Case Study
The AVAX Headquarters Building

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1. Building Description

The headquarters of AVAX, an Hellenic construction company, are based in a newly constructed building in the Ambelokipi neighbourhood in Athens, Greece. This is a densely populated area of Athens with all the buildings of the area lying in close vicinity to each other.

The building is oriented east along a north-south axis, with its back and narrow sides touching adjoining buildings. It makes full use of the total surface permitted to be built by planning regulations, leaving free space in the front and at the back as an interior garden.

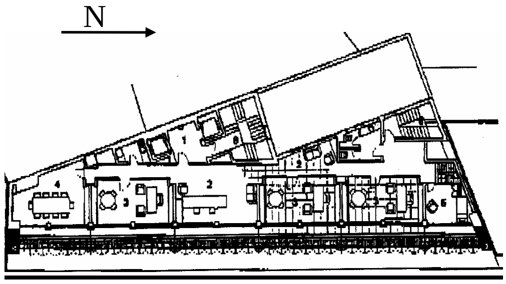

Figure 1 - Cross-section of a typical floor plan of the AVAX building

Picture 1 - AVAX Headquarters Building (front view)

The building comprises of 5 floors and 3 underground floors with a total floor area of 2346 m^2, of which 991 m^2 are climatised. Level (-3) has been assigned to the engineering installations of the building, level (-2) as an office area and level (-1) as an underground parking area. The remaining floors are allocated to office spaces. On average, 100 to 150 people work in the building.

The office areas are situated along the east-oriented glazed front facade separated from secondary spaces (WC, kitchenettes and vertical circulation shafts) by a circulation area. Each level is, thus, divided into a front/activity zone and a service/back-up area.

1.1 Building fabric

The main east-facing facade is designed to act as a double skin - a diaphragm protecting the inner glazing, by selective control of thermal gains and daylight. On the three middle floors, the outer skin consists of the custom-made solar fins, designed to perform as shading devices while on the first and fifth floor, exterior venetian blinds perform the task of solar control. The inner skin of the east elevation is made of double glazed windows with interior venetian blinds for glare control.

The building characteristics are displayed in Table 1.

Component	Materials (out to in)	Thickness (cm)	U-Value (W/m^2K)
Exposed east wall	Steel Plasterboard Mineral Wool Concrete	0.005 0.02 0.1 0.2	0.35
Exposed west wall of office, circulation and auxiliary areas	Plaster Brick Mineral Wool Brick Plaster	0.02 0.1 0.1 0.1 0.02	0.36
Exposed west wall of staircase/elevators	Plaster Concrete	0.02 0.2	3.22
Exposed west wall of staircase/sanitary	Fair-faced brick Concrete	0.1 0.2	2.63
Ground floor of 3rd basement	Water Proofing Concrete Scread	0.01 18 10	1.88
Roof	Marble slate Extruded Polystyrene Water Proofing Concrete	0.03 0.1 0.002 0.1	0.31

Table 1 - Opaque building components

Component	Type of glazing	Frame material	U-Value (W/m^2K)
Windows	Double glazing	Aluminium insulated	2.8

Table 2 - Transparent components

1.2 Bioclimatic architecture

The building was built based on the principals of bioclimatic architecture aiming on low energy consumption with high comfort levels.

1.2.1 Natural lighting

The building was designed in such a way as to maximise the natural lighting of the building while at the same time minimising the amount of incident sunlight radiation on the building's fabric. The basis for good natural lighting is ensured through the narrow layout of the building and the "intelligent" permeability of the east facade. The dimensions of the standard offices (7.0m width - 3.0m depth) ensure the best exploitation of natural light.

The dominating natural lighting feature, the solar fins, are found on the eastern facade of the building. The western facade requires no special shading due to its proximity to the adjacent buildings. These fins, consist of vertical glass silk screen printed panels, providing a shading coefficient of 70%, automatically rotated in response to temperature and solar radiation. Manual override is provided via infrared remote controls. The shading provided by the movable fins is complemented by a series of fixed white horizontal metal grate grills provided on every floor. The top and mezzanine floors are shaded by conventional external venetian blinds also controlled by the central system with manual override.

1.2.2 Natural ventilation

Natural ventilation is provided through operable openings in the east and west (rear) facade. These natural ventilation schemes are possible depending on the opening of internal doors and windows of the rear facade.

2. Electrical and mechanical installations

The target regarding the thermal design of the building was to avoid/minimise the use of air-conditioning by the use of various installations and equipment that will be described in the following sections.

2.1 BMS system

The BMS is based on the decentralised processing and intelligence of the Remote Control Systems. These remote systems are fully autonomous stations concerning their software and hardware and have the capability of central data collection from a personal computer and its peripheral equipment with a user-friendly interface. Seven remote control systems exist with the capability of full extension and connection of other remote systems if required.

Each control point is characterised by a code number indicating the location (floor, area) and the installation (air conditioning, lighting etc.). The remote stations issue a report to the central computer at stated time periods or when a problem arises, mentioning problems that have occurred, operational characteristics, energy consumption and statistical data. Local intervention of the installation and the control program can be done using a remote terminal connected to any remote control system by the responsible maintenance personnel. The central computer processes the data arriving from all remote stations and presents the graphic diagrams of the installations and the control points.

The installations of the building controlled by the BMS are:

- control of exterior shading fins
- cooling-heating-ventilation
  - fans of night ventilation and day pre-cooling system
  - air handling units
  - fan coil units
  - exhaust fans
  - heat pumps-ice banks
  - primary/secondary circuit pumps, plumbing, drainage
  - water supply systems
  - booster sets
  - water tank

- fire extinguishing system
- fire detection system
- lifts
- telephone system
- electrical installations
    - low voltage electric board
    - emergency electric board
    - reserve generator
    - uninterrupted power supply (UPS)
    - indoor lighting
    - outdoor lighting

2.2 Lighting

The artificial lighting system has been designed and is intended to be used as a back-up system to the natural lighting of the building. Several choices have been made to minimise energy consumption:

- walls and ceilings have been painted in light colours (white) to maximise light diffusion.
- general low indirect lighting (200-250 Lux) has been combined with additional task lighting for each work space (two lamplight units, dimmable, ballast driven, sized 4x58 W are installed in each office unit).
- most spaces are equipped with high efficiency fluorescent luminaires.
- light level is controlled centrally by the TRIOS system, using luxometers. A movement detector controls an on-off switch in order to turn off the lights when no movement is detected.

2.3 Ventilation

The building has a raised floor which acts as an air plenum. This permits the installation of fan-coil units (FCU) covering the local load demand and fresh air demands, air conditioning units as well as inlet and extraction fans for natural ventilation.

The introduction of air into the offices is by way of FCU units placed near the east facade glazing. Fresh air is diffused into the underfloor plenum by a system of air ducts. Special diaphragms are used to balance the recirculated and fresh air quantities. The recirculation of the air is operated from and by floor mounted louvers.

In total, 96 FCU cabinets are installed in the underground plenum for the recirculation air treatment, while 2x5 FCU cabinets are dedicated to full fresh air intake. All the FCU units are 3W valve, on/off type. On level (-2), the office ventilation is provided for by two air handling units. Exhaust flow is taken by a separated air duct network which is fan driven.

In order to decrease the daytime cooling loads of the building, nocturnal ventilation is performed with the operation of 16 hidden underfloor supply and 16 hidden underfloor exhaust fans on each floor. This pre-cooling of the building with nocturnal mechanical ventilation is designed to operate at 30 air changes per hour, from 21:30 to 07:00, when appropriate. The night operation is disabled when the outdoor temperature is above 25^{0}C. Furthermore, electronic controlled shutters remain open during the night in order to increase the heat transfer between the internal spaces and the external environment.

Moreover, the building also has 48 manually controlled two-speed ceiling fans to extend the comfort zone from 25 to 29^{0}C.

2.4 Cold and Heat Generation

The building, which functions as the headquarters for the AVAX construction company, is essentially an office building. The people who work in the building therefore follow usual office hours and the building is thus regularly occupied from 08:00 to 18:00 on weekdays. The level of occupancy after 18:OO and on weekends is relatively low.

The building is split into six zones, each one of which is served by individual supply and return pumps. Local climate control of the building is achieved by FCU units located near the east facade glazing. On basement level (-2), climate control is performed by two air handling units.

The building design was undertaken by a Greek engineering consultancy firm. In order to predict the heating and cooling loads of the building and thereby size the equipment required, they used a Greek engineering software package. The design parameters used as inputs to the software package are shown in Table 3:

Outdoor	Winter	Summer
Dry bulb (^{0}C)	0	35.7
Daily oscillation (K)	-	13
Relative humidity (%)	80	50
Indoor		
Dry bulb (^{0}C)	20	25.6
Relative humidity	35	50
Loads (kW)	170	188

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Table 3 - Design temperature/humidity conditions

The system chosen to meet the cooling and heating loads of the building is an air-cooled reciprocating heat pump with an electrical input of 86.8 kW and a cooling capacity of 234 kW at 35^{0}C external temperatures. Furthermore, there are also three ice storage tanks of 670 kWh storage capacity placed on basement level (-3).

