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# Ventilated Hollow Core Slab; A low energy strategy to improve energy efficiency of the built environment.

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## Abstract
This paper presents the results of summer investigation in one collage and one university building in UK climate. The study deals with the analysis of the effectiveness of Ventilated Hollow Core Slab (VHCS), (i.e. the ventilation air, before entering the room, flows through the ducts of the hollow core concrete ceiling slab) to improve thermal environment within the buildings thus thermal comfort of the occupants; and how this system influences the energy consumption of the buildings.
On-site measurements were performed over two weeks and the internal climate conditions of several rooms within the buildings and surface temperatures of the VHCS as well as supply air temperature were recorded. Moreover, occupants of the collage building were surveyed regarding thermal comfort levels.
Results of this study confirm effectiveness of the VHCS by reducing the daily temperature swing and also increasing the ability of a space to handle daytime heat loads. Comparing the overall energy consumption of the buildings with the CIBSE benchmark indicates reduction up to 10% can be achieved.

Keywords: Ventilated hollow core slab (VHCS), thermal mass, energy consumption, thermal comfort, energy efficiency.

## 1 Introduction
During the last few years comfort requirements, indoor air quality and energy efficiency show an increasing trend. In Consequence, highest numbers of passive techniques have been reintroduced in order to decrease or eliminate the need for mechanical ventilation, cooling and heating thereby reduce energy consumption.

One approach that decreases energy consumption in buildings and maintains the thermal environment within the comfortable range is utilizing the building fabric as a thermal storage. In this case the maximum and minimum indoor temperature are reduced and so is the energy consumption. Total energy saving potential can be increased by the active utilization of the building mass. One of these active strategies is utilizing Ventilated Hollow Core Slab (VHCS). The VHCS is a precast slab of pre-stressed concrete that has tubular voids extending the full length of the slab. In this technique, ventilation air is passed through the hollow cores of the floor and ceiling slabs, therefore the airflow will increase the convective heat transfer. This system can be used for heating and cooling buildings. Energy savings from this system have been reported of between 13% and 70%, depending on the building type and the prevailing weather conditions (Zmeureanu, 1988).

This study is specific to further and higher education sector of the building industry that a significant proportion of all energy generated is used for heating and cooling of the buildings. Therefore, intention of this study is to demonstrate that by utilizing the VHCS, thermal performance of the building can be improved; also heating and cooling energy demand within

these buildings can be significantly reduced and consequently the overall energy consumption of the building can be cut down.

## 2 Methodology

To achieve the aim of this study, summer investigation throughout one Collage (Luton Sixth Form Collage) and one university building (Thomas Paine) has been conducted over 10 days. Placing a couple of the iButton (temperature data loggers) in various spaces within the buildings and one of the loggers outside each building produced valuable information of hourly indoor and outdoor ambient temperature. Furthermore, by placing the iButtons at the ceiling, temperature of the hollow core slab has been recorded. Recorded data has been used to produce several graphs, which allowed evaluating the thermal performance of the buildings.

Additionally, the assessment of energy performance of the buildings has been done based on the annual electricity consumption of the buildings which will be compared against figures of a typical practice and good practice published by the Charted Institution of Building Services Engineers- CIBSE benchmark.

## 3 VHCS control strategies applied in the case studies

The VHCS systems deliver heating, cooling and ventilation. A number of air handling unit (AHU) serve the VHCSs utilized in different zones at these buildings. The AHU's supply heated or cooled air into the respective zones through a system of ductwork, thermal planks and supply air diffusers. The ductwork from each AHU is separated into the independent thermal zones. Generally, the air will be supplied to each slab and discharged through soffit-mounted diffusers. The AHU's can be started either manually or automatically under the commands of the Building Management System (BMS). There are temperature sensors in each zone, which show when the AHU needs to start in order for the average temperature to reach its desire set point. When the temperature reaches the suitable value or at the end of the occupancy time, the AHU revert to normal temperature control. When the AHU is started, both supply and extract fans are enabled from the control system with a constant speed.

Series of temperature sensors are recording the slab temperature of different zones. In order for each AHU to determine the supply air temperature for that zone, the highest 'zone average slab temperature' is considered. The temperature set point for the slabs is 22ºC in winter and 21ºC in summer. A dead band of 1.5ºC is placed around the set point of (+o.5º C / -1.0ºC) during both seasons. The only different between Thomas Paine building and the Luton collage is the way air is supplying to the spaces within the Thomas Paine building. Basically when the supply air is passing through the slab, instead of being diffuse from the ceiling, air is distributed from the walls.

