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THE NEW BREWHOUSE, MRIEHEL: ENVIRONMENTAL CONTROL THROUGH NATURAL VENTILATION AND SHADING DEVICES

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ABSTRACT: Beers are as much the product of their environment as the output of a process. The new Farsons Brewhouse works as a protective shell accommodating the various building services whilst simultaneously assisting the environmental control of the interiors through two primary strategies: natural ventilation in the brewhalls and shading devices in the office building. Based on a simulated model, results showed that the induced air flow reduces the temperature by 10.7 °C and 8.5 °C in the lower and upper brewhalls respectively during the summer months. Whilst the ventilation system works successfully during most of the time, air changes drop when wind forces create a higher pressure outside of the building, as a result reverse flow occurs. The office building adopts a different design strategy; it incorporates various passive measures with the main feature being an expanded aluminium shading mesh. Monitoring of the internal temperatures before and after the mesh is installed shows that the introduction of shading reduces the peak temperatures in summer whilst maintaining a well lit internal environment. A simulated energy analysis of the building shows a potential reduction in energy consumption of 24% when compared to the same building with typical construction materials. The study concludes that by introducing moderate insulation, shading and night time ventilation internal temperatures are reduced effectively. On the other hand, the type of double glazing has to be carefully weighed, so as to avoid counter-productive results given the mild climate of Malta.

Keywords: Natural Ventilation, Shading, Environmental Control, Energy Efficiency

1 INTRODUCTION

As part of Simonds Farsons Cisk (SFC) modernisation programme, a new Brewhouse has been constructed to accommodate the increase in demand and improve the efficiency of the process.

The design of the new Brewhouse is closely linked to SFC's core values; Proud Tradition, Enduring Values, Exciting Future. As such the concept focused on developing a sustainable building that provides an efficient and good quality workspace - All the Best from Farsons.

The new building is reminiscent of the past, older Brewhall through the use of materials and environmental control measures. The new Brewhall is clad in copper sheeting recalling the old copper vessels which are now replaced by stainless steel ones. Passive cooling through natural ventilation and use of high thermal mass materials is also common in a number of SFC's buildings including the new Process Block which formed part of the modernisation programme and now the new Brewhouse.

Besides housing the brewhalls, the brewery also accommodates offices, laboratories, workshops, a malt store and a malt tower which form two distinct work environments:

- Process Area
- Office Area

These two areas accommodate very different functions and thermal environments, which call for different design strategies to be applied. This paper focuses on two particular features of the environmental design aspect:

- Natural Ventilation in the Brewhalls
- Shading devices in the offices

Figure 1 is a plan of the building.

The brewhalls consist of a lower and upper brewhall which accommodate five brewing kettles. A concrete floor separates these two spaces with the kettles standing in the lower brewhall (L.B.) and emerging into the upper hall (U.B.). The lower brewhall also accommodates other machinery and equipment which generate a considerable amount of heat during the brewing process. Although less heat is generated in the upper brewhall, glazed areas were introduced to display the vessels and introduce natural light, which makes this space more exposed to solar gains through the east and west facades. Both spaces are unconditioned, which calls for passive measures to counteract the heat build-up and maintain good air quality. This was achieved by introducing a natural ventilation system.

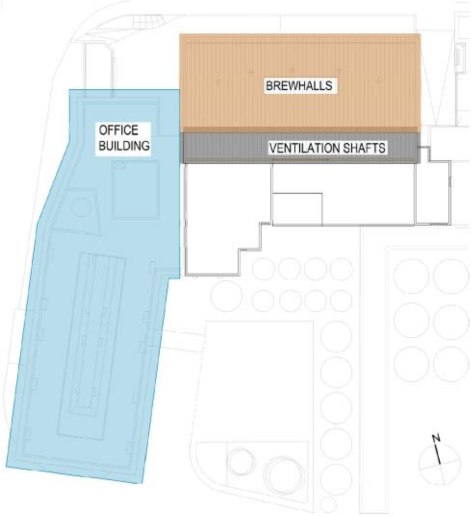

Figure 1: Roof plan of the new brewhouse

The office building consists of two floors, partly raised above ground level. The lower floor accommodates the laboratories which have strict environmental requirements, whilst the upper floor accommodates meeting rooms, cellular and open plan offices and have typical office requirements. Both floors are air-conditioned however the top floor was designed to allow for natural ventilation. This was not incorporated in the laboratories due to hygienic requirements. The building envelope is enclosed by a distinct expanded aluminium shading mesh. Other passive measures include insulated roof and walls, double glazed windows and a skylight to allow penetration of natural light in the central spaces and facilitate natural ventilation. Originally all walls and ceilings were intended to be exposed concrete so as to utilise the thermal mass of the building for night cooling, however soffits had to be introduced over significant areas to mask electrical wiring and other services.