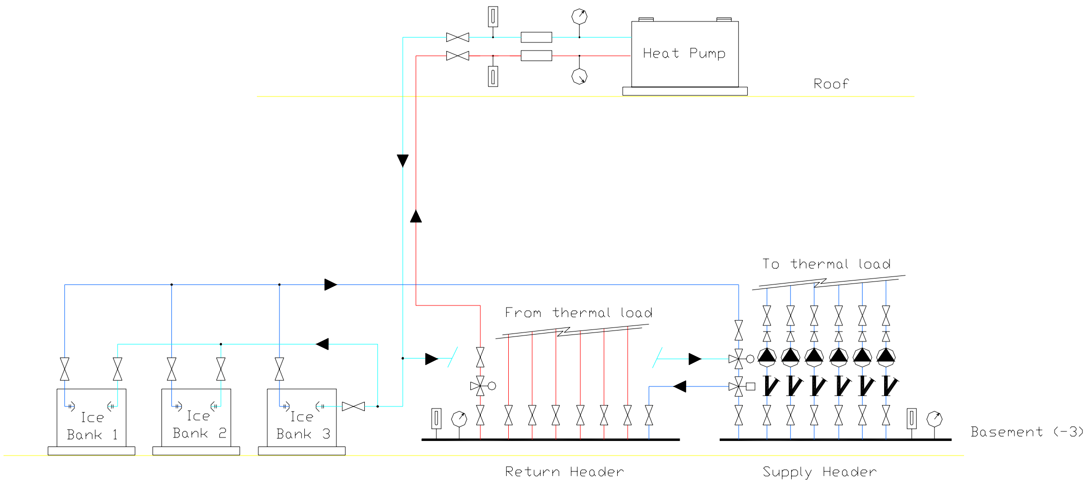


Figure2 - Schematic of heating and cooling equipment

During the winter and autumn months when the building has heating demands, heating is performed by the operation of the heat pump which feeds the FCU and AHU units with warm water (45^0C Supply - 40^0C Return). On the other hand, in the summer and spring months when the building has cooling demands, the heat pump charges the ice banks (ice building) during the night hours when the cooling load is low and the daytime cooling demands are met by the discharge of cold water from the ice banks (7^0C Supply - 12^0C Return). The cold water supply temperature is achieved via a mixing valve which regulates the amount of water exiting the ice bank and the water coming from the return header. All the hydraulic circuits are fed by glycolated water (20%).

Picture 2 - AVAX building ice banks, Basement level (-3)

The cooling storage system installed is therefore a full storage system (i.e. the cooling load of the building during the day is met solely from the cooling discharge of the ice banks). The system was designed to operate during week days from 21:00 to 07:00 for ice building (heat pump operation) and from 07:00 to 21:00 for meeting the cooling load (ice bank operation). During Saturdays the system is shut and during Sundays the system operates from 08:00 to 14:00 and from 18:00 to 22:00 for ice building.

If the supply water temperature exceeds 8^0C for more than 15 minutes, then that is taken as a clear indication that the ice in all three ice banks has completely melted (ice bank, full discharge) and the heat pump starts to operate.

2.4.1 Heat pump characteristics and performances

Type	CXAD 209/R
Brand	TRANE
Dimensions (mm) LxWxH	3785 x 2100 x 2750
Operating Weight (kg)	3600
Number of refrigeration circuits	2
Description	Semi-hermetic reciprocating compressors, ring type suction and discharge valves

Table 4 - Heat pump characteristics

Picture 3 - AVAX building heat pump, roof

Performance	Water supply temperature (^{0}C)			
	7	0	-4	-8
Cooling Capacity/ Electrical Power Consumption (kW) (25^0C - ambient temperature)	266 / 87	182 / 63	161 / 62	141 / 60

Performance	Ambient temperature (^{0}C) db/wb		
	13.5/12.0	7.0/6.0	0/-1
Heating Capacity/ Electrical Power Consumption (kW) Hot water leaving temperature (45^0C)	271 / 78	226 / 72	181 / 65

Tables 5,6 - Heat pump performances

2.4.2 Cooling storage container specifications and characteristics

The ice storage tanks are LEVLOAD Ice Banks Model 1190 as manufactured by Calmac Manufacturing Corp. They basically consist of a cylindrical container, constructed of high density polyethylene with the bottom and sides of the container insulated with a polyurethane coating and the top covered with an 0.8 cm thick aluminium plate, and a spiral-wound, mat-type heat exchanger consisting of polyethylene tubing arranged in multiple parallel circuits with opposite direction of flow in adjoining tubes.

Total storage capacity	669 kWh
Latent storage capacity	567 kWh
Sensitive storage capacity	98 kWh
Maximum operating temperature	38^0C
Initial discharge cooling capacity	106 kW
Size (diameter/height)	2262 / 2540 mm
Weight (empty/full)	704/ 7.598 kg
Load per m^2	2200 kg/m^2

Table 7 - Ice bank characteristics and performances

2.5 Power supply

The building is supplied with medium-voltage power by means of a private transforming system. The electrical price tariff chosen was the B2 tariff of the Hellenic Public Power Corporation.

B2 Invoice

P_s>250 kVA Medium Voltage (Demand Charge)

UT = Utilisation time
E = Energy consumed per month
P_m = Maximum demand power, monthly, refereed for 15 minute time segments
$P_{m\text{-on peak}}$ = Maximum demand during on peak hours (1000 - 1300 h)
P_s = Power subscribed
P_i = Power invoiced

$$UT = E / P_m$$

$$P_i = P_m * k / \cos\varphi * d * y$$

where $k = 0.80$ if $\cos\varphi <= 0.80$
$= 0.85$ if $\cos\varphi >= 0.85$
$= \cos\varphi$ if $0.80 < \cos\varphi < 0.85$

$$d = 0.50 + (0.50 * (P_{m\text{ - on peak}} / P_m))$$
$$y = 1.0$$

Under request of the consumer…see next value *y = 0.0* during off peak hours (2200 - 0800 h) and Sundays

Short UT (<360h), all values of E

Tariff list B2: 3.02 (ECU/kW) * P_i + 0.065 (ECU/kWh) * E

High UT (>360h)

0<E<400 (kWh/kW) * P_m

Tariff list B2: 8.38 (ECU/kW) * P_i + 0.033 (ECU/kWh) * E

Note: 1 ECU = 330 Drs

3. Monitoring procedure

The monitoring of the AVAX headquarters building was carried out between the 18th of September and the 1st of October on the cooling and lighting installations of the building. The main values recorded were the following:

- water-glycol temperatures at various points in the system (PT100 temperature sensors)
- pressure drop within the system (flow rates at various points of the system)
- ambient temperature and humidity (meteorological station)
- BMS hourly recording data of electricity consumption of the heat pump, internal temperatures of the five floors and electricity consumption of the lighting system for the five floors

The pipe layout and points of measurement are shown in Figure 3:

