilation of the various chapters contained within this handbook have been produced by COST Action TU1205 members having sole responsibility of the material presented therein.*

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PREFACE

This handbook produced by the members of the COST Action TU1205 – Building Integrated Solar Thermal Systems (BISTS), funded by COST, 2013-2017. It covers introductory subjects on the presentation of the Action, the classification and characterisation of BISTS and basic resource (solar radiation) analysis. Following on, Section 2 details the basic BISTS design, including architectural planning, thermal and optical design of BISTS, modelling of the systems, installation, testing, commissioning and maintenance as well as life cycle analysis, economics and legal issues. Section 3 presents new options with respect to emerging architectural design concepts, system and application options, materials, retrofitting BISTS and thermal storage integration. Section 4 presents five different innovative BISTS designs developed by various Action members, a building erected in Israel where BISTS are applied extensively, as well as the modelling of novel solar thermal collectors suitable for building integration. The last two sections deal with the outlook of the technology and basic conclusions obtained from this Action with supporting material, including journals that publish material relevant to BISTS, participant research and testing centres and infrastructures, international activities, networks and projects and a comprehensive database of BISTS applications, presented in a connected publication produced by this Action. Many more details can be found in the Action website: http://www.tu1205-bists.eu/.

We hope that the material presented in this handbook will be of interest to architects, solar engineers, building services engineers, government bodies and anyone who has an interest in this subject. Many thanks to the Action members and non-members who participated in the writing of the various chapters and of course to the COST Office for funding this Action.

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4.6 PORTER BUILDING, TEL AVIV, ISRAEL

Yasha Grobman, Nir Chen[9], Joseph Cory[9], Sandra M. Silva, Ricardo Mateus, Manuela G. Almeida

4.6.1 Introduction

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

4.6.2 Description of the building

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

4.6.3 Design concept and building features

The Porter School was designed on a site that served as a Parking lot and was previously the dumpsite for building debris of the Tel Aviv University. It is located on one of the highest hills in Tel Aviv overlooking the Cities of Tel-Aviv and Ramat Gan and the Yarkon metropolitan park. The site is exposed to the harsh condition of the Israeli southern sun radiation and to the acoustic pollution from the automobile and rail transport rising for Israel’s busiest highway (Figure 4.6.1).

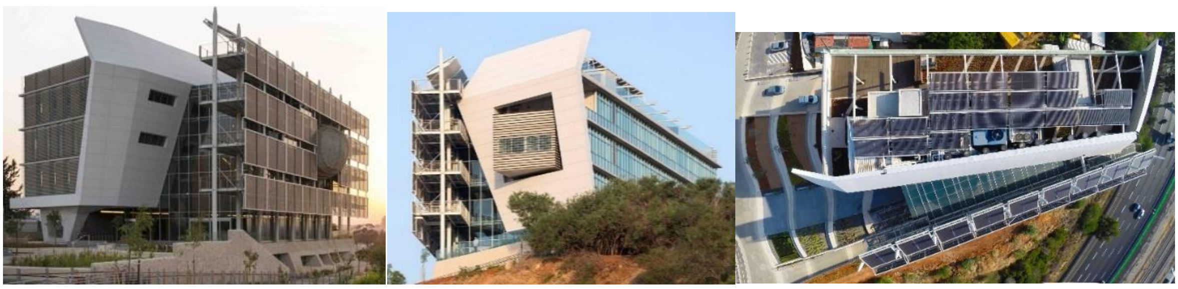

Figure 4.6.1. General views of Porter Building (west, south, east and north façade and roof).

The building form is a rectangle stretched out along an east-west axis. The south facing area is due to the public and the main offices and other functions are located on the northern façade area. An atrium connects these two areas housing the public activities and the main

[9] Non-COST Action member.

building circulation paths. The main materials of the building are exposed concrete, Euro panel cladding tiles, wood (mainly bamboo) and metal. The colour scheme of the building is mainly white grey and natural wood.

The auditorium, which is the largest function of the building, is located in the basement, with an independent entrance (designed using ideas from vernacular traditional terraces design) for external events. The main conference room of the building is “the capsule” (Figure 4.6.2). “The capsule” creates a balance in the composition of the south façade and serves as a screen on which the building’s energy savings and regional air pollution can be publically projected.

Figure 4.6.2. “The capsule” view from outside and inside.

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

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

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

A four-storey atrium is the center of the buildings mixed-mode ventilation strategy. Equipped with solar chimneys at the roof level (Figure 4.6.3), the stack effect generated helps to provide ventilation to most of the building when conditions permit (Figure 4.6.4). Supplementary ventilation as well as air conditioning is provided by a rooftop makeup air unit equipped with energy recovery. At the zone level, spaces are conditioned by fan coil units, 4-pipe active chilled beams, and radiant floor. Occupancy and photo-sensors throughout the building tune the lighting system to the precise level required as dictated by space use and available daylight.