Studies were carried out in order to understand the effects and efficiency of the ventilation system and shading mesh. Results of these studies are presented and discussed in the sections that follow. Both the brewhalls and office building are currently being monitored to assess the actual performance of the two systems.

2 NATURAL VENTILATION IN THE BREWHALLS

2.1 Natural Ventilation Strategy

Because of the nature of the operations taking place in the brewhalls, high internal loads are generated. Natural ventilation was therefore introduced, both to maintain good indoor air quality and to control the build-up of heat.

The magnitude and pattern of the airflow depends on the pressure difference across the airflow path and resistance to the flow. Furthermore the pressure difference is a function of wind and buoyancy driven forces [1]. Due to the variability of wind speed and direction, the building was designed to allow for buoyancy to be the primary driving force and for wind driving forces to assist the flow as much as possible.

As shown in the Figure 2 low level inlets on the north facade and high level outlets on both the north and south facade were introduced in the brewhalls and ventilation shafts. Because of site limitations, the size of north facing inlets was constrained. Additional inlets were therefore introduced on the sides of both spaces. The ventilation shaft is internally split in two;

- Central shaft connected to the lower brewhall
- Side shafts connected to the upper brewhall

The lower levels of the side shafts also accommodate a corridor connecting the process area to the office area. The shafts were therefore split to avoid having used exhaust air mix with the clean air in the corridor spaces.

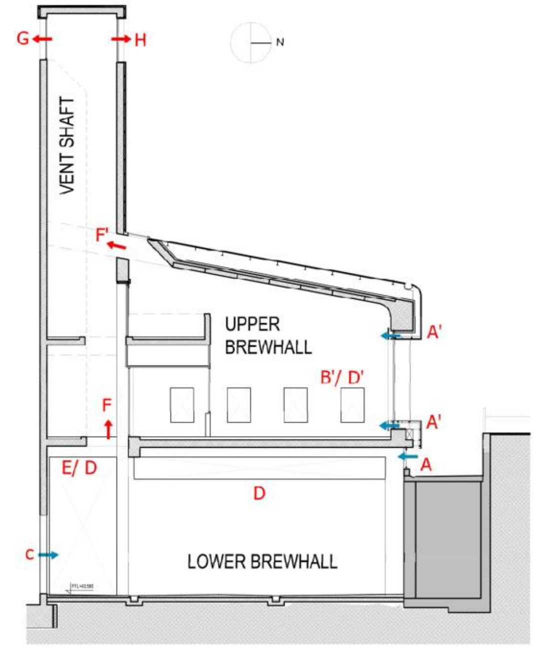

Figure 2: Ventilation Scheme

Table 1: Schedule of Openings

	Effective Area, m^2	
Inlets	**Lower Brewhall**	**Upper Brewhall**
A	**13 (North)**	**1.8 (North)**
B	**2.1 (East)**	**1.98 (East)**
C	**2.9 (South)**	**-**
D	**5.4 (West)**	**1.98 (West)**
E	**3.6 (West)**	**-**
Interzone		
F	**9.5**	**18.5**
Outlets		
G	**5.1 (South)**	**13.4 (South)**
H	**5.4 (North)**	**16.8 (North)**

2.2 Results and Discussion

The building was simulated in Open Studio and Energy Plus software [2] to assess the predicted airflow of the designed ventilation scheme and resulting internal temperatures. Figure 3 shows the building model.

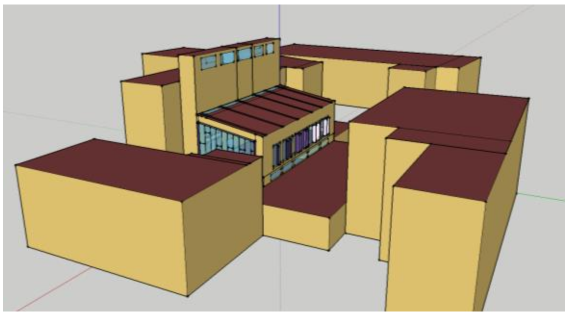

Figure 3: Model in Open Studio

In order to quantify the effective area of openings required and identify the optimal set-up to maximise airflow, various scenarios were tested as shown in Table 2.

