Building Advanced Ventilation Technological examples to demonstrate materialised energy savings for acceptable indoor air quality and thermal comfort in different European climatic regions.

Advanced Ventilation Technologies

Case Study No 1
ARCHAEOLOGICAL MUSEUM OF DELPHI
DELPHI, GREECE

Supported by

Intelligent Energy Europe

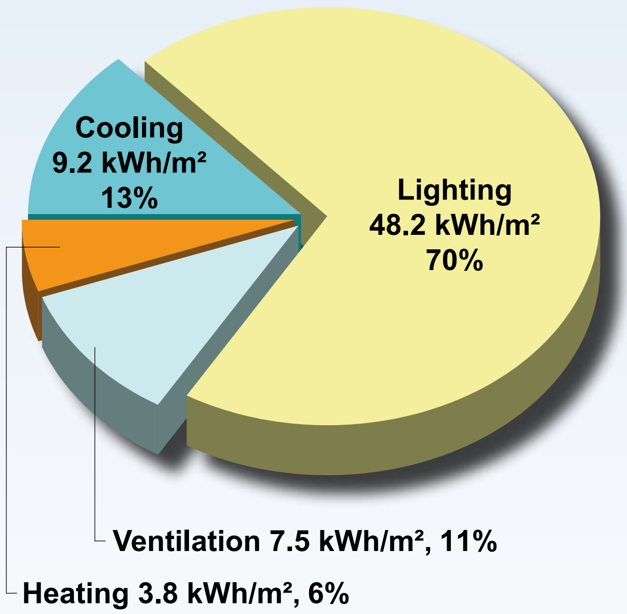
INTRODUCTION

The museum of Delphi is situated on the side of Mount Parnassos. It is a free standing building, located next to the archaeological site of Delphi. The site does not contain any other built structures; therefore no features obstruct the solar penetration or the natural ventilation of the building.

Summary Table of key design parameters.

Building data	
Building type	Museum
Total floor area	2 500 m²
Mean occupant density	Variable – up to 2 500 visitors per day.
Occupied hours	3 600 hrs/year
HVAC data	
Ventilation system type	Hybrid ventilation – mechanical ventilation in conjunction with openable windows controlled by CO_2 level.
Building fabric data	
Window U-value	2.7 W/(m² K)
Window g-value	0.75
Exterior wall U-value	0.38 W/(m² K)
Base floor U-value	0.5 W/(m² K)
Roof U-value	0.6 W/(m² K)
Climate data	
Design outdoor temperature for heating	-6°C
Design outdoor temperature for cooling	34°C
Heating degree days (include base temperature)	1 428 days (base 18°C)
Cooling degree days (include base temperature)	186 days (base 25°C)

The building is situated in a climate zone with a high cooling load.



