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Passive Cooling Strategies for a Digital Creative Industry Hub in Malta

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Abstract
The cooling load for offices in Malta may account up to seventy per cent of the workplace total electricity consumption due to the influence of solar radiation and elevated internal heat gains. Therefore the research project documents the design of an office complex, set as a catalyst in a disused dockland area, which relies on passive cooling strategies. The study is structured in three sections. Initially the climate analysis, supported with a literature review, identified ground cooling, nocturnal ventilation and evaporative cooling as the main potential cooling strategies. Subsequently the effectiveness of each strategy was analysed through dynamic thermal modelling. The research led to the design of solar chimneys that draw ground-cooled displacement ventilation and the use of roof ponds. Finally the research, through further thermal modelling, solar and daylight studies, informed the workplace morphology, façades and external areas such that thermal and visual comfort is ensured for the occupants.

Keywords: Passive Cooling, Offices, Solar Chimney, Ground Cooling and Solar Control

1 Introduction
The tertiary sector is a rapidly growing market in the Maltese economy, contributing to 44% of the GDP in 2008 as opposed to 28% in 2000. This economic growth is also characterised with the development of new office hubs with a major expansion envisaged in the creative industry sector. The office building is regarded as one of the most energy demanding typologies, consuming on average around 130kWh/m² in mechanical cooling annually in Southern Europe (Yannas, 2006) due to elevated occupancy densities and heat-intensive equipment. The commercial[1] sector in Malta consumes one third of the electricity generated on the island. Thus office cooling is regarded as a main component of the national electricity peak demand in summer (MRA, 2006). The study looks into how passive cooling strategies may offset the office workspace high cooling load demand.

2 Climate Analysis
Malta is a Mediterranean island located 35°50'N, 14°35'E. The Climate is characterised by mild winters and hot humid summers with a high solar intensity. Global horizontal radiation reaches up to 8kWh/m² in July. The mean maximum summer temperature is 30.2ºC while the mean minimum temperature is 21.2ºC; a diurnal temperature range of 9.0ºC. The average temperature during this period is 26ºC while temperatures over 35˚C are frequent from June to September.

In order to judge thermal comfort CIBSE EN 15251 was applied, deriving 24.9ºC and 29.9ºC as the extents of the summer comfort band for a naturally ventilated building.

[1] The commercial sector includes both office developments and retail outlets.

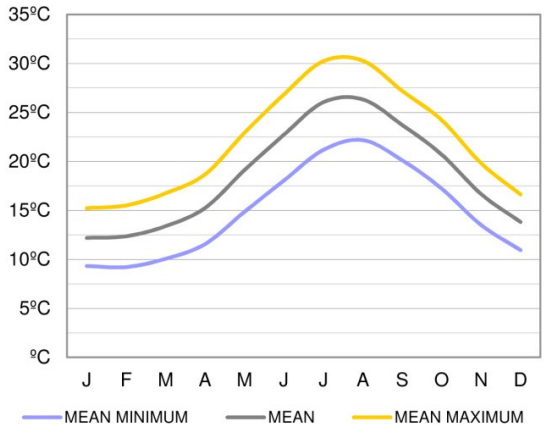

Figure 1. Typical meteorological year (1996-2005)