Table 2: Natural Ventilation - Tested Scenarios

Scenario 1	No Ventilation
Scenario 2	Inlets only on the North façade Outlets open on North and South facades
Scenario 3	Inlets also introduced on the other facades Outlets open on North and South facades
Scenario 4	All inlets open Outlets L. B. only south windows open Outlets U.B. only south windows open
Scenario 5	All inlets open Outlets L. B. only north windows open Outlets U.B. only north windows open
Scenario 6	All inlets open Outlets L. B. north and south windows open Outlets U.B. only north windows open

The client requested an air change rate of 8 air changes per hour (ACH) for the lower brewhall therefore this was used as a benchmark for both halls.

2.2.1 Ventilation Rate and Internal Temperatures

Figure 4 shows the percentage of hours over which 8 ACH was achieved in the brewhalls per scenario during operation. Results show that scenario 6 is the one which gives the best overall results with 8 ACH or more being achieved for 82% of the time in the lower brewhall whilst a frequency of 35% being achieved in the upper brewhall.

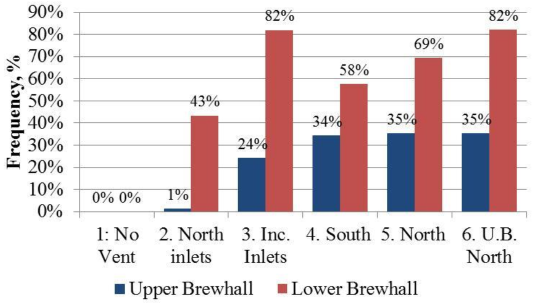

Figure 4: Frequency occurrence of 8 ACH during operation

Ventilation was primarily introduced to control the heat build up in the two spaces. According to CIBSE standards the comfortable indoor operative temperature in summer is 25 ºC in non-air conditioned buildings. In addition the peak temperature during the day should not exceed 28 ºC for 1% of the time [3]. By considering 28 ºC as the overheating benchmark, Figure 5 and Figure 6 show the overheating frequency compared to the average air change rate for each scenario.

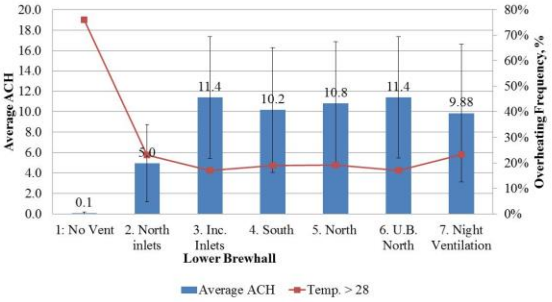

Figure 5: Average ACH and overheating frequency for the L.B.

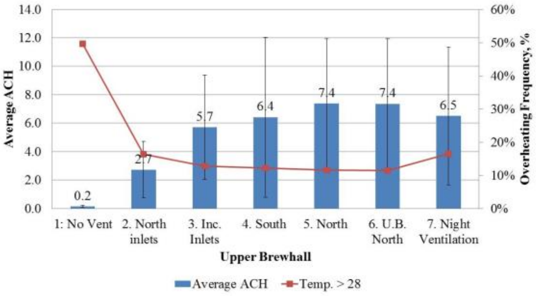

Figure 6: Average ACH and overheating frequency for the U.B.

A significant decrease in temperatures is observed as ventilation is introduced even though the air changes are rather low. As the air changes increase further, the temperatures decrease at a significantly slower rate. By considering Scenario 6, overheating frequency decreased from 76% to 17% in the lower brewhall and from 50% to 11.5% in the upper brew hall. It was also observed that increasing the average air change rate in the upper brewhall from 5.7 ACH to 7.4 ACH only decreased the overheating frequency by an additional 1.2%. This indicates that the maximum ventilative cooling capacity is being approached although the temperature can potentially be decreased further.

The possibility of limiting ventilation to night time only during the summer months was considered, however due to the high internal heat being generated in the spaces, night ventilation was not as effective.