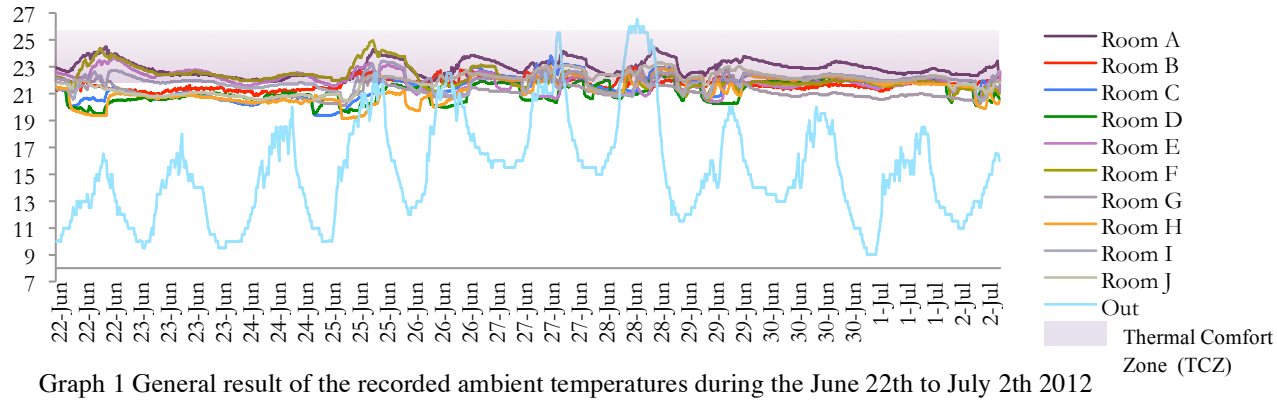
## 4 Analysis considerations

- As mentioned before, to monitor the temperature, iButtons are used. They have an accuracy of +- 0.5ºC that is take to account when analyzing the results.
- In order to assess thermal performance of the building regarding occupant comfort, Thermal Comfort Zone (TCZ) is registered between 22ºC and 26ºC .
- In the final, total energy consumption of the buildings is considered to evaluate the energy performance of the buildings. Therefore, these values do not display share of the VHCS in this achievement.

The author is only presenting part of the vast investigation has done this paper. Further complementary documents are available in thesis that this paper is based on.

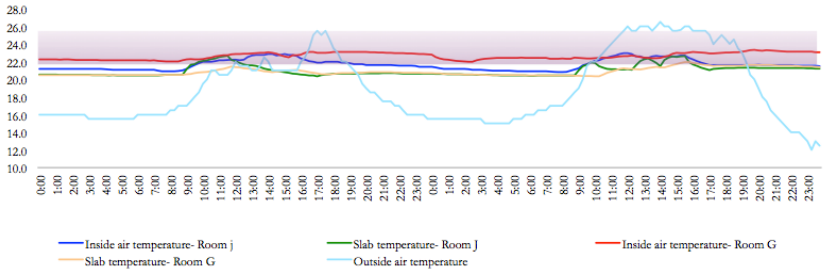
## 5 **Results and observations**

Considering the overall results of the recorded temperature, significant amount of information related to thermal environment of the Luton Sixth Form Collage could be pointed out. Graph (1) shows relatively small temperature variation within the rooms though the outdoor ambient temperature is highly fluctuating and the rooms are located in different orientations. Also the inside temperature remains significantly constant due to a greater effect of the VHCS utilized in these spaces.




Graph 1 General result of the recorded ambient temperatures during the June 22th to July 2th 2012 (Luton Sixth Form Collage)

Graph (2) illustrates the thermal performance of two classrooms during the warmest days of the recorded period, when one is north facing (room G) and another is south facing (room J). The slabs temperatures are relatively constant and within the same range. Whereas, the ambient temperature inside the room G is approximately one degree higher than the room J. This can be as a result of more solar radiations entering the room G. Higher temperature of the room G results in higher percentages of time within the TCZ. Although during the working period from 8 AM till 9 PM, room J is also within the TCZ, but the inside temperature is around the minimum level of TCZ. It can be concluded that the system is over cooling while by pumping the air in the higher temperature thereby rising the slab temperature, a more thermally comfortable environment can be achieved. Looking at the indoor temperature of the room J, In the morning 27th it is clear that by rising the slab temperature, the indoor temperature is increased. The interesting point in this growth is that the slab reaches the peak at 11:30 AM, whereas the indoor temperature peak occurs at 2:30 PM. This phenomenon is due to the time lag created by the VHCS.