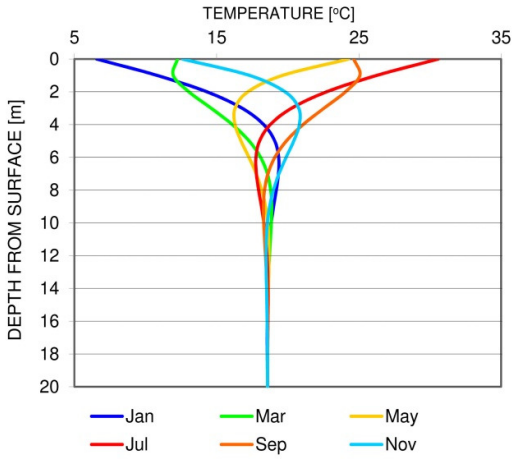

Figure 2. Ground temperature variation with depth

3 Passive Cooling Potential

Due to the influence from maritime currents the island experiences an average wind speed of 4m/s blowing predominantly from a west-north-west direction. This allows natural ventilation to be one of the most effective cooling strategies during the midseason and winter period. Furthermore the large diurnal temperature range is an indication of night-time ventilation cooling potential. Nocturnal ventilation in offices with high internal thermal capacitance in this climate may reduce the cooling load even by 60% (Allard, 1998).

Water bodies and ground cooling may also be a source of coolth. A mathematical model (Robinson, 2003) indicates that the local ground temperature follows an exponential decay, setting at 18.5ºC, the mean annual ambient temperature. This may provide a cooling source at 18.8ºC at 4m below ground during the hottest months (Figure 2). Moreover water bodies may also serve as potential heat sinks. A mathematical model by Givoni (1994) indicated that a shaded roof pond may stay below 23ºC when the daytime ambient temperature is 27ºC.

4 Cooling Strategies Dynamic Thermal Modelling

The initial sensitivity studies on a typical local office block (Figure 3) highlighted shading as the foremost measure in reducing an office cooling load. Subsequently ventilative cooling reduced the load for the midseason period. Thermal mass coupled with night-time ventilation on the other hand proved to lower the cooling demand during the summer period. Ground cooling combined with night-time ventilation proved to be the most effective strategy for the hottest months. This led to further research on the use of earth pipes to pre-cool the intake air.

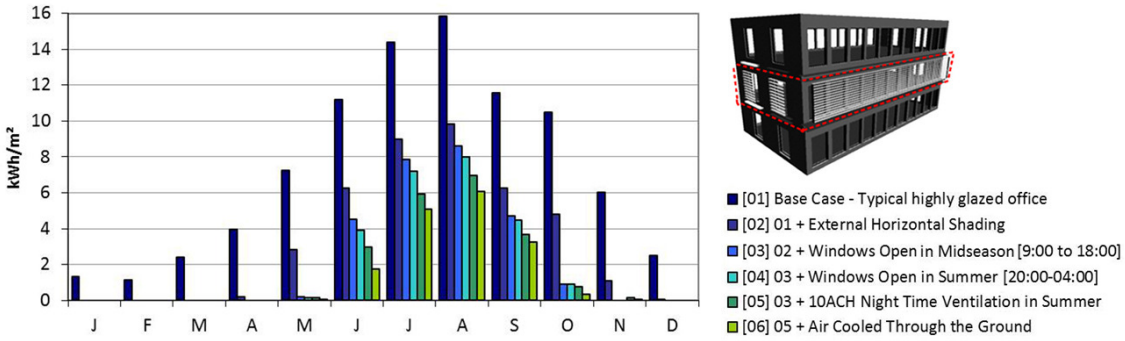

Figure 3. Multi-parameter cooling strategies cumulative sensitivity study. U Values used [Wm-²K-¹]: Glazing 2.9, Walls 1.5 and roof 0.5. Infiltration rate : 0.3ACH; Ventilation rate: 1.2 ACH [30m³/hour per person]. Internal heating gains based on CIBSE 2006.

4.1 Buoyancy-driven ground-cooled displacement ventilation

The potential of a solar chimney to induce ground-cooled displacement ventilation was investigated. The predicted pressure difference through the chimney is defined by:

[1][2] $P_{STACK} = (0.043 \times h) \times (\Delta T)$ (Baker,2000):

Since the air in both the offices and the earth ducts, known as earth-air heat exchangers [EAHX], is cooler than the ambient air the thermal force within the solar chimney, P_{STACK}, needs to overcome a negative stack pressure, ΔP_{EAHX}; defined by:

[2][3] $\Delta P_{EAHX} = \Delta P_T - D_{TR} - D_{TT}$ (Wang,2004)

$\Delta P_{EAHX} = -(po - pr)\, gHr - (po - pt) gHt$

The stack sizing was based on the amount of extraction required for a given rate of internal heat gains according to Lomas (2007). Figure 4 illustrates that the thermal force within the solar chimney proved to be sufficient to induce pre-cooled displacement ventilation, allowing the office resultant temperature to stay within the comfort band on a hot summer day.