In order to understand better the cooling capacity of the ventilation system, the temperature profile for the hottest week was observed. Figure 7 compares the temperature profile of the lower brewhall for scenarios 1 and 6. The sudden increase in temperature along the *Lower Brewhall No vent* curve represents the temperature rise due to heat generated by the equipment which is in operation 4 times a week. Introducing natural ventilation reduced the temperature by 11 °C in the lower brewhall and by 8 °C in the upper brewhall during the hottest week. Similarly, when comparing the average temperature during the summer months, a reduction in temperature of 10.7 °C and 8.5 °C is achieved in the lower and upper brewhalls respectively.

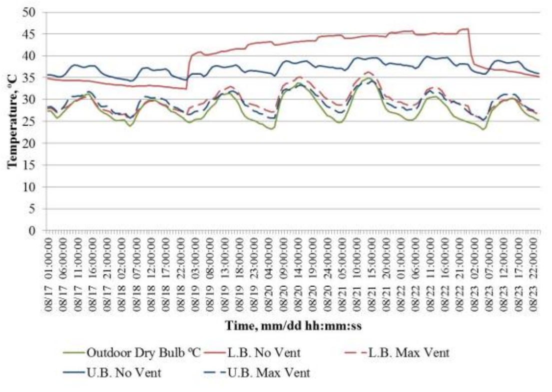

Figure 7: Temperature profile during hottest week for L.B. and U.B.

2.2.1 Airflow Analysis

Figure 8 shows the distribution curves for the brewhalls for scenario 6. From the curves it can be seen that the most frequent range of air changes in the lower brewhall is 5 – 17 ACH and 3 – 12 ACH for the upper brewhall with an average of 11.4 ACH and 7.4 ACH respectively.

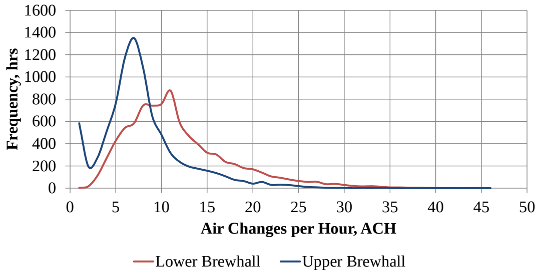

Figure 8: ACH distribution curves for Scenario 6

The upper brewhall curve peaks at 1 ACH because in scenario 6 only the north facing outlets are open therefore when the wind direction is north, the shaft acts a wind scoop, creating a positive pressure outside the outlet and cooling the air temperature in the shaft.

The general behaviour of the air change profile throughout one year was also analysed by looking into the following:

i. Minimum Airflow
ii. Maximum Airflow
iii. Average Airflow

A plot of the wind speed and direction was computed to understand the conditions under which the above situations occur.

Lower Brewhall (L.B.)

Minimum airflow occurs under the following conditions as shown in Figure 9:

- Wind direction is SE, S, SW (140 – 220º E of N)
- Wind speed is between 2 ms^{-1} and 8 ms^{-1} (light to moderate breeze)
- Plant is not in operation

Under these conditions the stack is not effective and reverse flow occurs. The ventilation shaft acts as a wind scoop allowing air to flow down the shaft hence pushing the warm air back down. Because the plant is not in operation the temperature difference between interior and exterior spaces is also minimal. As winds gets stronger some cross ventilation occurs also through the low level openings which increase the airflow slightly.

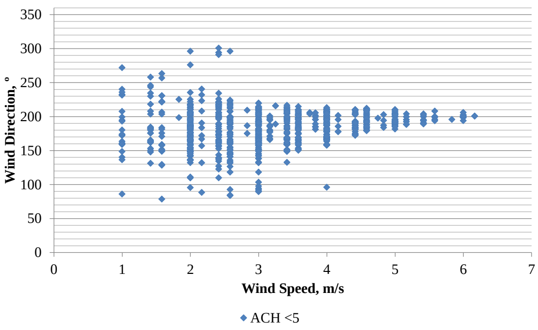

Figure 9: Conditions for minimum ACH in L.B.

Maximum airflow occurs under the following conditions as shown in Figure 10:

- Wind direction is between SW, N, SE (220º to 140º E of N)
- Wind speed is > 5ms^{-1} (moderate to stronger breezes)
- Plant is in operation

Under these conditions, buoyancy forces and wind driven forces work together. The wind increases air flow through the north facing inlets when blowing from the north and does not disrupt the flow due to stack effect when blowing from the East and West sides.