Graph 2. comparative temperature results room G and room J during 27th and 28th June 2012

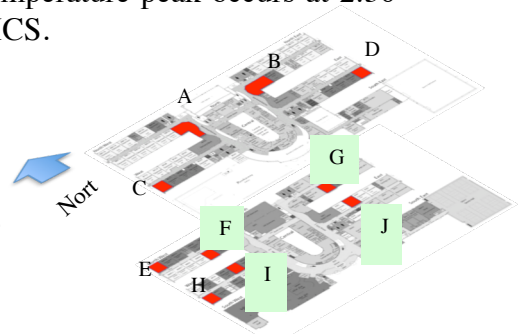
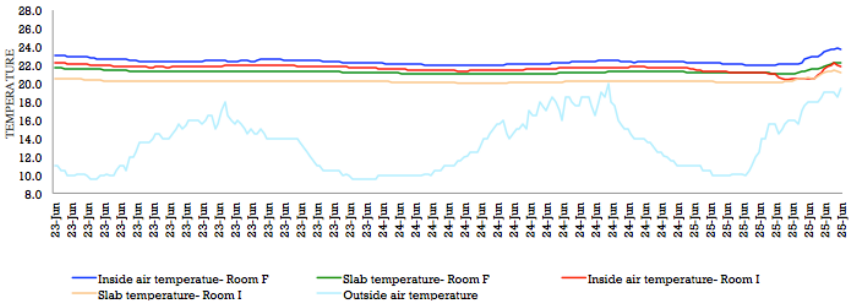



Figure 1. Key map of Luton Sixth Form College, showing the rooms that have been monitored.

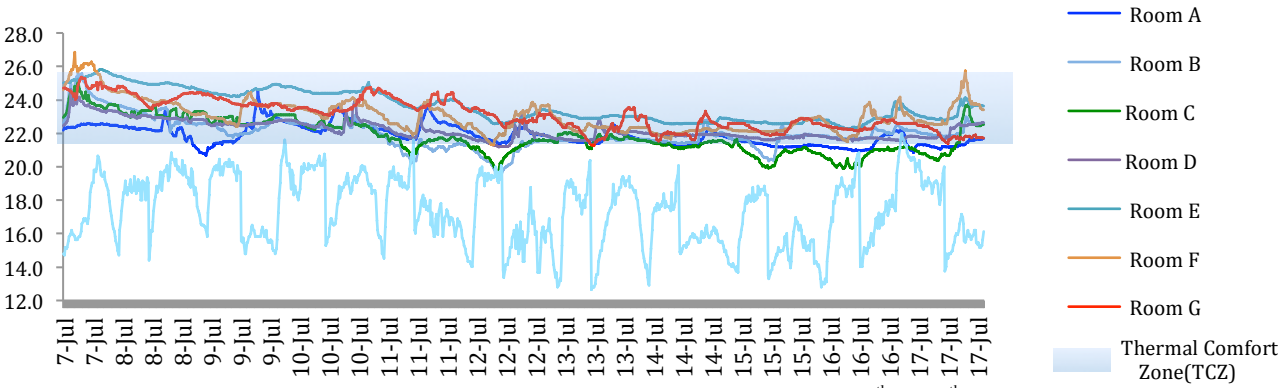
Looking deep to the thermal performance of two rooms with the same dimensions, orientation and occupancy pattern during the first three days (graph 3), the slab temperature and ambient temperature in the room F are higher than room I also the difference between the slab temperature and the room temperature is around 2°C. The possible reason is that control system of this wing was probably reduced or even shut down during this weekend therefore the temperature of the slab went up but remained relatively stable because of its thermal mass,

and the effect of thermal mass is detectable in the slight wave. Furthermore because the building is highly insulated with high thermal mass even if the control system is shut down not only the inside temperature remains stable but the slab temperature remains also relatively stable and the effect of the outside temperature is minimal



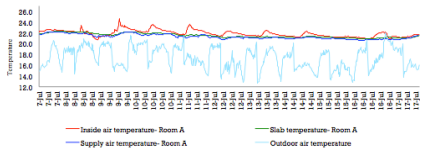

Graph 3.comparative temperature results room F and room I during 23th , 24th and 25th June

Graph (4) displays overall ambient temperature recorded over ten days during July. It is clear that inside temperatures are fairly steady and most of the time within the TCZ while the outside temperature is highly fluctuating. The maximum outside temperature is recorded at July 15th and it is 22°C while the lowest temperature is occurred at July 13th and it is around 12.5°C. Furthermore, the maximum and minimum temperatures have been measured in the rooms F and B, with the temperature of 27°C and 19.5°C, respectively.