[1a] $P_{STACK} = (0.043 \times 15) \times (8) = 5.16$ Pa

[2a] $\Delta P_{EAHX} = (-0.025)\ 9.81 \times 3 - (-0.025)\ 9.81 \times 12\text{m} = -3.44$ Pa

$P_{STACK} > \Delta P_{EAHX}$

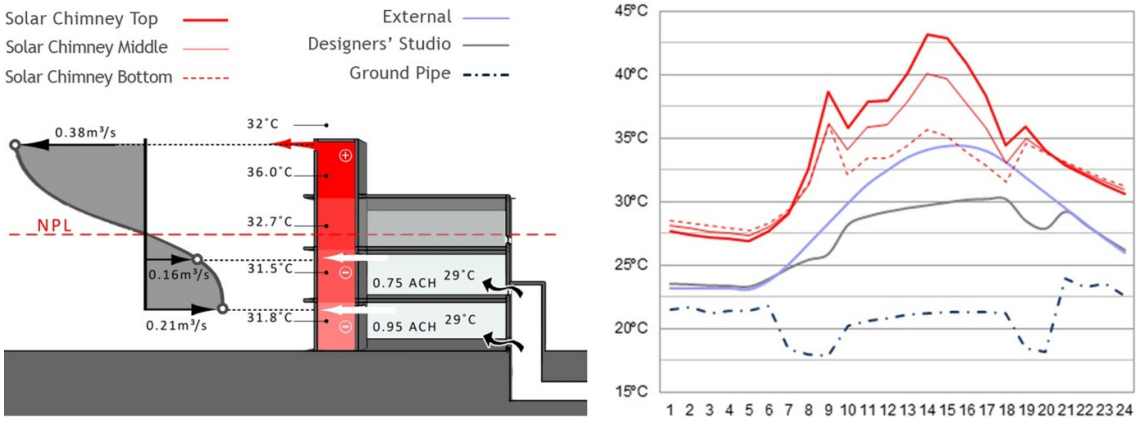

Figure 4. Free running dynamic thermal simulation (EDSL Tas) results for a typical hot summer day. Internal heat gains: 34.2W/m². Infiltration rate: 0.1; Ventilation rate: 0.7 ACH; Ground pipe: 30m length.

4 Design Application.

The creative industry hub proposal is set to become a catalyst at the edge of a disused dockland area. The proposal respects the footprint of the demolished 19th century market. Due to the north-south orientation of the site south-facing facets were morphed within the east façade to embed the solar chimneys (Figures 5 and 7). Additionally the chimneys were inclined by 25˚ as the 6kWh/m² incident direct solar radiation on a horizontal plane in summer is six times larger than that on a vertical south facing plane. Furthermore the chimneys exhausts were set facing SE in order to allow the predominant northwest winds to enhance the stale air extraction and preventing stack backflow.

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[2] h is the stack height; ΔT is the temperature difference between the stack and the exterior.

[3] ΔP_{EAHX} is the updraft pressure, Pa; ΔP_T is the pressure loss inside the pipe, Pa; D_{TR} is the occupied space extraction pressure, Pa; D_{TT} is the upward pipe extraction pressure, Pa; po is the external air density, kg/m³; pr is the room air density, kg/m³; g is gravity, m/s²; Hr is the distance between cooling tube outlet and inlet; pt is the air density at the outlet of the cooling tube, kg/m³; Ht is the depth of cooling tube below tube outlet.