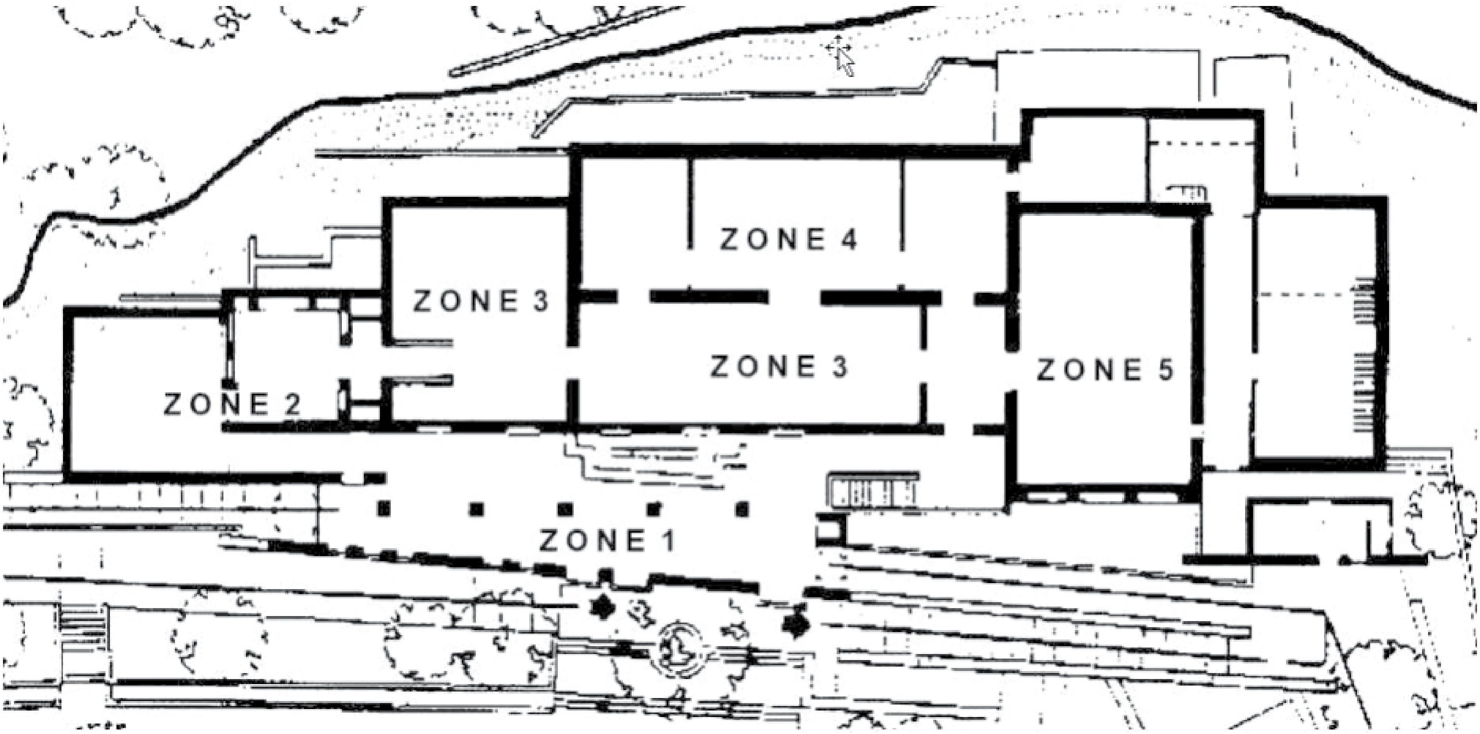
Annual energy use.

BUILDING DESCRIPTION

The original building dates back to 1903 and was constructed by the French architect Tournaire. Since then, the building has undergone four modifications. The present building design is the result of modifications carried out in 2003 and designed by A.N. Tombazis and Associates, within the frame of the EU project 'Museums – Energy efficiency and sustainability in retrofitted and new museum buildings', contract no NNE5/1999/20 (duration 2000-2004).

The Delphi museum is one of the most renowned museums of Greece. It receives more than a half a million visitors from abroad annually with over 2 500 people visiting on a peak day. The building is open to the public from 8.00 to 19.00 daily apart from Monday and from 12.00 to 18.30 on Monday.

The building has a total area of 2 500 m² of which 1.150 m² are exhibition areas. It has a rectangular layout and its long axis runs from north to south. It has two floors (ground level and upper level). The upper level of the Museum is mainly used as an exhibition floor and consists of four main zones (Hall of the Charioteer, Hall of the Athenians, Hall of Apollo and Hall of Siphnians). The layout of the Museum and location of the main zones are shown in Figure 1. Figure 2 shows a typical exhibition area.



