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To cite this article: Murat Özdenefe *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **609** 072058

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# Ventilated slabs: Energy consumption mitigation and thermal comfort augmentation

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**Abstract.** This study is an effort to investigate the energy and thermal comfort performance of a ventilated slab application for a particular building type-office building-that is located in Cyprus, which has typical Mediterranean climate with hot dry summers and mild rainy winters. In Cyprus, almost all of the buildings employ reinforced concrete (high thermal mass) for the building frame and slabs. Daytime maximum and night-time minimum temperature difference is substantial, particularly in inland regions of the island during summer time (up to 16 °C). This traditional building structure together with high diurnal temperature difference generates convenient conditions for the application of ventilated slabs. In this work model of an office building, which is incorporated with ventilated slab is simulated with Energy Plus for the Cyprus weather conditions. The results revealed that the ventilated slab system reduced the cooling energy significantly and augmented the thermal comfort. The variation in the ventilated slab hollows' length and diameter is not effective if the air flow rate is not increased. Thus, the authors suggest to increase the air flow rate through the slab for the best practice.

## 1. Introduction and methodology

The use of ventilated slabs (VS) can help to reduce daytime peak temperatures thus can aid to attenuate thermal loads via precooling the slabs-an integral part of the buildings- by exploiting cool night-time air during summer. This technology is effective for buildings with high thermal mass slabs where diurnal temperature differences are adequate. A rigorous design and operation of this system will offset the effects of internal gains hence will lower the energy consumption of the buildings. Besides, the system will have an impact on reducing the average surface temperatures of the building envelope resulting in reduced mean radiant temperature thus increased thermal comfort. There are extensive studies in the literature regarding the VS systems extending from simulations/numerical modelling [1–3] to experimental investigations [4–6]. Although well documented VS technology has not been studied under the conditions of Cyprus, which the authors think is ideal for its application. This is the prime motive of this study.

This work strives to reveal the contribution of VS system -a passive design strategy- to cooling energy attenuation as well as to thermal comfort improvement during cooling season. Besides the study intends to propose the possible best practice for its operation in Cyprus, which has typical Mediterranean Climate conditions, particularly in cooling season.

It is intended to generate a model of an office building, which is incorporated with VS. This model will be simulated for the Cyprus weather conditions and its energy performance and thermal comfort conditions will be revealed. The study will also attempt to investigate the effect of the hollow length and hollow diameter of the VS as well as air flow rate through the VS on energy performance of the building and on the thermal comfort levels.

Energy Plus, which is an energy simulation and thermal load calculation software [7] has modelling and simulation capability of VS systems, hence the authors opted to use it as the tool in this

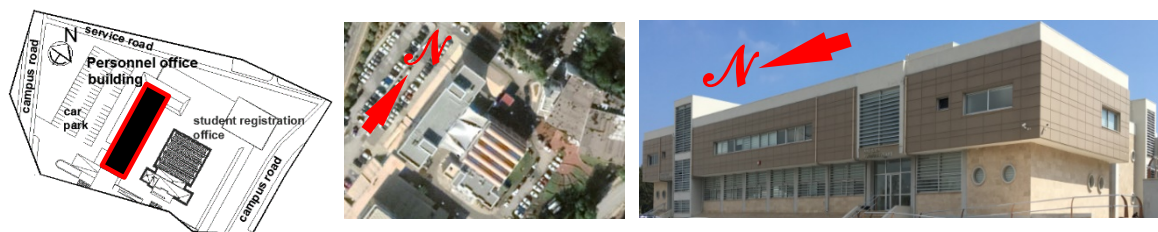


study. The office building in consideration is a real occupied building that employs mechanical air conditioning (ac) system for its heating and cooling demand. The building does not include any passive operation strategy for easing the burden on the mechanical ac system.

This work comprises four stages; i- comparison of the base case building (building with mechanical ac system) with the building having VS system to reveal the cooling energy reduction potential and effect on thermal comfort, ii- comparison of different hollow length VS systems, iii- comparison of different hollow diameter VS systems, iv- comparison of different air flow rate VS systems.