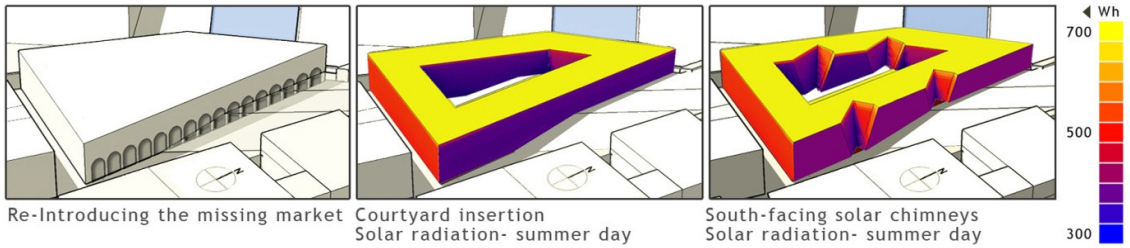

Figure 5. Building morphology development

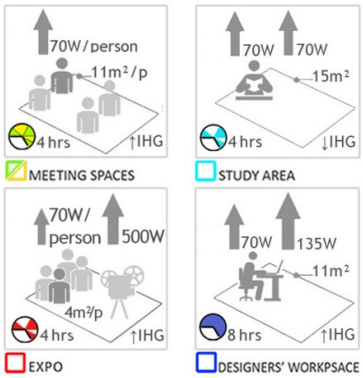

Figure 6. Internal heat gains per function

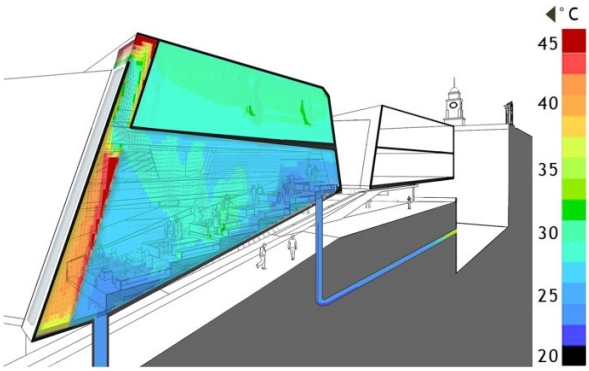

Figure 7. Solar chimney CFD performance

The building program was based on both spatial and environmental requirements in order to facilitate the workflow and provide the required visual and thermal comfort. The hub includes stepped networking areas to increase encounter possibility between different offices (Van Meel, 2010) and an expo as a public interface at ground level. The areas with high internal heat gains are accessed by the EAHX, with intensive areas thermally coupled with roof ponds.

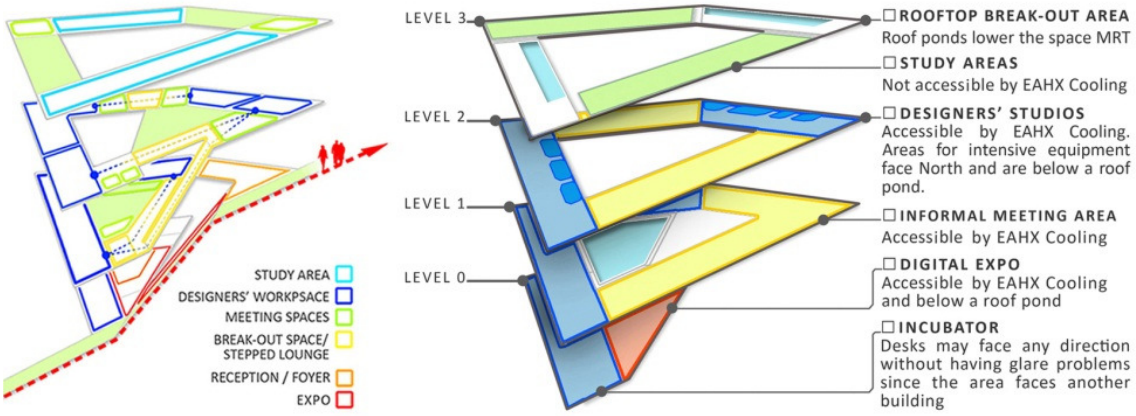

Figure 8. Building program development; combining architectural and environmental requirements