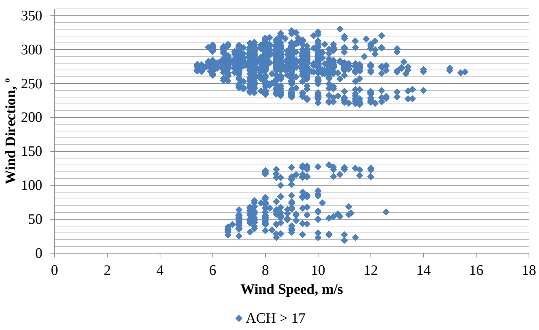

Figure 10: Conditions for maximum ACH in L.B.

The average airflow occurs under the following conditions as shown in Figure 11:

- Wind direction is between SW, N, SE (220º to 140º E of N)
- Wind speed < 5ms^{-1} (calm to gentle breeze) and
- Wind speed < 3ms^{-1} (calm to light breeze)

In this case, buoyancy is the dominant driving force. When the wind speed is < 3ms^{-1}, wind driven forces are less influential hence an average air flow is obtained by stack effect only. Furthermore when wind speeds increase to 5ms^{-1} therefore wind forces become more influential, the direction of the wind is to be limited to East, North or West so as not to disrupt stack ventilation.

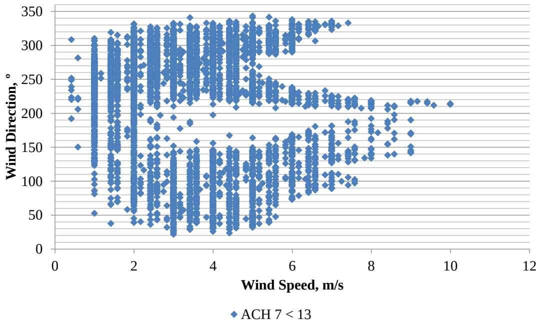

Figure 11: Conditions for ACH > 8 in L.B.

Upper Brewhall (U.B.)

Considering that the best results for the upper brewhall were obtained with the south facing high level outlets closed, the lowest airflow occurs when the wind direction is between 300 – 70º E of N. In this case the ventilation shaft acts as a wind scoop drawing cool air downwards.

Due to construction limitations, the south facing outlets in the ventilation shaft are smaller than those on the north façade. A simulation was computed with the south facing windows adjusted to have same size as the north facing ones. Results showed that the air changes increase to equal that of scenario 4 (north windows open). Therefore scenarios 5 and 6 gave better results because the size of the outlets is larger.

Maximum airflow occurs under the following conditions as shown in Figure 12:

- Wind direction is SE and SW, W (100 – 150º E of N and 230 – 290º E to N)
- Wind speed is > 5ms^{-1} (moderate to stronger breezes)
- Plant is in operation

Behaviour is similar to that observed in the lower brewhall therefore maximum flow is obtained when buoyancy and wind driven forces act together. In this case the wind direction is such that wind forces increase infiltration through low level side openings and yet does not penetrate through the north facing high level outlets.

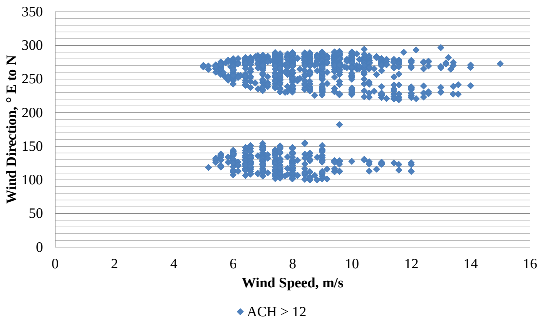

Figure 12: Conditions for maximum ACH in U.B.

The average airflow occurs under the following conditions as shown in Figure 13:

- Wind direction is E to NW (80 – 330º E of N)
- Wind speed is variable

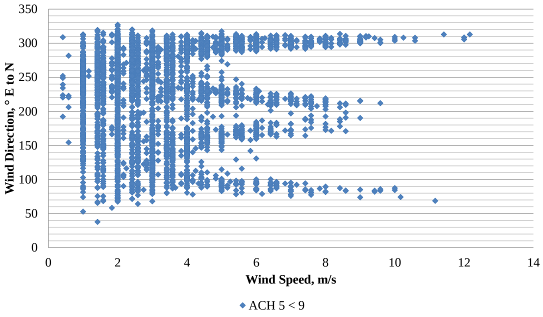

Figure 13: Conditions for average ACH in U.B.