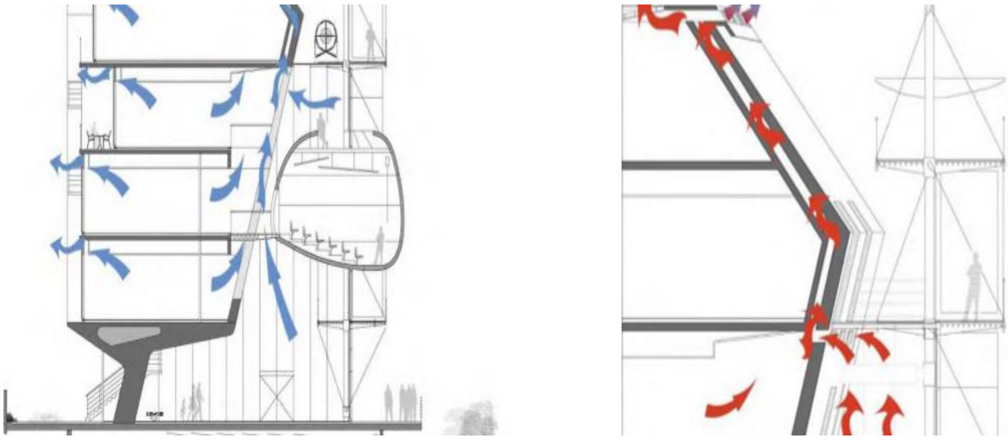

Figure 4.6.3. Passive ventilation scheme (left) and hot air chimney - hot air discharges through special chimneys in the building envelope (right).

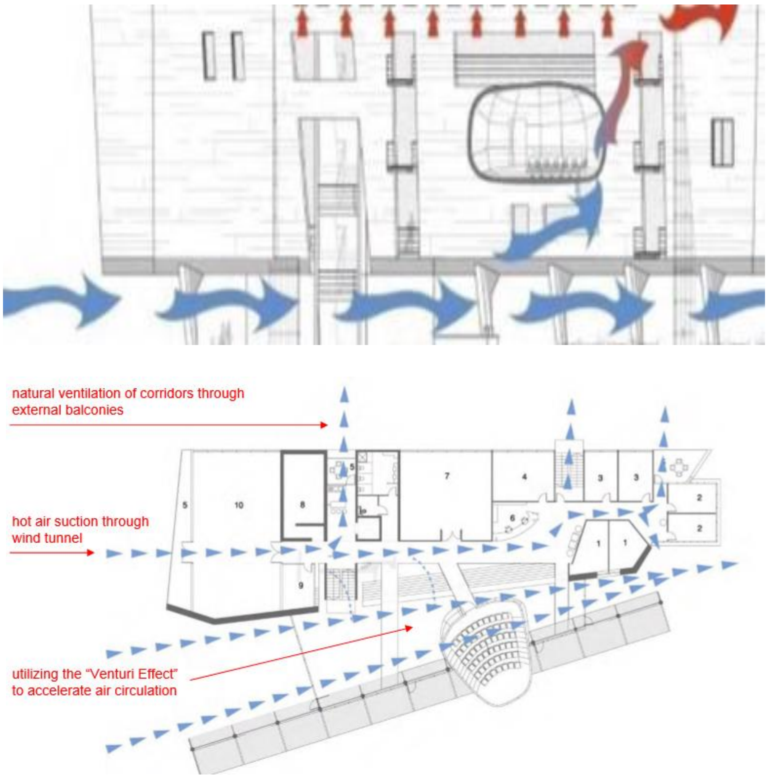

Figure 4.6.4. Passive ventilation through Main Atrium.

The building incorporates the following technologies:

- A thermo solar air-condition system running on energy created via a system of vacuum tubes on the building facades and roof (Figure 4.6.5). This system (the air condition system or the vacuum tubes system) transfers energy surplus generated in the building to adjoining buildings in the campus;

- Chilled beam system for air condition – an air condition diffuser that works about 20% more efficiently than normal systems (works on higher temperatures and does not need strong electric fans to distribute the cool air);

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

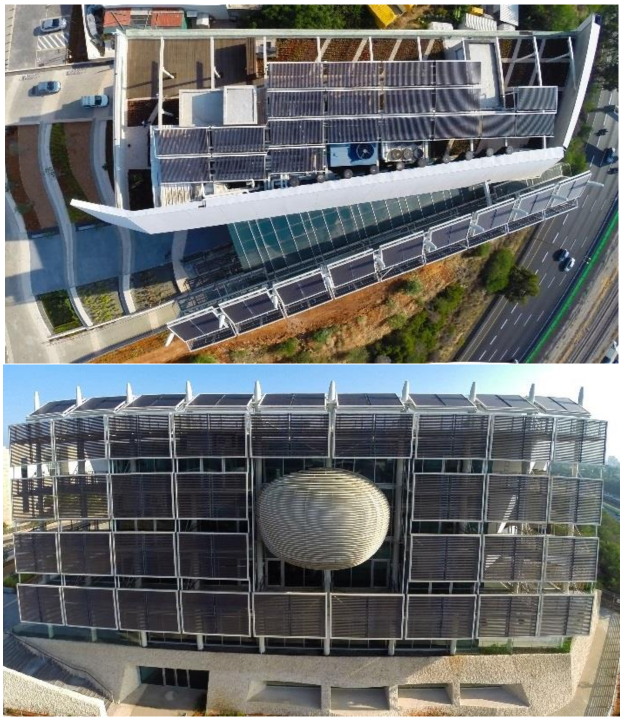

Figure 4.6.5. General view of the vacuum tubes installed on the building roof and façade.