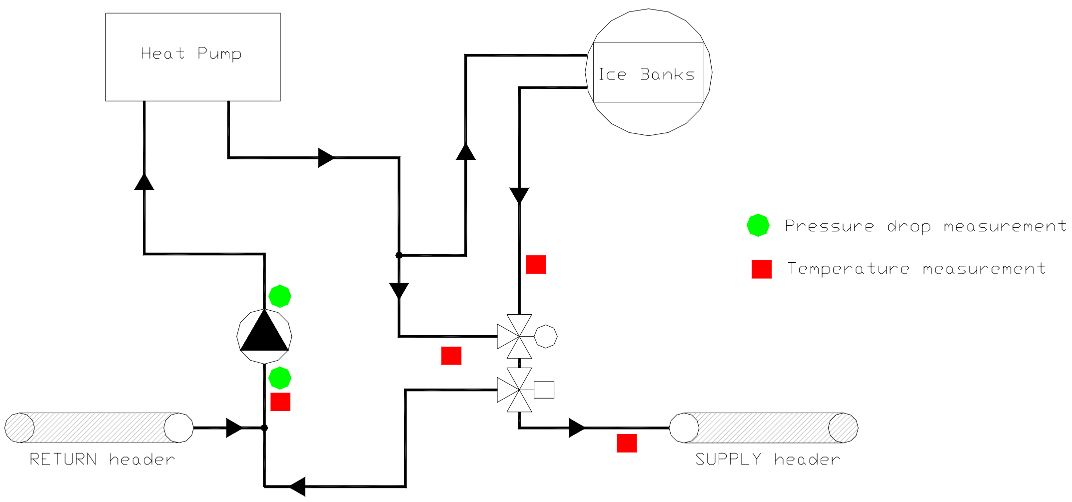


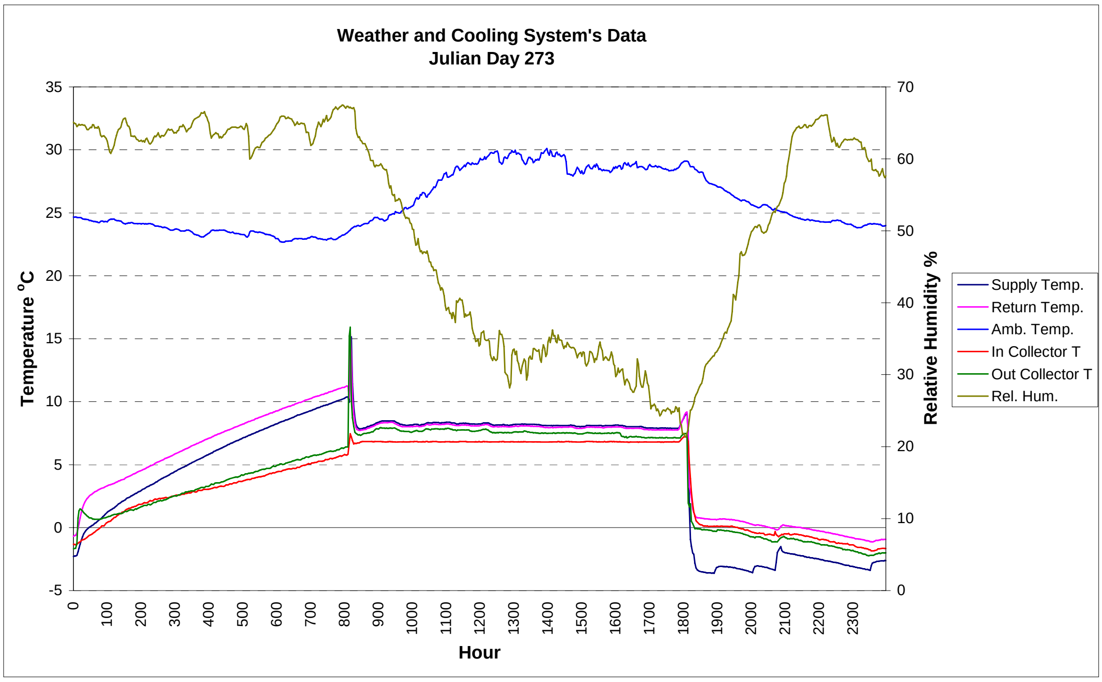
Figure 3 - Schematic of monitoring points

Picture 4 - Meteorological station, roof

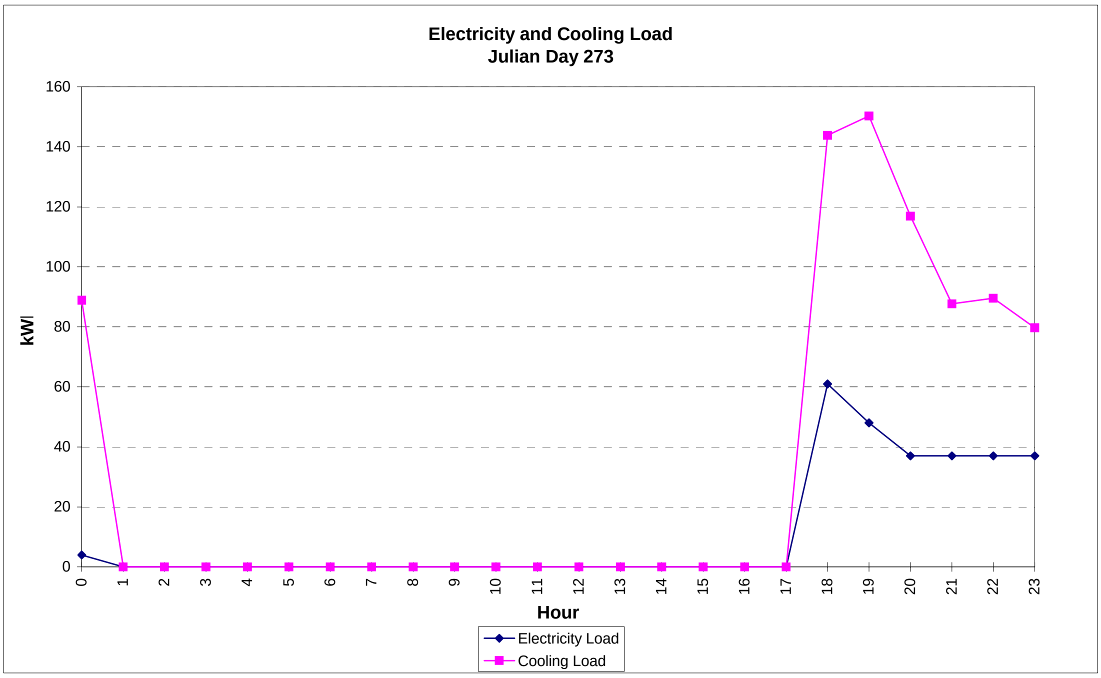
Picture 5 - PT100 temperature sensors, basement level (-3)

3.1 Monitoring results

The following graphs give the monitoring results for the 30th of September, a day for which the cooling profile was considered to be typical.

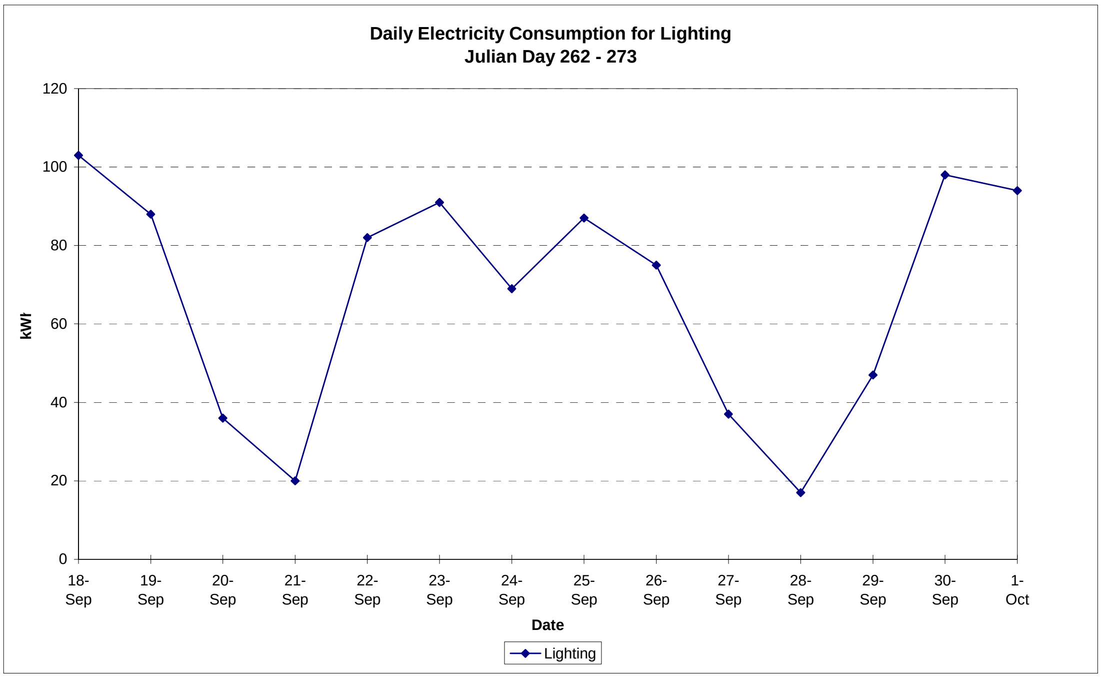


Graph1 - Weather and cooling system monitoring results



Graph 2 - Electricity and cooling load of heat pump, monitoring results

Graph 3 displays the electricity consumption for lighting for the duration of the monitoring period which result from the BMS recording system of the building.



Graph 3 - Daily electricity consumption for lighting, BMS recordings

As can be seen from Graph 3, the electricity consumption for lighting is a minimum during the weekends when the building is, in general, not occupied and attains its maximum value during the weekdays. The consumption inevitably depends on a variety of factors (i.e. brightness, sunshine duration) and is therefore never a constant value.

When compared to the total electricity consumption of the building (obtained from readings from the electricity board meters), it results that lighting is from 5-17% and cooling is from 15-40% of the total electricity consumption of the building. Based on the measurement results, it was also found that the average coefficient of performance of the cooling system is C.O.P = 2.7.

During the monitoring period, problems with the noise level of the heat pump, operation of the BMS and heat pump controller made it impossible to operate the system fully automatically following the originally designed scheduled. Thus, it was not possible to take full advantage of the system. More specifically, due to the noise levels of the heat pump the heat pump charged the ice banks during weekdays from 18:00 to 24:00 and the ice banks discharged cooling from 08:00 to 18:00. Only just recently have these problems been solved and the building's system restored to its originally designed operation schedule.