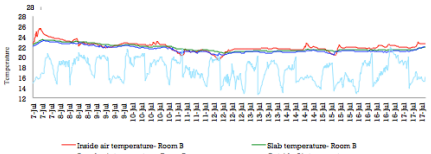



Graph 4. General result of the recorded ambient temperatures during the July 7th to 17th 2012 (Thomas Paine Building)

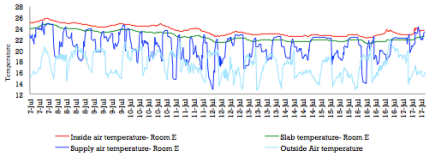
The results of the recorded temperature in three rooms in Thomas Pain building are presented in table (1). Outcomes indicate the outside temperature fluctuates widely whereas the indoor temperature is relatively steady. Comparing the graphs of the rooms A, B and E( Graph 5,6,7), it is clear that in the room A and B the slab temperature and the rooms temperatures are very similar and the peaks that have occurred during the week days can be a result of internal gains. Room E is providing the thermally comfortable environment for over 90 per cent of the time. While for room A and B the temperature within the TCZ is around 40 per cent. It can be concluded the higher the temperature more the rooms are thermally comfortable. The average slab temperature for room E is one degree higher than the room A. and slab temperature in room E is changing between a wider rangs than the others. The average supply temperatures for the rooms are very similar, but in the room E the supply air is



Graph 5 Recorded temperatures, room A



Graph 6 Recorded temperatures, room B



Graph 7 Recorded temperatures, room E

fluctuating between very wider ranges of the temperatures. Looking at room E, though the supply air temperature is varying too much during the period, the inside air temperature and the slab temperature remain very constant. This possibly has happened because the air flow rate was highly reduced. This means that when the air flow rate is minimal does not effect significantly the temperature of the space.

| July 7th 2012 to July 17th 2012 | Room A Ground floor | Room B First floor | Room E Second flooe |
|---|---|---|---|
| Ave. Ambient Outside Temp. °C | 17.5 | | |
| Ambient Outside Temp. Range °C | 12.5 to 22 | | |
| Time Ambient Outside Temp. within TCZ, as % | 0.0 | | |
| Ave. Internal Room Temp. °C | 22.5 | 22 | 23.5 |
| Internal Temperature Range °C | 20.5 to 24 | 19.5 to 25.5 | 22.5 to 26 |
| Time Internal Temp. within TCZ, as % Internal Temperature Range °C | 41.5 | 44 | 99.9 |
| Ave. Slab Temp. °C | 21.5 | 22 | 22.5 |
| Slab Temperature Range °C | 21 to 22.5 | 21 to 23.5 | 21 to 25 |
| Ave. Supply air Temp. °C | 21.5 | 21.5 | 21 |
| Supply air Temperature Range °C | 20.5 | 20 to 23 | 13to 25 |

Table 1. General results of the analyzing the recorded temperature in room A, B and room E.

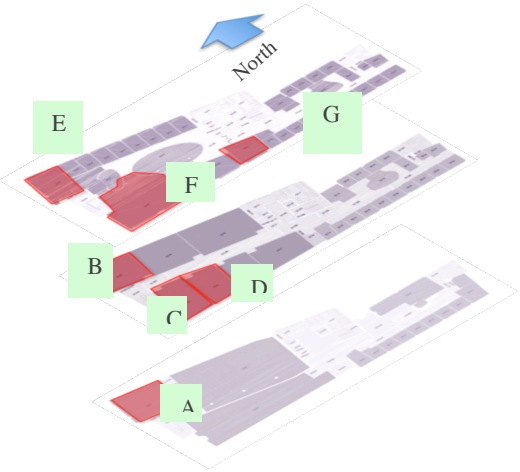



Figure 2. Key map of Thomas Paine building, showing the rooms that have been monitored.

## 6 Assessment of energy performance of the buildings

Since colleges and universities are comprised of a wide range and mix of space such as classroom, lab, library, catering and offices, it seems wise to use a modified benchmark in order to appropriately assess energy performance of the building. For this reason, the buildings are divided into different categories with the same function and occupancy characteristics. Furthermore, dividing the buildings into different space type by percentages of their total area provides greater insight into the energy usage of each sector and highlights the potential of saving in each space category. Figure below schematically shows the process of analysing the energy performance of the buildings using the modified benchmark.