## 2. Building and system model

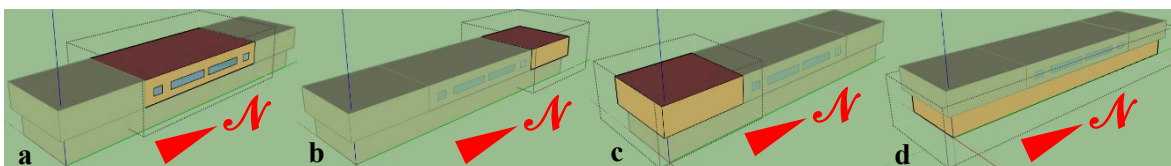
Office buildings possess considerable amount of internal loads and this makes them high potential candidates for VS applications. High thermal mass in addition to the existence of handsome amount of internal loads increases the prospective success of the VS applications. In this study, an office building located in Famagusta, Cyprus is the setting for the VS system. The building resides in the campus of Eastern Mediterranean University and serves as the main building for the university service personnel. It has two storeys with total floor area of 1802 m<sup>2</sup>. There are halls, open space offices and discrete offices in ground floor, whereas first floor involves toilets, archive rooms, halls and an open space office. Figure 1 shows the office building together with its site plan and Google Earth view.



**Figure 1.** Office building site plan, Google Earth view and photograph.

### 2.1. Building zoning and envelope

The authors opted to model the building in four zones; open space office zone, 1<sup>st</sup> floor north zone, 1<sup>st</sup> floor south zone and ground floor zone. Ground floor zone is a single zone and comprises from the spaces that exist in the ground floor, whereas 1<sup>st</sup> floor north and south zones involve the halls, toilets, and archive rooms in the first floor. The open space office zone on the other hand contains the open space office in the first floor. Among four zones only one, open space office zone (floor area= 378.9 m<sup>2</sup>, ceiling height=4 m) is considered for the VS system and investigated. Figure 2 illustrates the zones of the building model.



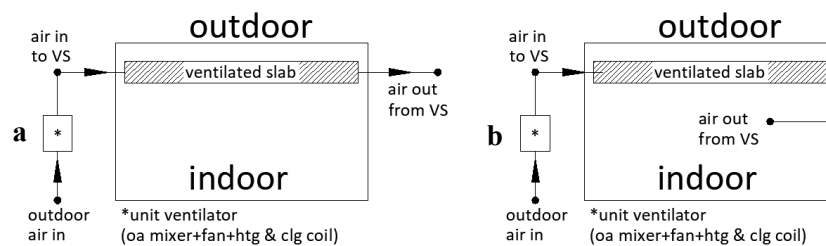
**Figure 2.** Building zones. a) Open space office zone (zone considered for VS application), b) 1<sup>st</sup> floor north zone, c) 1<sup>st</sup> floor south zone, d) ground floor zone.

Heavyweight materials such as concrete and brick are the main fabric for the buildings of Cyprus. In this study, the model building involves principally these traditional construction materials i.e. concrete and brick. The external walls are perforated clay bricks with internal and external cement plaster rendering together with travertine cladding on the outer surface. The internal walls have the same configuration except the travertine cladding. The roof is reinforced concrete with an insulation layer on

the outer surface and cement plaster on the inner surface. The floor is also reinforced concrete with marble as inner surface finish. The windows are double-glazed with air layer between the glasses. U values of the constructions are; external walls  $\rightarrow$  1.2 W/m<sup>2</sup>K, internal walls  $\rightarrow$  1.1 W/m<sup>2</sup>K, roof  $\rightarrow$  0.6 W/m<sup>2</sup>K, floor  $\rightarrow$  2.1 W/m<sup>2</sup>K, windows  $\rightarrow$  2.7 W/m<sup>2</sup>K. The properties of the construction materials for U factor evaluation are sourced from CIBSE guides [8] and ASHRAE guides [9].