Stack effect works well when the flow is not disrupted due to wind driven forces. As seen in the diagram, the higher the wind speed the higher the air changes as wind forces act in combination with the buoyancy forces.

By considering the air changes per hour during periods with very low wind speed, the ventilation induced by bouyancy only was determined. The average air change rate for the lower and upper brewhalls are 8.2 ACH (standard devitaion of 1.94) and 6.1 ACH (standard deviation of 0.99) respectively.

Results show that natural ventilation has a significant effect on the internal temperature and in both spaces buoyancy induced ventilation gave satisfactory air changes. The variability of the wind direction and small percentage of days with very low wind speed tend to interfere with the flow. By introducing actuators to control the openings according to the wind direction, those periods with very low air changes can be eliminated.

3 SHADING DEVICES IN THE OFFICE BUILDING

3.1 Design Strategy

One of the main objectives when designing the office building was that of providing a high quality work space with ample natural light and a comfortable thermal environment for its occupants. Several measures were implemented in order to meet this design intent. Measures include:

- Shading mesh around the building
- Insulation on roof and walls
- Double glazing
- Exposed concrete to increase thermal mass
- Natural ventilation
- Skylights to introduce natural light in central areas and to enhance natural ventilation

A compromise had to be found between the degree of shading and penetration of natural light in the space. Because the expanded aluminium mesh is wrapped around the whole building, it has a significant impact on the quality of the interior space both in terms of shading and penetration of natural light.

Preliminary checks indicated that by placing the mesh such that it maximises shading, the daylight factor would result to be below the design acceptable limits. It was therefore decided to place the mesh such that it offers less shading but allows more light through. This also gave a better view to the occupants from the interior space and made the building less transparent from street level therefore increasing privacy.

In order to assess the overall performance of the building envelope, a few tests were carried out:

1. The internal temperatures were monitored before and after the mesh was installed;
2. The internal temperatures were monitored over a period of occupied and unoccupied days;
3. An energy analysis was carried to quantify the energy consumption and compare the performance of the mesh in the two considered orientations.

3.2 Monitoring the Effect of the Shading Mesh

The temperature in the laboratories was monitored for a period of 6 weeks from the 9th of July till the 23rd of July whilst construction of the upper level was still in progress. In order to record the impact of the mesh, monitoring started before the mesh was installed.

Five temperature/ humidity loggers were placed as follows:

- Two loggers along the internal east wall
- Two loggers along the internal west wall
- One logger on the internal south facade

Based on the readings from the temperature loggers, an immediate reduction in the indoor temperature was observed after the mesh was installed.

The recorded temperatures on the east and west walls were very similar. Figure 14 shows that the maximum temperature reached during the first two weeks were higher than those on the following weeks (after mesh was installed) even though the external temperature remained significantly high throughout this period indicating that the mesh has a positive impact in the internal temperature.

The south wall exhibits the same temperature profile as the east and west walls; however the temperatures are slightly lower. This is due to the fact that on the south side the sun would have reached a higher elevation therefore the shading effects are strongest.

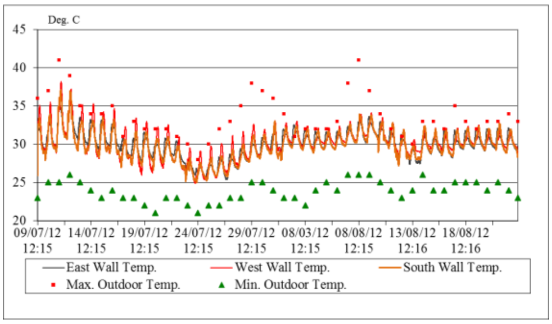

Figure 14: East, West and South Wall temperatures, together with the maximum and minimum outdoor temperatures for days preceding and following the installation of the shading mesh. Mesh installation was carried out on two consecutive days, starting on 24 July 2012.

3.3 Temperature Profile during Occupied and Unoccupied Periods

Figure 15 shows the internal and external temperature on site. During the month of December, one notes the effect of operating the heating systems during working hours and the cooling down of the building during the weekends. In particular, one notes this during the Christmas shut-down. It is clear that the offices were only used once during the two-week break.