Zone 1: Ground floor and offices
Zone 2.: The old and new Hall of the Charioteer
Zone 3: The Halls of the Athenians (Daohos, Kouros, Shields.)
Zone 4: The Hall of Apollo
Zone 5: The Hall of Siphnians

Figure 1. Layout of the Museum and principal zones. [Source: Zannis, 2004]

DESIGN SOLUTIONS

The last retrofit of the building, in 2003, was aimed at improving indoor environmental conditions and minimising energy consumption. In order to reduce thermal losses during winter, the existing building envelope was externally insulated with 50 mm of extruded polystyrene. Additionally, all windows were replaced with double glazing. The opening of 50% of these is controlled by the building management system (BMS). Some of the windows of the original building were redesigned in order to increase the natural ventilation and the daylight. External shading was provided to the east-facing windows of Zones 3 and 4. In Zone 5, the existing roof was replaced with a new glazed roof fitted with external louvres to regulate solar gain (Figure 3).

The original air-conditioning system was replaced with a new system that incorporates a heat recovery unit. All standard luminaires were replaced with highly energy-efficient luminaires. Daylight compensation is applied through the BMS. For acoustic reasons, all suspended ceilings were replaced with new ones, made from recycled glass fibre, that also maintain the desired light reflectivity.

In order to enhance the thermal comfort levels, while minimising the use of air-conditioning, ceiling fans were installed in the main exhibition areas. With the use of ceiling fans, the cooling set point can be increased from 26°C to 29°C, thereby reducing air-conditioning running hours. The advanced BMS controls all building services, air-conditioning, heat recovery, demand control ventilation, ceiling fans, lighting and shading devices.

Figure 2. Typical exhibition area. [Source: Meletitiki, 2004]

VENTILATION STRATEGY

The building is fitted with mechanical ventilation, supplemented by openable windows. The original mechanical installation of the building was replaced by an air to air HVAC system equipped with heat recovery. The number of people visiting the Museum at any one time is variable and seasonally dependent. For this reason, the ventilation system includes demand control that allows fresh air to be supplied to the occupied zones only when the carbon dioxide concentration reaches a preset level. In this way, indoor air quality is maintained at an acceptable level even when the exhibition areas are crowded while allowing energy savings to be achieved.

Controlled by the BMS, automated windows are opened and closed, according to the ventilation demand determined by carbon dioxide concentration, providing air flow through the building. The use of ceiling fans to provide air movement allows the set point of the air-conditioning supply to main exhibition areas to be raised by 2 to 3°C while retaining the same level of thermal comfort.

The openable windows also provide night ventilation which, in conjunction with the high thermal mass of the building assists in maintaining peak air temperatures within the comfort levels and avoiding overheating during the summer period.

PERFORMANCE

(i) Energy performance

The data monitored by the BMS for the year 2004 shows that the total annual electricity consumption was 64.9 kWh/m² of which 9.2 kWh/m² is attributed to cooling, 48.2 kWh/m² to lighting and 7.5 kWh/m² to ventilation. Therefore the greatest part of the total electricity consumption is consumed by the lighting equipment, while the remainder is divided between cooling and auxiliaries (ventilation, etc.). As expected, cooling and ventilation consumption increase during the summer months. The monitored heating consumption of 3.8 kWh/m² is low, although this was artificially low as the building was not in full operation for part of the winter period and the weather was unusually mild. Nevertheless, a comparison before and after retrofit, shown in Figure 4, demonstrates the very considerable overall reduction in energy consumption.

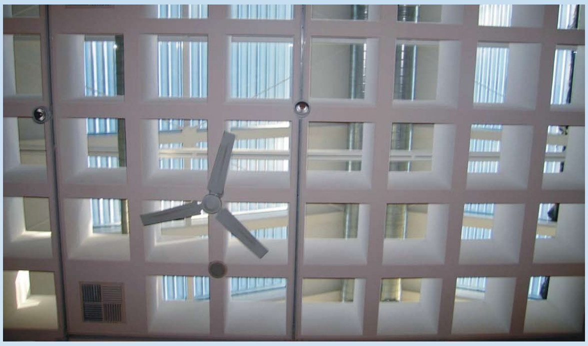


Figure 3. Ceiling fans and glazed roof.