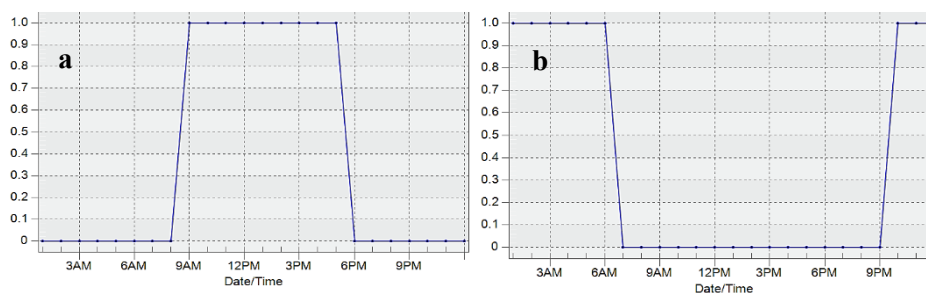
## 2.2. System model and parameters

The authors employed Energy Plus building energy simulation and load analysis program for the energy and comfort simulations. Energy Plus is a rigorous tool and can simulate VS systems with various operation strategies. Chaea, Y. T. and Strand, R. K had already validated the VS simulation module of the Energy Plus for different modes of operation [3]. VS system can run the cool night air through the slab (air cools the slab) and then delivers this air to the outdoors or the air is delivered to the indoor space (zone). The first mode is slab only mode and the second one is slab and zone mode [10]. In both cases, air runs through the slab via a unit ventilator system, which includes an outdoor air mixer and a fan. The unit ventilator system can also involve a heating and/or cooling coil in case the user requires heating up or cooling down the outdoor air more if its temperature is not at desired level. Since this study considers the VS system as a passive strategy to exploit cool night air only and does not aim to lower or boost the slab temperatures by an external means the unit ventilator model involves no cooling or heating coil. In addition the system running mode is slab only; air runs through the slab and leaves to the outdoor air (do not enters to the zone). Figure 3 illustrates two different operation modes of VS system.



**Figure 3.** VS operation strategies. a) Slab only mode, b) slab and zone mode.

Typically VS systems are employed as passive measure to cool down (or heat up) the thermally heavy structures, thus they are not designed to cover the whole demand of the buildings. They usually intend to reduce the daytime peak loads and energy consumption of the buildings. This necessitates the coupling of VS with a mechanical system to cover the rest of the load. Therefore, the model building has a mechanical ac system that runs during the occupied hours (08:00 to 17:00 for weekdays) to cover the load and attain desired comfort conditions. During the unoccupied hours however, the mechanical ac system is off whereas, the VS system is on from 21:00 to 06:00. The thermostat setting for the ac system is 25 °C. Thus, if the zone mean air temperature exceeds this value during occupancy period, system supplies cooling. Figure 4 shows the occupied hours, ac system availability schedule and VS system availability.



**Figure 4.** Schedules for the open space office zone. a) Occupancy and mech. ac system availability schedule b) VS availability schedule. (1  $\rightarrow$  occupied/available, 0  $\rightarrow$  not occupied/not available)

Since the building is an office building, there is substantial amount of internal gains. These are taken from CIBSE guide [8] as 10 W/m<sup>2</sup> and 18 W/m<sup>2</sup> for the lighting and electric equipment respectively. The area allocated per person for evaluating the occupancy density is also sourced from CIBSE guide [8] for a generic office building as 10 m<sup>2</sup>/person. The people in the office do work at seated most of the time thus the internal gain from the people is 105 W/person. Since the period is in cooling season it is assumed that the people's garments insulation value is 0.5 clo at all times during occupancy period. The ventilation rate during the occupied hours is 1 ach which corresponds to about 10 l/s per person (evaluated from: zone floor area= 378.9 m<sup>2</sup>, zone volume=1515.7 m<sup>3</sup> and occupancy= 10 m<sup>2</sup>/person). This value i.e. 10 l/s per person is the suggested ventilation rate for open space offices in CIBSE [8].

### 3. Simulations

This study considers the cooling season only thus the simulations were performed for the period of May 1-August 31, which covers the most severe portion of the cooling season for Cyprus. The rest of the year is not considered for the simulations. The office building is located in Famagusta, however; the simulation weather data file is not available for it. Therefore, an available weather data file for another location in Cyprus, which is Larnaca is used (lies 35 km SW of Famagusta as the crow flies).