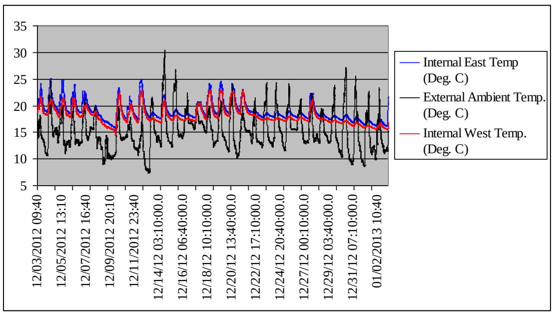

Figure 15: Internal and external temperature profile

During this period, the indoor temperature has only dropped by 0.8 °C, while the external temperature has decreased by almost 6 °C. Qualitatively, this shows that the building has good insulation and air leakage control.

Another observation may also be made on the thermal mass of the building. It is clear that the external temperatures are dampened substantially during the shut-down period.

Indeed, the external temperature is seen to be high for this time of the year. This may be explained by the fact that the temperature measured here is in the confined space between the shading mesh and the building envelope. It seems that during sunshine hours, the air around this region warms up substantially, due to the fact that the mesh is actually inverted and its construction reduces air flow within the immediate vicinity of the building. In other words, the mesh also acts as a wind breaker.

3.4 Energy Analysis

In order to understand the influence of the implemented measures on the energy performance of the building, a dynamic building energy modelling software: DesignBuilder-EnergyPlus was used to simulate the existing conditions and a number of other scenarios [4]. The EnergyPlus Weather (EPW) file for Malta was adopted in all simulations [5]. The energy requirements for artificial lighting, computers, heating, cooling and water heating were included in the energy analysis.

The office block consists of two floors partly raised above ground level. The lower level accommodates laboratories whilst the upper level accommodates offices. The study focuses on the upper level although the model also includes the laboratories to accurately simulate the current conditions.

The study compares the energy performance of the existing building as currently used to various scenarios as indicated in the table below:

Table 3: Tested scenarios for the office building

	Walls, U-Value	Windows, U-Value	Shading	Night Ventilation
Scenario 1 (Typical construction)	1.5 Wm^{-2}	5.778 Wm^{-2}	No	No
Scenario 2 (As built)	Insulated	Double	Mesh	No
Scenario 3	Insulated	Double	Mesh	Yes
Scenario 4	Insulated	Double	Inverted	No
Scenario 5	Insulated	Double	Inverted	Yes

Figure 16 compares the energy requirements of the existing building with those of the same building but with typical construction materials. Results show that the lighting load for the existing building is 22% higher than that of a typical construction however both the cooling load and heating load are reduced by 27% and 44% respectively. This is a result of the shading mesh and double glazing which reduces the amount of light and solar radiation entering the building hence affects the lighting and cooling loads. The heating load is reduced as a result of the lower u-value of the glass, walls and roof. Although the double glazing has a positive effect in winter, it has a negative effect in summer as internal heat gains and solar radiation is trapped inside the building. This can be counterbalanced by introducing ventilation to allow the warm air to escape.

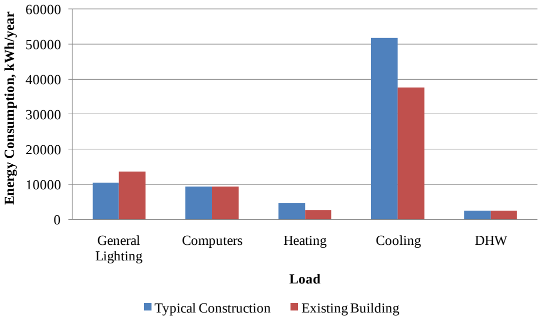

Figure 16: Typical construction vs existing building

Since the building was designed to facilitate natural ventilation, a comparison was also made between the performance of the existing building with and without night ventilation, as shown in Figure 17.

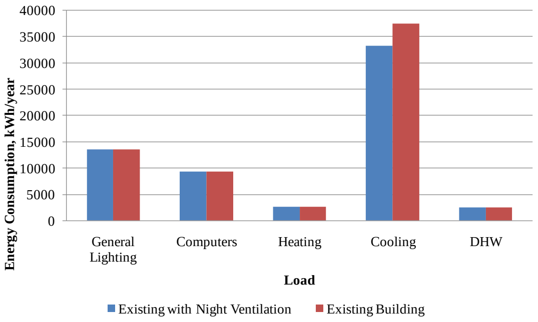

Figure 17: Existing building with night ventilation vs existing building without ventilation

A further reduction in the cooling load of 11% is obtained with the introduction of night ventilation during the summer months.