5 Façade Design

Due to the high use of computer screens in the offices direct solar radiation was obstructed in order to avoid glare. However daylight and external views were not to be compromised to ensure occupant comfort (HSE, 1997). Therefore using Ecotect Analysis shading masks a device was generated to mask radiation from 09:00 onwards throughout the year (Figure 9) [A]. Subsequently a light-shelf was introduced to provide a better daylight distribution [B]. Finally in order to provide better plan flexibility and more uniform daylighting the window

dimensions were altered and the shade took the shape of an inclined panel [C] as illustrated in Figure 9. On the other hand shading devices in break-out areas [i], where there is limited computer use, were aligned with the winter vertical solar angle [ii] such that solar radiation penetrates the building during the cold season but not during summer (Figure 10).

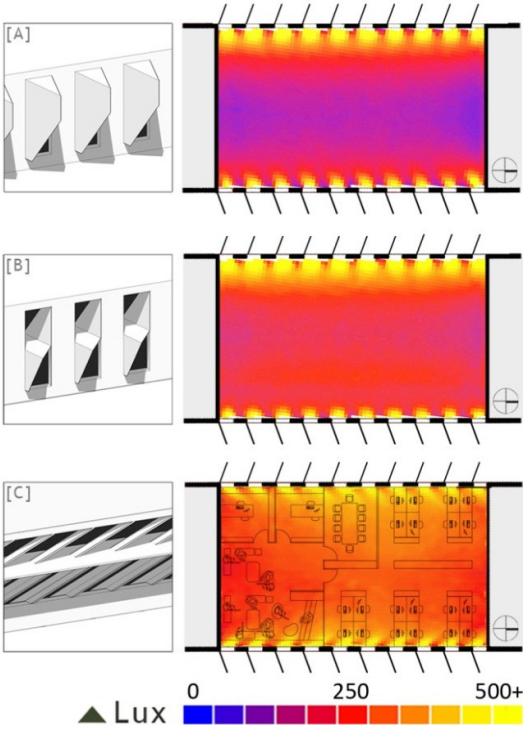

Figure 9. Workspaces solar control

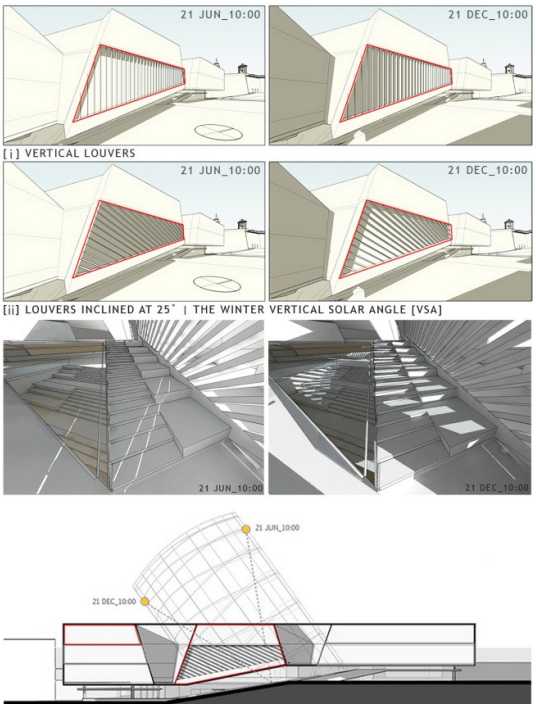

Figure 10. Break-out areas solar control

6 Courtyard Comfort

A collapsible fabric solar control system is proposed for the courtyard. This allows radiative cooling to store night-time coolth within the high thermal capacitance of the courtyard hardstone surfaces since the mean summer night sky temperature is 16˚C (EnergyPlus calculation). Subsequently the daytime courtyard Physical Equivalent Temperature stays within the comfort band. Simulations results (Figure 11) demonstrate that a sitting occupant PET stays 29˚C even on days when the ambient temperature reaches 33˚C.