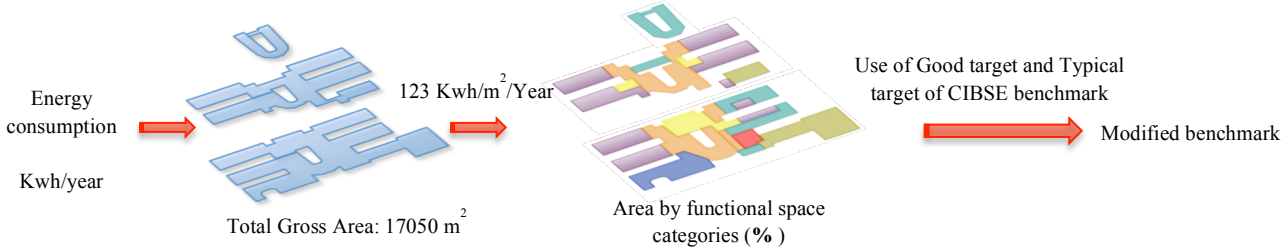



Figure 3. Schematic plan of the process of energy assessment.

Tables (2) and table (3) show the calculated values for each space categories along with the energy consumption from the CIBSE benchmark, Guide F. The highlighted values are the modified targets for the typical and good practice. Comparing the electricity consumption of the building (Kwh/m$^2$/y) with the modified benchmark, the trend for the typical target shows 33.5 per cent lower consumption for the Luton collage when the real consumption is calculated 123 Kwh/m$^2$/y. And this value is around 10.5 per cent less than the modified benchmark for the good target. The Thomas Paine building in terms of energy performance is 182 Kwh/m$^2$/y. This value is lower than the modified benchmark for typical practice (205 Kwh/m$^2$/y) and shows 11 per cent improvement in electricity consumption. However comparing to the modified good practice benchmark (147 Kwh/m$^2$/y) the real electricity

consumption of the building is 4 per cent higher. These values indicate that the buildings performs reasonably well in terms of energy consumption.

| Space Type | Areas covered % | Energy consumption (Good Practice) Kwh/m² | Energy consumption (Typical Practice) Kwh/m² |
|---|---|---|---|
| Teaching | 31 | 113 | 129 |
| Research | 17 | 155 | 175 |
| Lecture hall | 2 | 67 | 76 |
| Library | 8 | 292 | 404 |
| Office | 21 | 128 | 226 |
| Catering | 8 | 137 | 149 |
| Leisure | 13 | 127 | 194 |
| Total building | 100 | 140 | 188 |

Table 2-Modified benchmark for Luton Sixth Form College.

| Space Type | Areas covered % | Energy consumption (Good Practice) Kwh/m² | Energy consumption (Typical Practice) Kwh/m² |
|---|---|---|---|
| Teaching | 29 | 113 | 129 |
| Lecture hall | 15 | 67 | 76 |
| Office | 25 | 234 | 358 |
| Catering | 4 | 137 | 149 |
| Services | 27 | 128 | 226 |
| Total building | 100 | 147 | 205 |

Table 3-Modified benchmark for Thomas Paine building.

However, because of the limitations of this study it was not possible to accurately estimate the influence of the VHCS in this performance, however taking to account the utilization of the VHCS within the considerable portions of the whole buildings it can be concluded that the VHCS amongst another strategies implemented in these buildings play an important role in the total energy performance of the building.

## 7 **Conclusions**

Based on the findings from all the previous research and the results of the investigation throughout two buildings, the following results can be highlighted as the final conclusions.

- Utilizing the VHCS in the building could reduce the peak temperature during the day and the temperature fluctuation. The VHCS also has a great influence on the reduction of the total hours with the excessive temperatures and capability of the building to handle the diurnal heat loads from the internal gains and solar gains.
- The effectiveness of the VHCS is influenced by several parameters mainly including the amount of thermal mass and ventilation strategy. It is also important to take to account a great role of the climate, set-point temperature, occupancy pattern and ventilation airflow rates, where the results of the collage confirm the high potential of the VHCS to be set for the higher temperature thereby results in the higher thermal satisfaction of the occupants and lower energy demand.
- The results also confirm that the VHCS could contribute to decrease the cooling/heating demand in buildings therefore improve the overall energy performance of the building.
- Finally, it can be concluded that VHCS can meet the net energy frame for the further and higher educations building sector, significantly enhance the thermal performance and thus increase the level of thermal comfort without consuming intensive and expensive energy.

## 8 References

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