So as to understand the implication of the orientation of the mesh, another simulation was computed with the mesh inverted. As shown in Figure 18. If the mesh was installed in the opposing direction, the lighting loads and heating loads would increase by 31% and 35% respectively but the cooling loads would decrease by 19%.

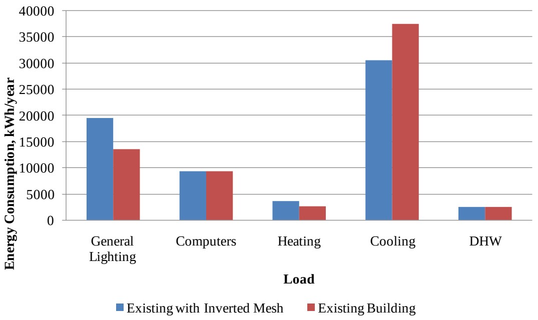

Figure 18: Inverted mesh vs existing building

Finally another simulation was carried out to assess the maximum potential decrease in the cooling load, as depicted in Figure 19, where a comparison is made between the existing situation to that of the existing building with inverted mesh and night ventilation.

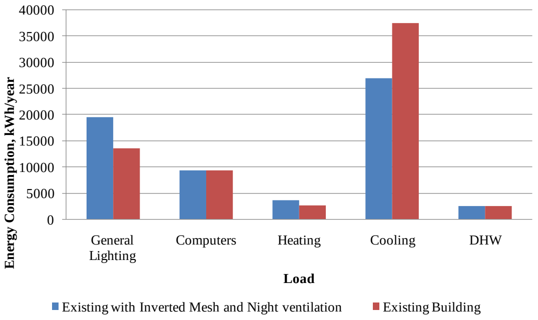

Figure 19: Inverted mesh & night ventilation vs existing building

In this case the cooling load is reduced further by 29% when compared to the existing and by 48% when compared to a typical construction. This scenario is the one which shows lowest cooling loads although not necessarily the lowest overall loads.

Having analysed the energy requirements for various sectors and scenarios separately, Table 4 compares the overall energy consumption and carbon emissions for each scenario.

Scenario 5 is the most efficient scenario, consuming 25% less energy than the typical building. This implies that maximising shading at the expense of increasing lighting loads is still more efficient in terms of energy and carbon emissions. The difference between scenario 5 and scenario 3 is limited to 2%. Therefore one might argue whether this reduction is justifiable considering the impact on the quality of the internal environment, for this particular building.

Table 4: Comparison of total energy consumption and CO_2 emissions for various scenarios

	Total Energy Consumption, kWh/yr	**CO_2, Kg**
1. Typical Construction	61381	42046
2. Existing Building	52581	36018
3. Existing with night ventilation	46684	31979
4. Existing Building with inverted mesh	52247	35789
5. Existing Building with inverted mesh and night ventilation	45726	31322

4 CONCLUSION

The new Brewhouse was designed with the intent of utilising passive measures to improve the quality of internal spaces. The effectiveness of these measures, which include a natural ventilation system in the brewhalls and shading mesh in the office building, were investigated and results were presented in this paper.

The natural ventilation systems implemented in the lower and upper brewhalls provide an average air change rate of 11.4 ACH and 7.4 ACH, respectively. As a result, the internal temperatures are reduced by 10.7 °C and 8.5 °C, respectively. The relation of the reduction in temperature with increase in air change rate indicates that a significant decrease in temperature is obtained even with a relatively low air change rate. Although buoyancy forces are strong enough to induce the required air change rate, the system is also influenced by wind driven forces which either enforces the flow or create a downdraught that reduces the air change rate. These periods of low ventilation can be minimised by introducing actuators, which control the openings according to the wind direction and speed.

On the other hand, the recorded temperatures in the office building showed that the addition of the shading mesh had an immediate reduction in indoor temperature especially on very hot days. When considering the overall performance of the building, it can be concluded that insulation and shading is essential to reduce energy loads, whilst consideration is also to be given to the quantity of light in this space. Night ventilation can also significantly contribute to further reduction in the cooling load. Double glazing on the other hand although beneficial in winter is effective in terms of energy efficiency, only when applied together with proper shading and ventilation strategies. Furthermore, the use of highly reflective and expensive double-glazing offers no added benefits to the building's energy performance, when compared to standard double-glazing.

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