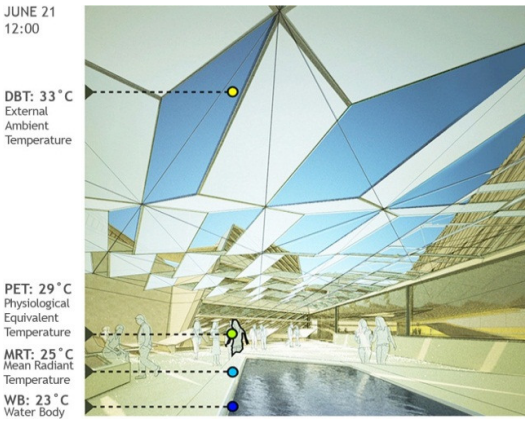

Figure 11. Courtyard summer day thermal performance

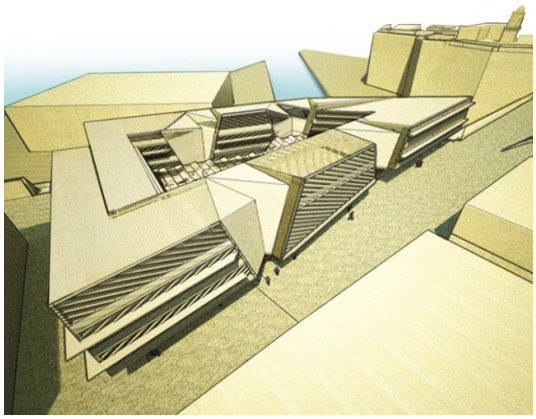

Figure 12. Passively-cooled workspaces

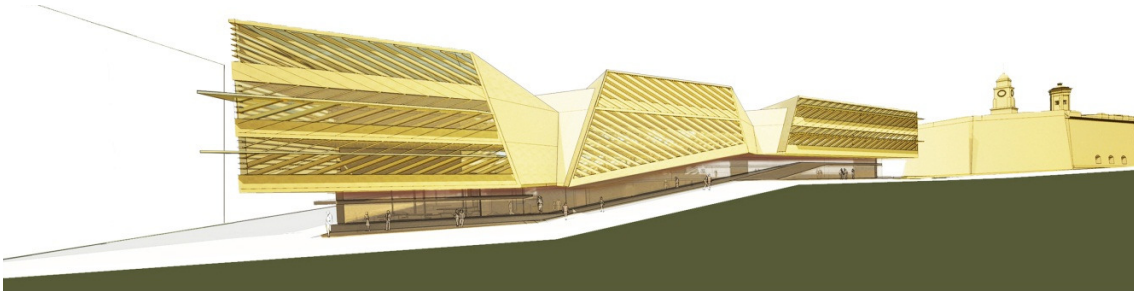

Figure 13. Design outcome sectional elevation

7 Conclusion

The project indicates that passive design strategies may provide thermal comfort throughout most of the year while significantly offsetting the cooling loads in contemporary digital workspaces. Simulations showed that the offices registered a low yearly cooling load of only 5.1kW/m². The energy demand of the building will however be influenced by the occupants' behaviour and adaptation as many may be accustomed to workspaces continuous mechanical cooling. The design of the Hub demonstrates the effectiveness of buried earth pipes as applied to high thermal capacitance architecture. The project further illustrates the potential of solar driven buoyancy in activating an EAHX system. However further experimental research would be required in order to assess the details and maintenance requirements of a combined solar chimney-EAHX system at such a scale.

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