4. Computer simulation

An annual simulation of the building's performance was carried out using the TRNSYS 14.2 computer software package. In this simulation, the cooling and heating loads of the building were calculated along with the electricity consumption of the heat pump. The simulation was performed for the case of cooling storage and also for the case of no cooling storage in the building.

4.1 Model inputs

In order to model the building using the TRNSYS 14.2 software, a multitude of inputs are required such as:

- building characteristics (orientation, thermal characteristics of components etc.)
- air conditioning and ventilation requirements
- internal thermal gains
- meteorological data

4.1.1 Building characteristics

The South and North facades of the building are partition walls and are in contact with the adjoining buildings and therefore these surfaces are not exposed to ambient atmospheric conditions. The long East facade of the building has no external obstructions, tree or other buildings and is therefore not shaded. On the contrary, the West facade has 3 or 5 storey buildings which shade it in the afternoon hours. Therefore the view factor of the West facade is assumed to be very low compared to that of the East facade.

The building is initially separated into climatised and non-climatised thermal zones. Basement level (-2), the entrance level and the five office floors are considered to be climatised. Basement level (-3), reserved for the engineering installations, and basement level (-1), the parking area of the building, are considered to not be climatised.

On the office floors, there is a front main area where the offices and meeting rooms are situated and a back secondary area where the kitchenettes, WCs and vertical circulation shafts are located. The front area is assumed to be climatised and the back area not climatised. It is assumed that the internal temperature of the secondary areas is 5 degrees lower or higher than the ambient temperature, in the summer and winter respectively.

The front main areas are divided by partition walls made out of plasterboard. As the plasterboard does not consist an important thermal mass the different offices were treated as one zone.

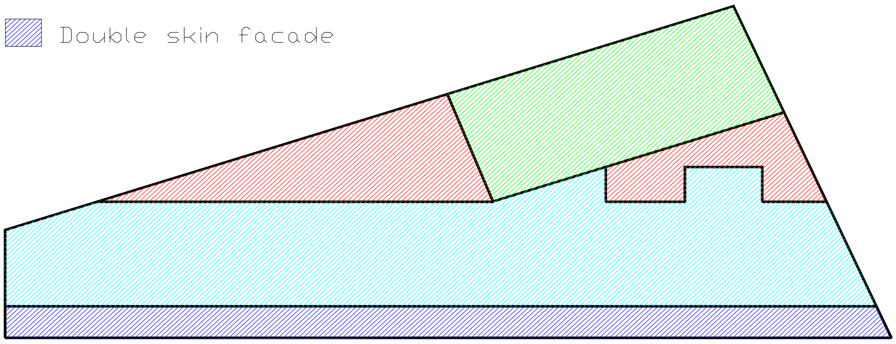


Figure 4 - Typical office floor level

4.1.2 Building surface properties

The building surface properties, namely the thermal conductivity, which were used in the description of the building, are those which satisfy the Hellenic norms for thermal insulation in buildings. A safety factor of 1.3 was considered to make up for any construction deficiencies. The thermal conductivity values taken are described in Table 8.

Building Layer	Thermal Conductivity ($W/m^2\ {}^0C$)
External walls	0.8
Walls neighbouring with non-climatised zones	2.0
Floor neighbouring with a non-climatised zone or the ground	2.0
Roof	0.6
Double-glazed windows	3.2

Table 8 - Thermal conductivity values of the building layers

The east facade of the building was also assumed to have 70% internal shading from the electronically controlled solar fins situated on its surface.

4.1.3 Climate Control

Table 9 displays the valued considered for the climatisation of the building thermal zones.

Indoor	Winter	Summer
Dry bulb (${}^0C$)	21	26
Relative humidity	35	50

Table 9 - Indoor climatic conditions

The office areas were considered to be ventilated at 1.5 air changes per hour and the meeting rooms at 2.5 air changes per hour.

4.1.4 Internal gains

Occupancy rates for the purpose of the simulation were established according to the actual occupancy of the building. A daily profile of the electricity consumption of computers and lighting was assumed in direct relation with the occupancy rates of the building.

Time	Weekdays (%)	Weekends and holidays (%)
0:00 - 6:00	0	0
6:00 - 7:00	10	5
7:00 - 9:00	10	5
9:00 - 12:00	95	5
12:00 - 14:00	80	5
14:00 - 18:00	95	0
18:00 - 19:00	30	0
19:00 - 22:00	10	0
22:00 - 24:00	5	0

Table 10 - Occupancy profile

Time	Weekdays (%)	Weekends and holidays (%)
0:00 - 8:00	10	10
8:00 - 9:00	70	10
9:00 - 21:00	90	10
21:00 - 22:00	70	10
22:00 - 24:00	10	10

Table 11 - Consumption profile, lighting

Time	Weekdays (%)	Weekends and holidays (%)
0:00 - 8:00	10	10
8:00 - 21:00	70	10
21:00 - 24:00	90	10

Table 12 - Consumption profile, computers

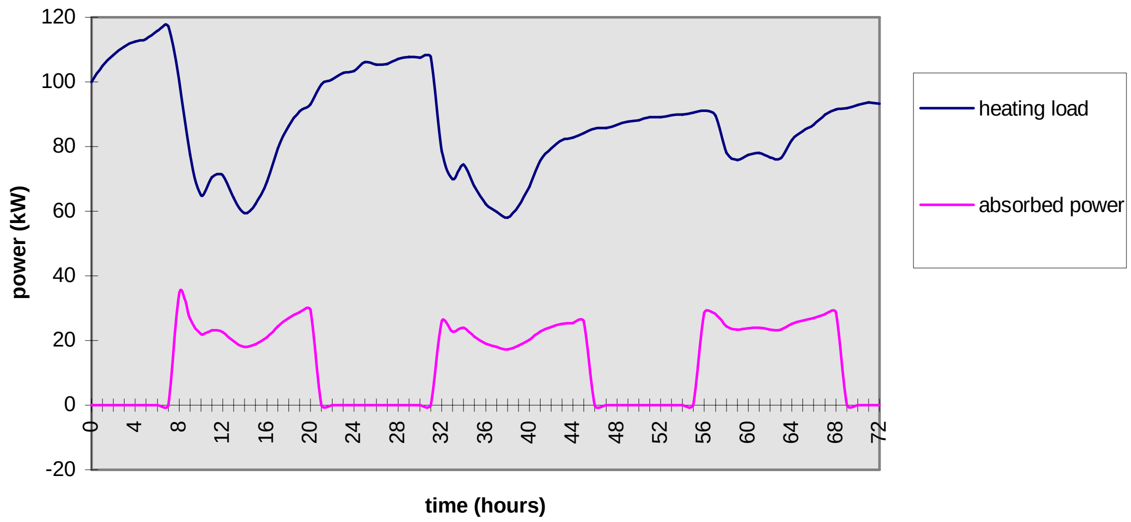
4.1.5 Meteorological data

The meteorological data required by the model for the simulation were the hourly values of the relative humidity (%), dry bulb temperature (^{0}C) and the total radiation on a horizontal surface (kJ/m^2). The data required was supplied by the National Observatory of Athens, Greece for the year 1996.

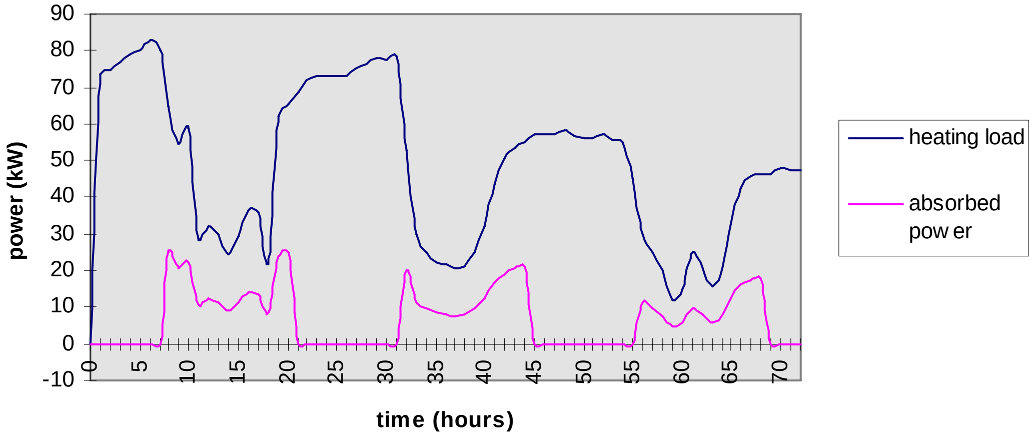
4.2 Model outputs

The following graphs display the results of the computer simulation of the AVAX building headquarters, using the TRNSYS 14.2 code. These results simulate the AVAX headquarters building for the case of cooling storage and also for the case of no cooling storage. The results displayed relate to three typical days of each month, namely the 19th -21st of each month and they show; the cooling load of the building, the absorbed power of the heat pump for heating and cooling for the case of no cooling storage, the capacity of the chiller when charging the cooling storage system, and the absorbed power of the chiller when charging the cooling storage system.