This work is an endeavour to observe the effect of VS system on the building energy consumption and occupant thermal comfort as well as to find the possible best practice of VS application by observing the effect in the variation in hollow length and diameter as well as air flow rate. Table 1 presents the system configurations and parameters that varied to reveal the aforementioned phenomena. Simulations for the cases given in Table 1 (Base case (BC), VS1, VS2, VS3, VS4) are performed with Energy Plus and results are given in the succeeding section.

**Table 1.** System configurations and parameters that are varied.

	<i>BC</i>	<i>VS1</i>	<i>VS2</i>	<i>VS3</i>	<i>VS4</i>
System	*Only ac	*VS+ ac	*VS+ ac	*VS+ ac	*VS+ ac
Hollow length (m)	-	13.85	27.36	13.85	13.85
Hollow diameter (m)	-	0.05	0.05	0.1	0.05
Distance between hollows (m)	-	0.015	0.015	0.1	0.015
Number of hollows	-	136	69	136	136
Hollow run direction	-	E-W	N-S	E-W	E-W
Flow rate through slab (m <sup>3</sup> /s)	-	2.4	2.4	2.4	4.8

\*Only ac → ac runs during daytime occupied hours and nothing runs during night-time, \*VS+ ac → ac runs during daytime occupied hours and VS runs during night-time.

### 4. Results and discussion

The simulations are set to yield these principal parameters: cooling energy required to keep the indoor environment at 25 °C during occupied hours, predicted mean vote (PMV) of the people, predicted percentage of dissatisfied (PPD) and the zone mean radiant temperature (MRT). PMV is an index for estimation of occupant thermal sensation, which can have a value between -3 and +3; -3 for cold and +3 for hot feeling, whereas PPD is an indicator for predicting the percentage of people dissatisfied with the thermal environment. MRT on the other hand is a temperature value that is associated with spatial average of the temperatures of surfaces in the space and is affiliated with radiant heat exchange between the surfaces and occupants [11]. Table 2 presents the results for the period in consideration (June 1-August 31). Note that the PMV, PPD and MRT values are the time averaged values for the occupied hours during the period. Certainly exposing the effect of various VS applications such as different hollow length/diameter and slab flow rate requires presenting the results comparatively.

Table 3 presents the results in this manner; i-comparison of BC with VS1 in order to reveal the effect of VS system over a conventional system, ii- comparison of VS1 with VS2 in order to expose the effect of the length change in the hollows, iii- comparison of VS1 with VS3 for unveiling the outcome of diameter variation of hollows and iv-comparison of VS1 with VS4 for observing the effect of flow rate change through the slab. Undeniably, additional investigation of BC vs VS1 for a typical day would unveil any

implicit details about the ventilated slab performance. Typical day (July 19) results are shown in Figure 5.