4.6.4 Building Controls

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

4.6.5 Cooling / Heating Plant Systems

4.6.5.1 Hot Water Loops

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

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

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

4.6.5.2 Chilled Water Loops

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

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

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

4.6.5.3 Absorption Chiller

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

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

4.6.6 Cooling tower

An open circuit cooling tower (Figure 4.6.6) is used to reject heat emitted on the condenser side of the absorption chiller unit. A variable speed fan regulates the cooling tower airflow so that leaving condenser water is at or below 30ºC going back to the chiller. Constant volume pump P-3 (84 m^3/hr) serves this loop.

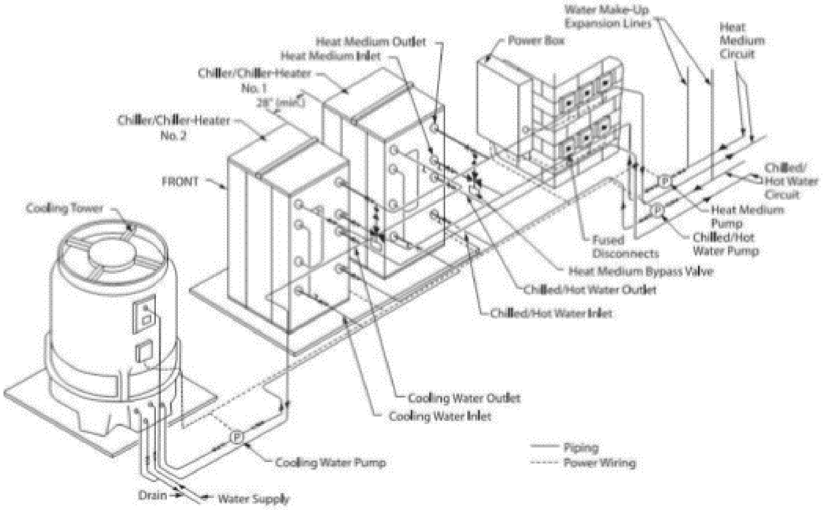

Figure 4.6.6. Cooling tower.

4.6.6.1 Air-Cooled Chiller

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

4.6.6.2 Solar Thermal Evacuated Tubes

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

75ºC and 120ºC. Variable speed pump P-2 operates the HW loop side of the HX-1 and modulates between 0 and 100% flow as the fluid temperature is between 30 and 100 ºC.

4.6.6.3 Boilers

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

4.6.7 Space Heating / Cooling systems

4.6.7.1 Fan Coil Units

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

4.6.7.2 Active Chilled Beams

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

4.6.7.3 Thermo-Active Slab

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

4.6.7.4 Offices and Classrooms Air Handling Unit

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

4.6.7.5 Lobby Air Handling Unit

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

4.6.7.6 Auditorium Air Handling Unit

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

4.6.8 HVAC Ventilation

4.6.8.1 Air Handling Units

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

4.6.8.2 Natural and Mixed Mode Ventilation

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

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

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

COST Action TU1205 - An Overview

Energy use in buildings represents 40% of the total primary energy used in the EU and therefore developing effective energy alternatives is imperative. Solar thermal systems (STS) will have a main role to play as they contribute directly to the heating and cooling of buildings and the provision of domestic hot water. STS are typically mounted on building roofs with no attempt to incorporate them into the building envelope, creating aesthetic challenges and space availability problems. The Action will foster and accelerate long-term development in STS through critical review, experimentation, simulation and demonstration of viable systems for full incorporation and integration into the traditional building envelope. Viable solutions will also consider economic constraints, resulting in cost effective Building Integrated STS. Additionally, factors like structural integrity, weather impact protection, fire and noise protection will be considered. The most important benefit of this Action is the increased adoption of RES in buildings. Three generic European regions are considered; Southern Mediterranean, Central Continental and Northern Maritime Europe, to fully explore the Pan-European nature of STS integration. The Action consortium presents a critical mass of European knowledge, expertise, resources, skills and R&D in the area of STS, supporting innovation and conceptual thinking.

Domain: Transport and Urban Development (TUD)

Action Webpages: http://www.tu1205-bists.eu/ & http://www.cost.eu/COST_Actions/tud/Actions/TU1205

Countries participating: Austria, Belgium, Bulgaria, Cyprus, Denmark, France, Germany, Greece, Hungary, Ireland, Israel, Italy, Lithuania, Malta, Netherlands, Poland, Portugal, Romania, Serbia, Spain, Turkey, United Kingdom.

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