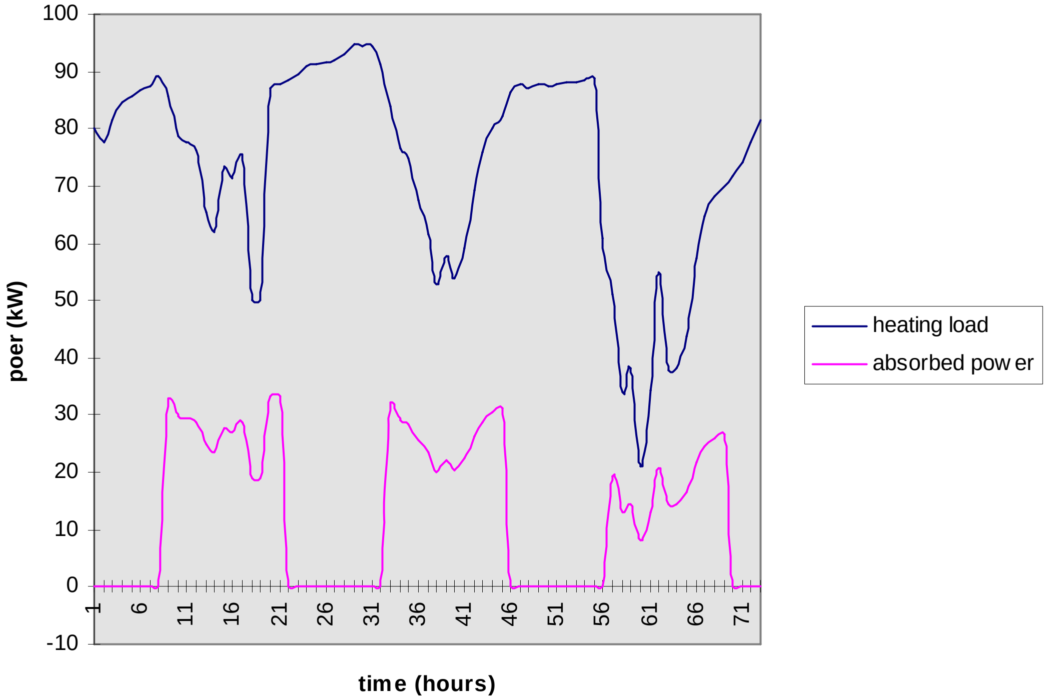
In the months of November, December, January, February and March when the heating load is predominant, the cooling storage system is not operational and the heat pump heats the building in the conventional way.



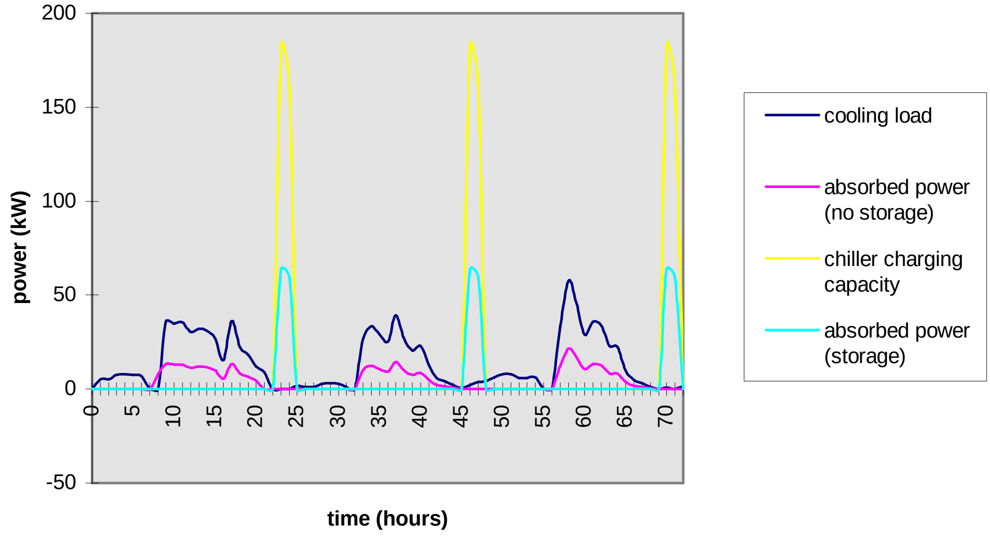
Graph 4 - Computer simulation results, January



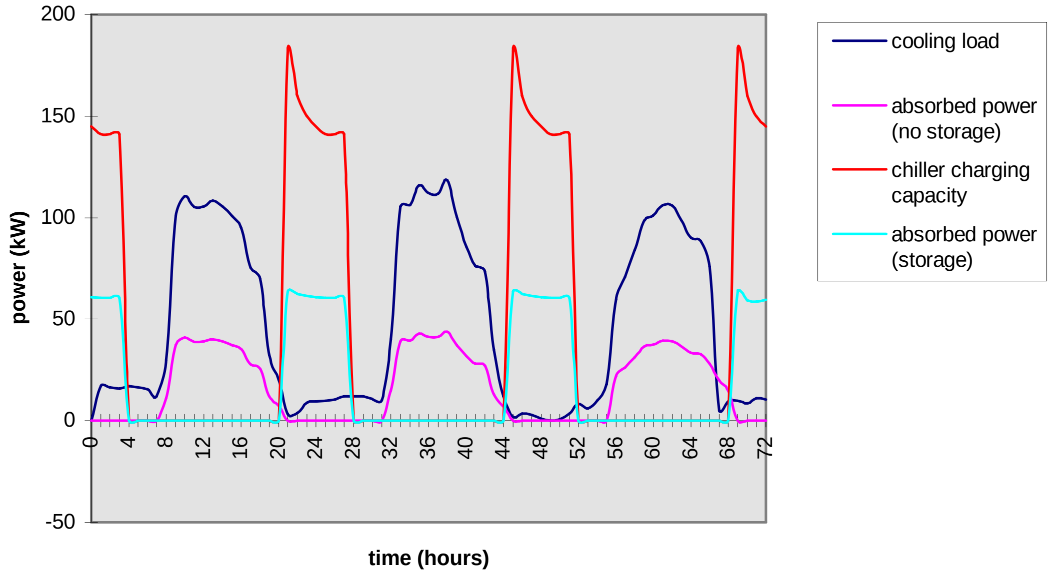
Graph 5 - Computer simulation results, February



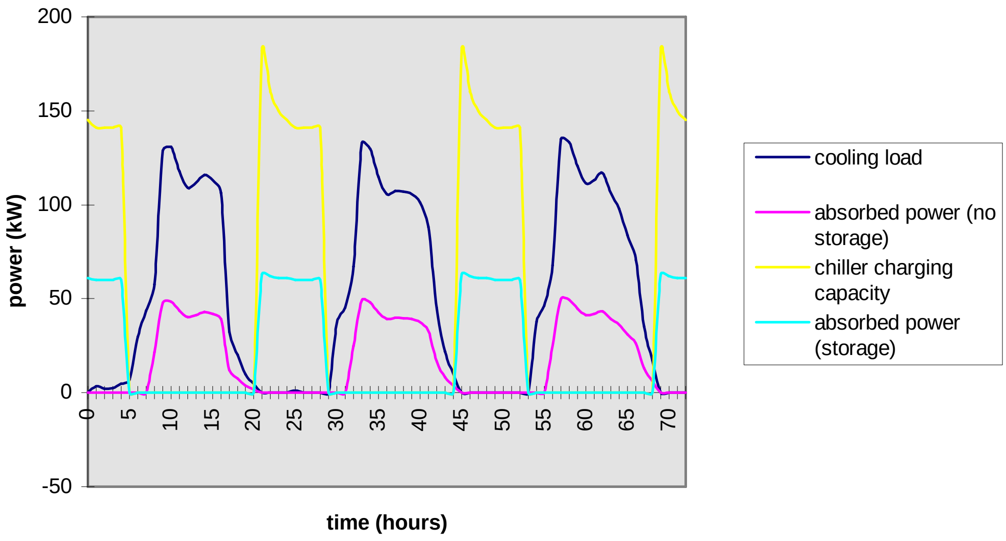
Graph 6 - Computer simulation results, March