(ii) Indoor environment performance

(a) Thermal

Temperatures in the building were monitored throughout 2004. Despite large variations in ambient air temperature which varied from below 0°C during the winter months to above 40°C during the summer months, internal temperatures remained quite stable, mainly in the range 24°C to 28°C, particularly as the changes to the building and the operation of its services settled down. Figure 5 shows the temperatures in the main zones for August. Of the exhibition areas, the Athenian and Apollo Halls (Zones 3 and 4) have the best temperature performance due to their higher thermal mass. The ground floor and offices also achieve the air-conditioning set-points exceptionally well, due to their high thermal mass and low exposure.

(b) Ventilation

Carbon dioxide (CO_2) concentration which is used to control demand ventilation was monitored in all areas of the museum by the BMS. The results are shown in Table 1 as CO_2 concentration above ambient. During the whole period of moni-

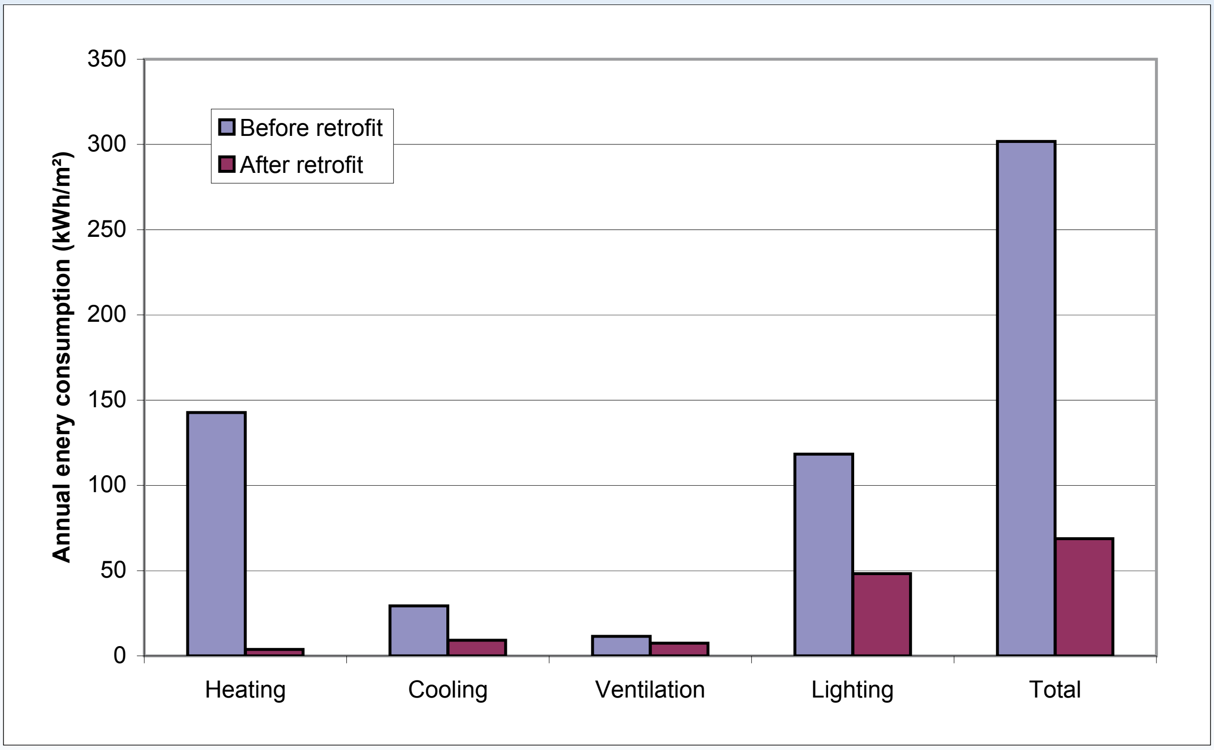


Figure 4. Energy consumption before and after the building renovation. [Source: Zannis, 2004]