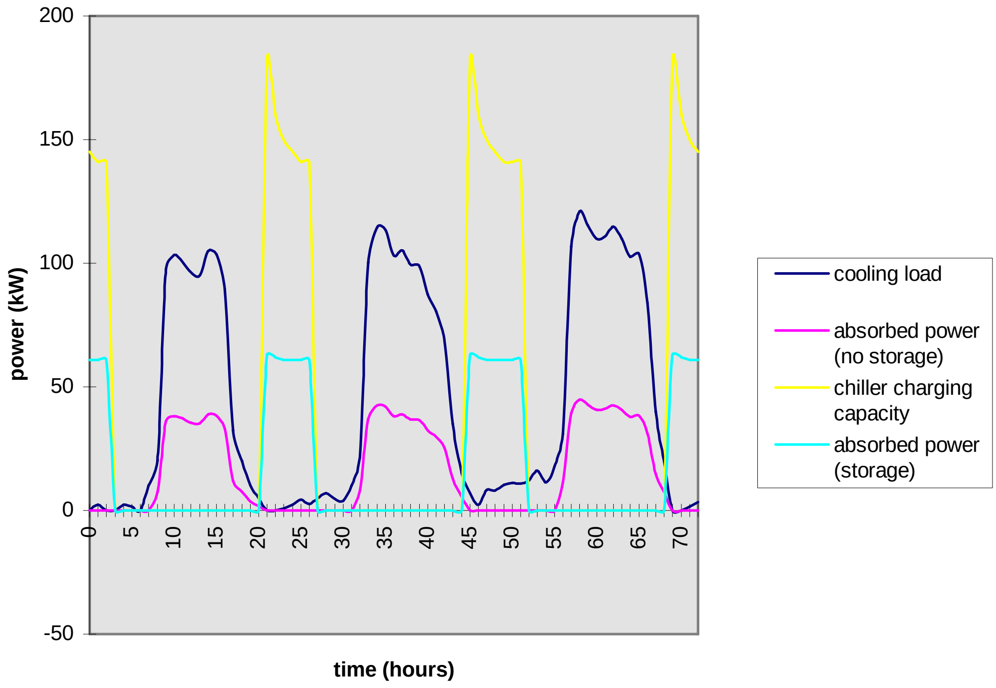
Graph 7 - Computer simulation results, April



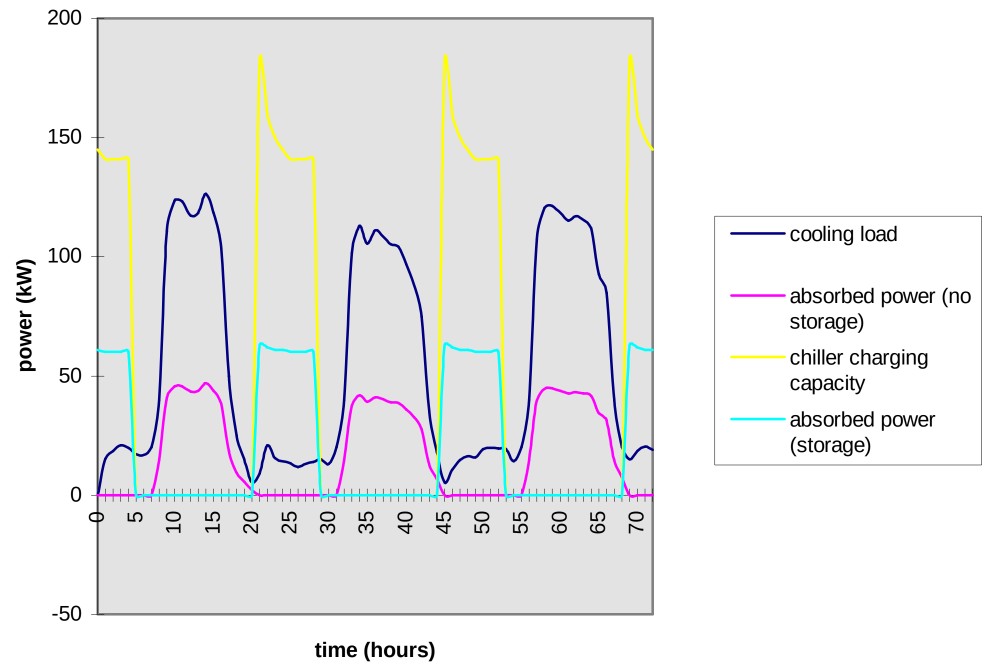
Graph 8 - Computer simulation results, May



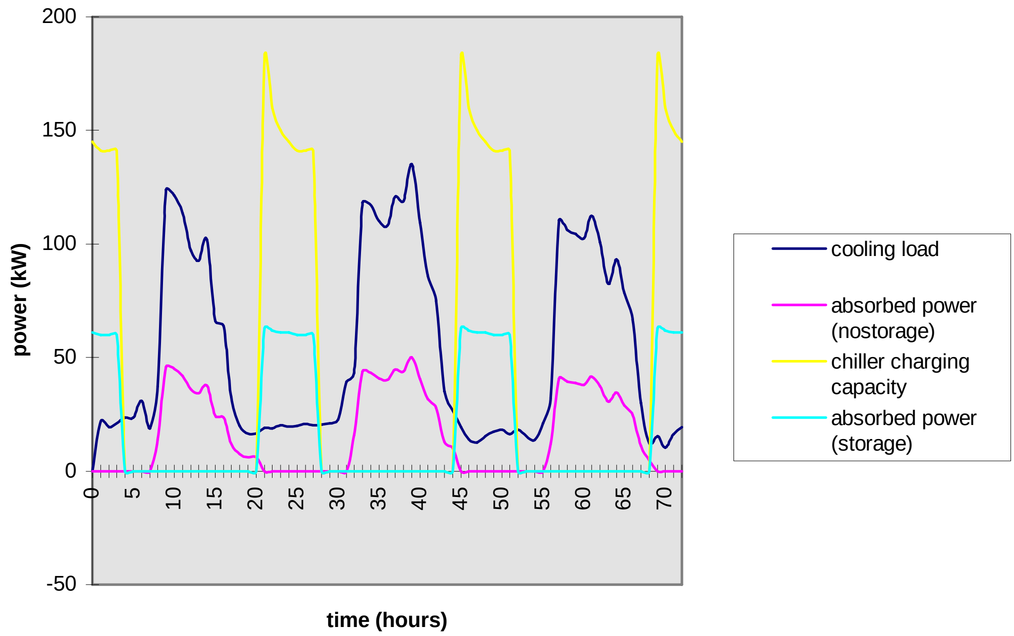
Graph 9 - Computer simulation results, June



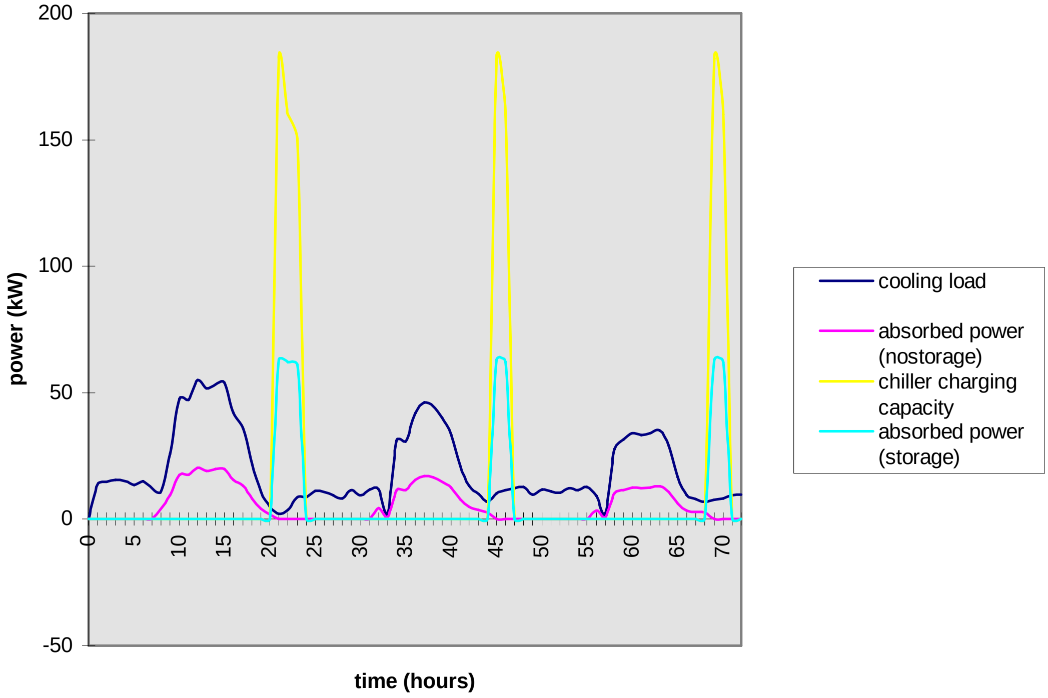
Graph 10 - Computer simulation results, July



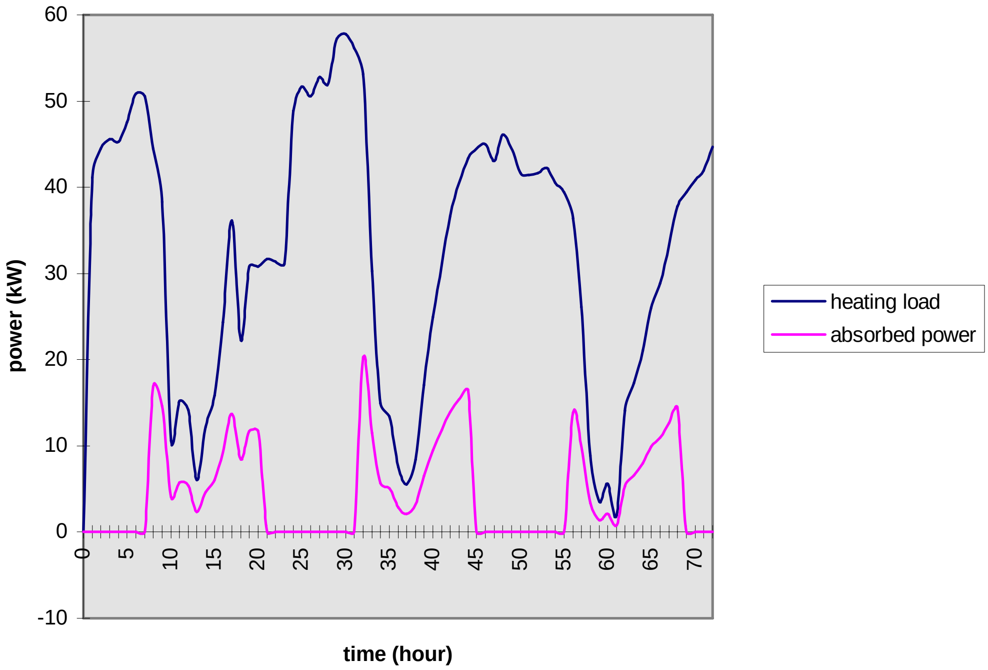
Graph11 - Computer simulation results, August



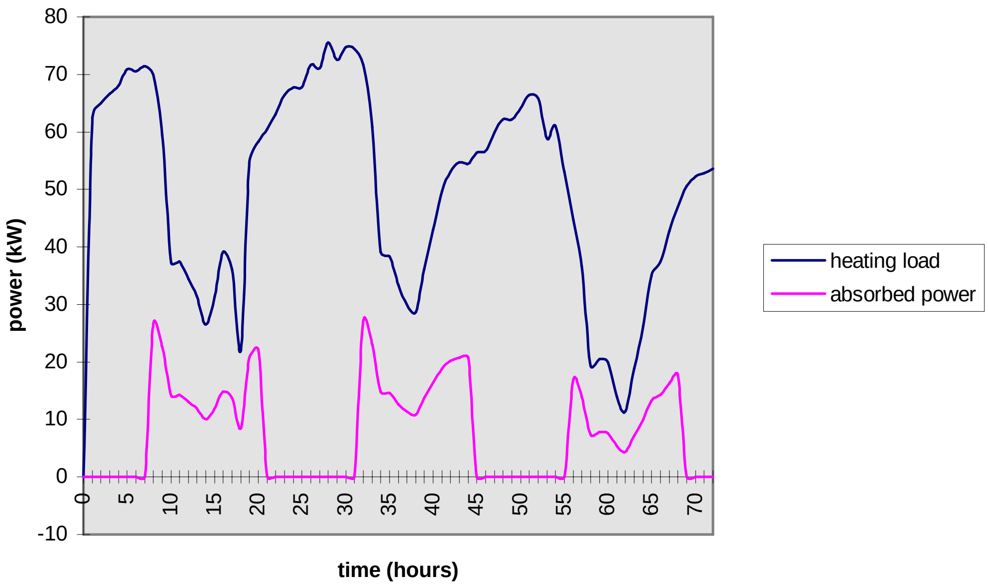
Graph 12 - Computer simulation results, September



Graph 13 - Computer simulation results, October

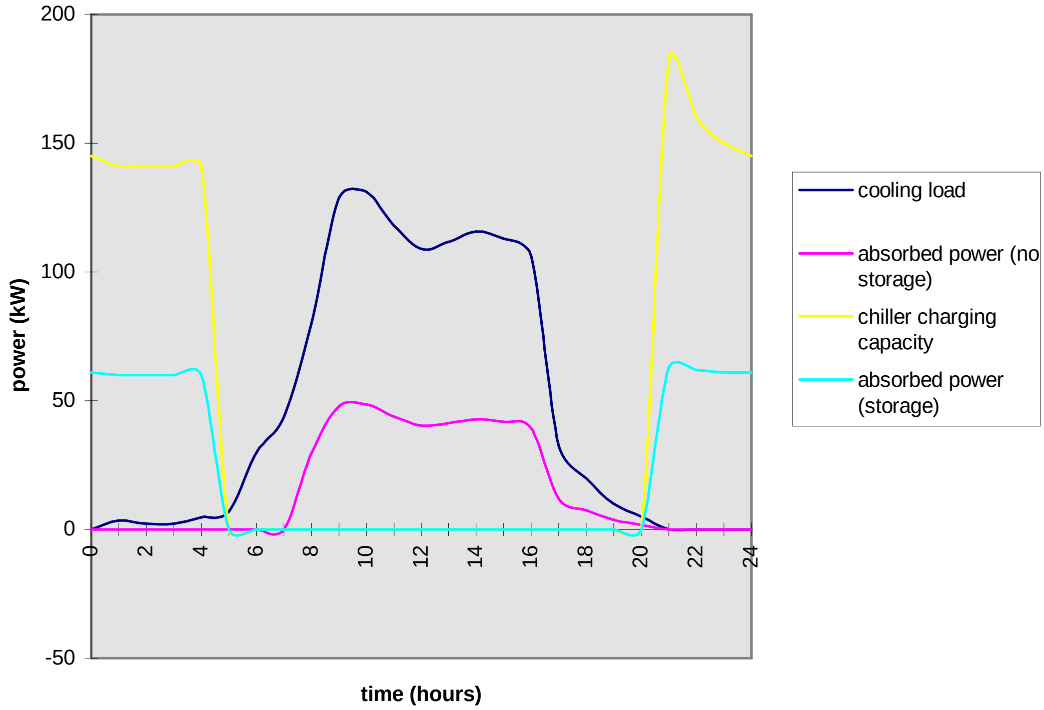


Graph 14 - Computer simulation results, November



Graph 15 - Computer simulation results, December

4.2 Computer simulation - July



Graph 16 - Computer stimulation of a typical warm July day (21st)

In Graph 16 it is possible to view in greater detail the cooling loads of the building and the related performances of the heat pump for storage and no storage conditions, for a typical day in July, one of the warmest months of the year. A brief overview of the system follows:

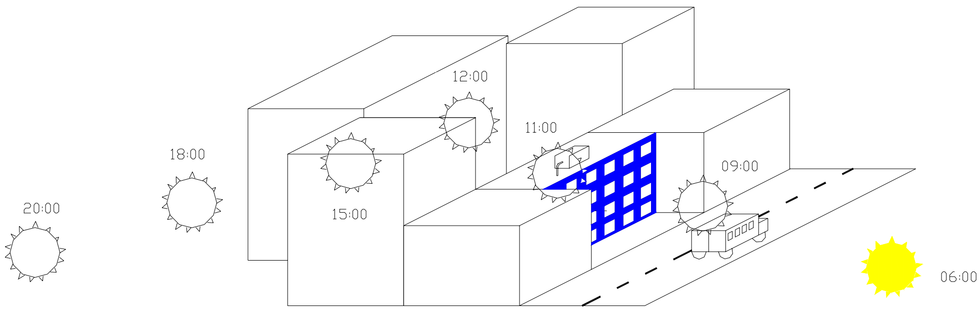


Figure 5 - Variation of sun's position during the day

Cooling Load (reference: Graph 10)

- The building which has most of its climatised office areas on the unobstructed east facade has high cooling loads in the morning hours when the sun shines its rays directly on the east facade. In July, the sun rises early, and therefore the cooling load starts to increase fairly early in the morning (06:00), see Figure 5. As the occupancy rate increases as people start rushing in to work and the sun rises higher and the sun shines its rays directly on the east facade, a peak cooling load is noticed (10:00).
- As the sun moves away from the east facade and its rays shine southwards (12:00), the cooling load, despite the increase in ambient temperature, also starts to decrease. This is due mainly to the fact that the south facade of the AVAX building is adjacent to another building and does not receive any direct sunlight.
- At 14:OO, the sun is now shining on the south facade of the adjacent building and the building is therefore receiving direct sunlight only on its rooftop. Despite that, the heat stored in the walls of the building during the day start to emit some of this heat and this, coupled with the maximum value of ambient temperature, results in a new increase of the cooling load of the building.
- In the afternoon (16:00), the sun has started to shine on the west non-climatised facade of the building. The higher buildings lying to the west of the Avax building provide considerable shading from the sun's radiation. These factors, coupled with

the gradual decrease in ambient temperature result in a rapidly decreasing cooling load.