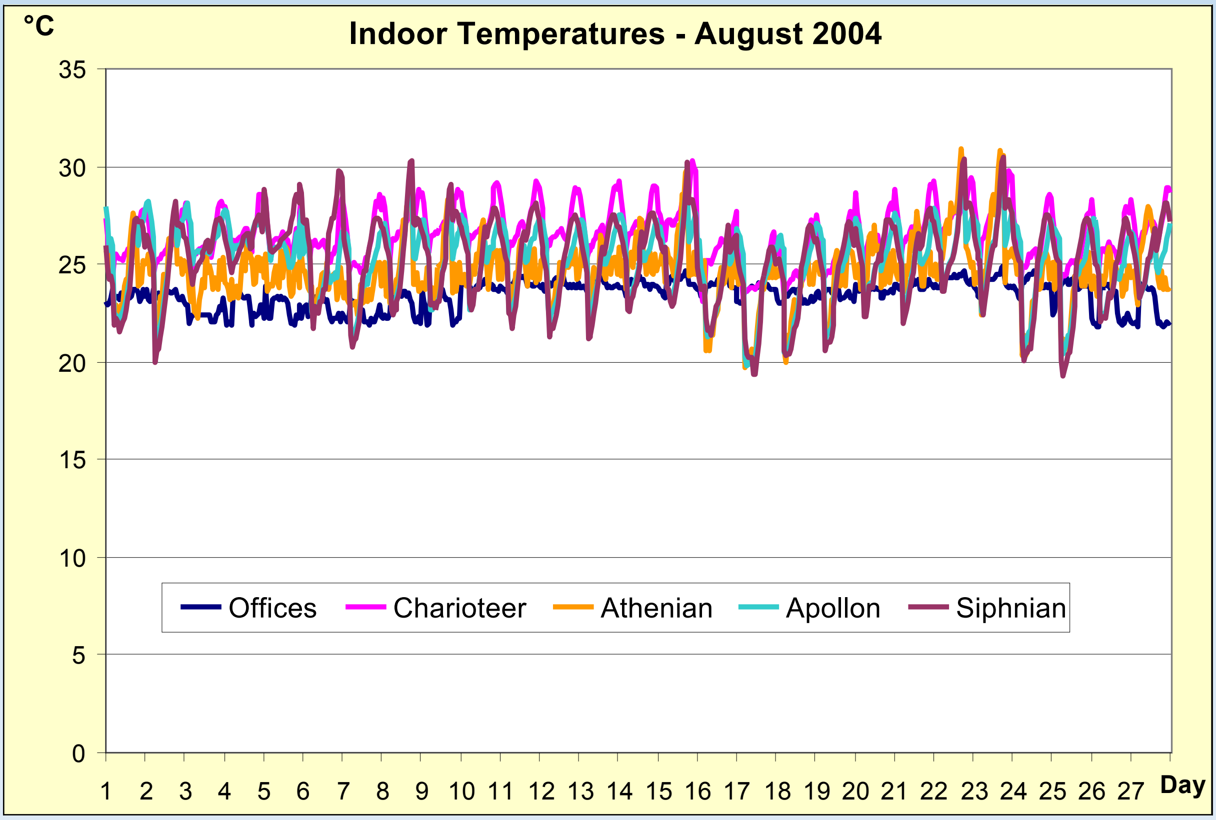


Figure 5. Indoor temperatures for August 2004. [Source: Zannis, 2004]

toring the concentration was always very low and below acceptable levels such as that given in the ASHRAE guidelines of 1000 ppm (equivalent to approximately 620 ppm above ambient) for a continuous 8 hour exposure.

(iii) Occupant assessment of performance

The results of a survey of visitors and permanent staff are summarised in Table 2. In general, the level of satisfaction is very good in winter but lower in summer, except for lighting which is high throughout the year for both artificial and natural lighting.