- The cooling load falls to it's minimum value after 18:00, when the building is gradually evacuated by the people returning to their homes after the day's work.

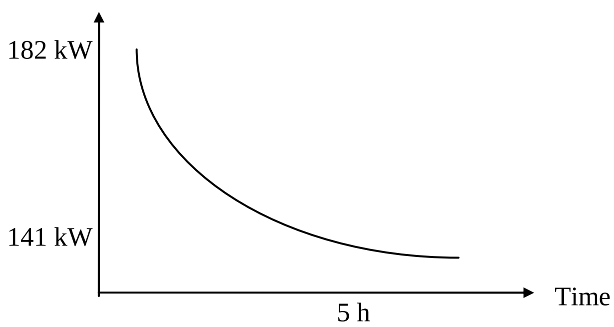
Absorbed power (no cooling storage)

For the theoretical case in which cooling storage is not used in the building, the heat pump operates as a conventional heat pump. It meets the cooling load of the building during the warm months of the year and it meets the heating load of the building during the cold months of the year. The period of operation of the heat pump is between the hours 0700 and 2100.

- The coefficient of performance of the heat pump during its operation is dependent on the ambient temperatures (see Tables 5,6), more so in the cold winter months. The absorbed power of the heat pump was approximated by dividing the heating load of the building with the C.O.P of the heat pump.
- In reality, the heat pump does not operate proportionally with the heating/cooling load. It has two 2-step reciprocating compressors which switch on and off depending on the heating/cooling load.
- Nonetheless, results obtained from the monitoring procedure on the absorbed power values of the heat pump, show that the values obtained using the approximation were quite close to the actual, measured values.

Chiller charging capacity

- In the case of cooling storage, the chiller starts charging the ice banks at 21:00, at which point the water-glycol temperature at the inlet of the chiller is 0^0C. The performance of the chiller is based on the data provided in Table 5.
- As the chiller charges the ice banks, the inlet temperature of the water-glycol temperature falls. This results in a decrease of the cooling capacity of the chiller as shown in Graph 17, which depicts the performance characteristics of the chiller.
- The chiller stops charging the ice banks when the ice banks are 90% full.



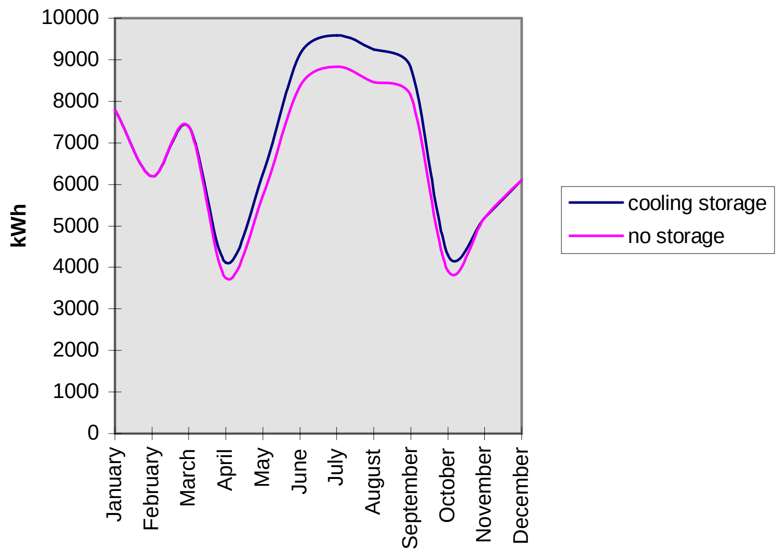
Graph 17 - Chiller charging capacity

Absorbed power (cooling storage)

- As seen in Table 5, during charging, as the water-glycol temperature entering the chiller decreases and the chiller charging capacity decreases, the chiller C.O.P also decreases. Therefore, even though the charging capacity decreases, the absorbed power remains virtually constant until the charging capacity stabilises at 141 kW, at which point the absorbed power also stabilises at 60 kW. This is evident from the absorbed power curve for the case of cooling storage, as seen in Graph 16.

4.4 Annual simulation results

Graph 18 displays the monthly values of electricity demand of the Avax building for heating and cooling purposes.



Graph 19 - Annual electricity demands for cooling/heating

It is evident from the results displayed on Graph 18, that the electricity demand for the case of cooling storage is slightly higher (9%) than that without cooling storage. This is due to the fact that the coefficient of performance of the heat pump falls at the low inlet temperatures required for the charging of the ice banks, and is therefore lower than the coefficient of performance of the heat pump when it is operating at the higher inlet temperatures required in the case of no cooling storage.

	With storage	Without storage
Energy cost (Greek Drs)	4,254,586	4,198,745
Power cost (Greek Drs)	2,113,894	2,551,844
Total	6,368,480	6,750,589

Table 13 - Comparison of energy costs of storage / no storage

However, despite the increase in energy consumption, the shift of the cooling load to the night and therefore the lowering of the average daily peak, allowed the user to take advantage of the favourable B2 price tariff of the Hellenic electricity utility. This resulted in an annual electricity cost saving of approximately 6% (see Table 13).

5. Discussion

From the results obtained from the monitoring of the building and the computer simulation of the building using the TRNSYS 14.2 code, certain conclusions can be drawn:

- The energy consumption of the building for cooling and heating purposes is marginally higher for the case of cooling storage, when compared to the conventional heating and cooling method without cooling storage. This is due to the reduced coefficient of performance of the heat pump (C.O.P = 2.3-2.9) when charging the ice banks, due to the low operating temperatures of the water-glycol mixture, compared with the conventional heat pump operation (C.O.P. =2.7-3.3).
- There is an apparent benefit from the use of the cooling storage system. Namely, a significant electrical energy consumption has been transferred from the daytime hours to the night. This is advantageous to both the Public Power Corporation and the building owners. The PPC benefits from this energy transfer as its peak daytime demands are relieved of the cooling/heating demands of the Avax building. The building owners, by reducing their peak daytime demand, take advantage of the PPC tariff which encourages the reduction of the peak demand by reducing the cost of the energy consumption (per kWh).
- The use of the ceiling fans and natural ventilation schemes within the building, increase the "comfort" of the people working in the building and the control temperature can thus be increased from 26^0C to 28^0C, thereby achieving significant energy savings.

Unfortunately, the reduction of the electricity cost per kWh due to the use of cooling storage, is partially offset by the increased energy consumption of the building due to the reduced efficiency of the heat pump when charging the ice banks at relatively low water-glycol temperatures. This factor, coupled with the high capital costs and installation costs of the ice banks as well as the space requirements of the ice banks, which could have been used for other purposes, seem to make the use of the system questionable. Measures which could be considered in the present case, or in future ones to make the cooling storage systems more competitive are:

- The PPC must be persuaded to consider more favourable tariffs (i.e. the introduction of a 3-zone tariff with a cheaper evening and night tariff). This will not only benefit the user who, if the tariff is advantageous, will seriously consider the increased capital and installation cost of the ice banks, but also the PPC who will significantly reduce or slow down the increasing future daytime peak demands if the cooling storage systems are adopted.
- The full storage solution with the present electricity tariffs should perhaps be reconsidered. With today's tariffs, perhaps the cooling storage strategy to be pursued should be that of partial storage. Partial storage will reduce the size of the required heat pump (a significant capital cost benefit!) as part of the daytime load is met by the heat pump and therefore, the size of the ice banks is smaller and so is

the required charging capacity of the heat pump. Moreover, the energy consumption of the building will be lower than the equivalent full storage system.

6. Conclusions

- The building was designed and built with the principals of bioclimatic architecture in mind which seeks low energy consumption with high comfort levels. Schemes used include; maximised natural lighting, natural ventilation and effective shading.
- The target regarding the thermal design of the building was to avoid/minimise the use of air-conditioning with the aid of electrical and mechanical installations and equipment such as; BMS system, low energy consumption artificial lighting, night ventilation for cooling and a full storage cooling storage system.
- The full storage cooling system allows for a transfer of electrical energy consumption for cooling from the day to the night hours.
- The transfer of the energy consumption to night hours relieves the Hellenic electricity utility of a significant energy demand during the peak daytime hours.
- The current PPC tariff results in a lower cost of energy per kWh with cooling storage for the user.
- The full storage cooling storage system has a higher energy consumption than conventional cooling due to the reduced efficiency of the heat pump when charging the ice banks.
- In order to promote cooling storage systems, the PPC must be persuaded to introduce more competitive price tariffs, such as multi-zone tariffs.
- With the current electricity utility tariffs (B2), the partial storage solution is preferable to full storage.
- The simulation of the building using the TRNSYS software package, yielded cooling and heating loads approximately 20% smaller than the local engineering software package used by the local consultant engineering firm.
- For the first time in Greece a dual-use heat pump (heating and cooling) has been installed and used to also charge the ice banks.