DESIGN LESSONS

The highly insulated building envelope in conjunction with its thermal mass performed well during winter months which were characterised by some days with very low temperatures. Internal temperatures were kept within the comfort zone

Table 1. Monitored CO_2 concentration in the five main zones. [Source: Zannis, 2004]

Carbon Dioxide (CO_2) concentration above ambient (ppm)			
Location	Maximum	Minimum	Mean
Zone 1	60	3	44
Zone 2	200	14	83
Zone 3	79	39	50
Zone 4	12	4	9
Zone 5	6	2	4

Table 2.
Summary of occupant assessment of the indoor environment.

	Summer %	Winter %
People finding the **overall indoor environment** acceptable	69	88
People finding the **thermal environment** acceptable	63	88
People finding the **indoor air quality** acceptable	63	94
People finding the **acoustic environment** acceptable	64	74
	Artificial %	**Natural %**
People finding the **lighting** acceptable	89	89

Exhibition Hall.

Design team information *Designers and contractors*	
Tenant	Hellenic Ministry of Culture
Architect	A.N. Tombazis & Associates Architects Ltd
Engineering – Energy	M. Santamouris, Associate Professor, Group Building Environmental Research, National and Kapodistrian University of Athens
Engineering Consultants	ANTEM Ltd
Engineering – M & E	ANTEM Ltd
Building contractor	J/V M.T. ATE-Alexandros Techniki S.A.

for the visitors and within the required levels for the displays.

Additionally, the demand control ventilation technique, based on the CO_2 concentration, (i.e. occupancy pattern), has proved to be a good solution for the provision of adequate ventilation for a building with highly variable occupancy, ensuring acceptable indoor air quality.

The implemented energy measures result in excellent energy and environmental building performance and ensure an A energy rating according to the EPBD.

GENERAL

Key points concerning the design

The museum of Delphi is an exemplar low energy building museum with good visual and thermal comfort due to an energy efficient HVAC system equipped with heat recovery and demand control ventilation in conjunction with the use of ceiling fans and the correct distribution of daylight.

REFERENCES

Meletitiki-A.N. Tompazis and Associates & Dept of Applied Physics, NKUA (2004), 'Museums Archaeological Museum of Delphi, Greece', European Commission Directorate – General Energy and Transport.

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Brochure authors: M Santamouris and I Farrou, National and Kapodistrian University of Athens.

BUILDING ADVENT

Full title of the project: Building Advanced Ventilation Technological examples to demonstrate materialised energy savings for acceptable indoor air quality and thermal comfort in different European climatic regions. Building AdVent is funded by the European Commission, Directorate-General for Energy and Transport as part of the Intelligent Energy - Europe Programme.

It is estimated that energy consumption due to ventilation losses and the operation of fans and conditioning equipment is almost 10% of total energy use in the European Union and that about one third of this could be saved by implementing improved ventilation methods. A number of projects have been undertaken under the auspices of the European Union (under the SAVE and ALTENER programmes) and the International Energy Agency (Energy Conservation in Buildings and Community Systems Annexes 26 and 35) to identify and develop improvements in ventilation technology.

The AdVent programme is intended to build on these and has three principal objectives:

- Classification of existing building ventilation technologies as applied in built examples and collection of information on building performance.
- Identification of barriers for future application.
- Preparation of case-studies in a common format, together with training material

BUILDING ADVENT PARTICIPANTS

Coordinator

Buro Happold Consulting Engineers .... UK

Participating Organisations

Brunel University .... UK
National and Kapodistrian University of Athens .... Greece
Helsinki University of Technology .... Finland
Aalborg University .... Denmark
Faculdade de Engenharia da Universidade do Porto .... Portugal
International Network for Information on Ventilation and Energy Performance (INIVE) .... Belgium

Major Sub-Contractors

Federation of European Heating and Air-Conditioning Associations (REHVA) .... The Netherlands
International Union of Architects .... France/Greece
—Architectural and Renewable Energy Sources Work Programme (UIA - ARESWP)

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