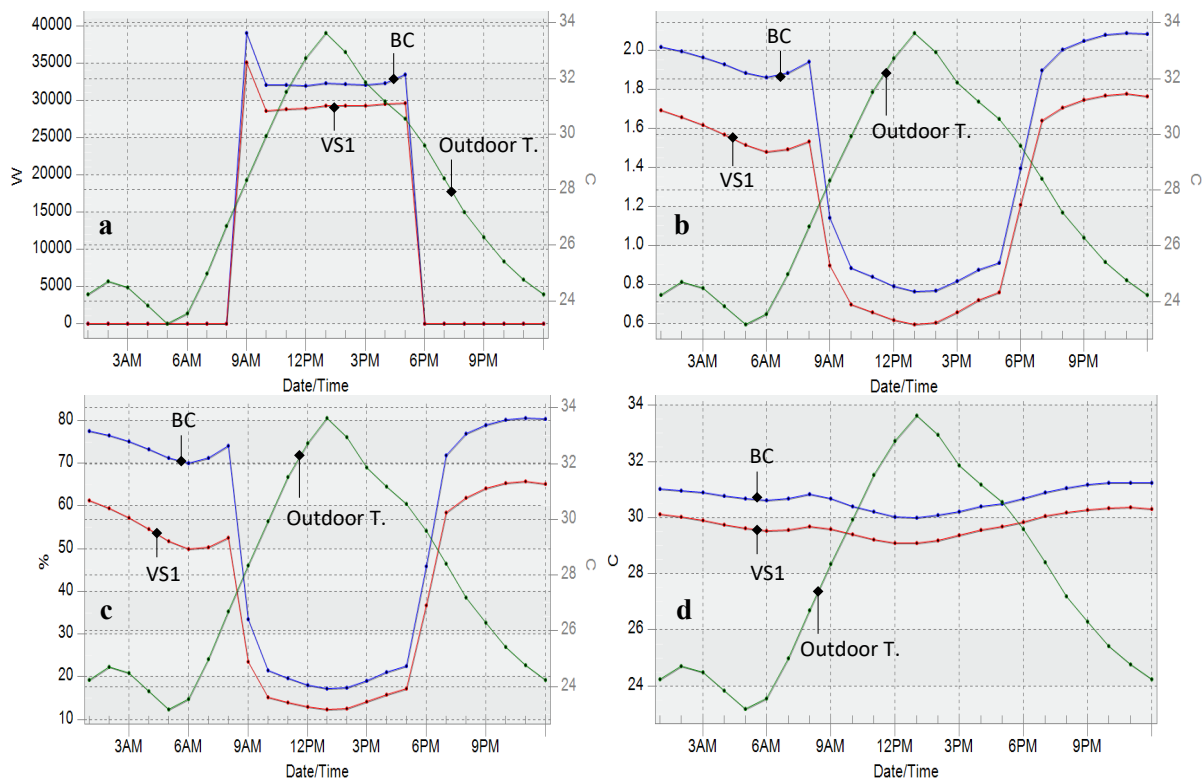
**Table 2.** Results of the simulations.

	<i>BC</i>	<i>VS1</i>	<i>VS2</i>	<i>VS3</i>	<i>VS4</i>
System	Only ac	VS+ ac	VS+ ac	VS+ ac	VS+ ac
Cooling energy (kWh)	19339.2	16857.7	16838.2	16966.3	15903.1
PMV	0.8	0.6	0.6	0.6	0.5
PPD (%)	21.2	14.6	14.6	14.9	12.5
MRT (°C)	30.3	29.1	29.1	29.1	28.6

**Table 3.** Comparisons to reveal the effect of various applications.

<i>Parameter</i>	<i>Differences*</i>			
	<i>BC-VS1</i>	<i>VS1-VS2</i>	<i>VS1-VS3</i>	<i>VS1-VS4</i>
System cooling energy	14.7 %	0.1 %	-0.6 %	6 %
PMV	0.2	0.0	0.0	0.1
PPD	6.6	0	-0.3	2.1
MRT	1.2 °C	0 °C	0 °C	0.5 °C

\*System cooling energy differences are in % whereas the others are absolute.



**Figure 5.** Typical day results. a) Cooling rate, b) PMV, c) PPD, d) MRT.

It is apparent in the results, particularly those given in Table 3 that the VS system is very effective in reducing the cooling energy requirements. The cooling energy requirement for the open space office zone for BC is 14.7 % more than the one for VS1. Besides PMV, PPD and MRT are less in VS1 case leading the occupants to feel less hot. This demonstrates that VS system paves the way for a more comfortable indoor environment. It is also obvious that the energy and comfort index outcomes of VS1,

VS2 and VS3 are almost equifinal. This shows that if the hollow length and diameter is doubled (L changed from 13.85 m to 27.36 m and D changed from 0.05 m to 0.1 m) the effect is trivial. On the other hand, if the flow rate through the slab is doubled (VS1-VS4 case) the VS system becomes more effective. In order to obtain more solid conclusions regarding the effect of changes in hollow length and diameter as well as in flow rate, variations in those parameters should be done more than once. Indeed a parametric analysis will be very useful in order to draw concrete conclusions.

Scrupulous investigation of Figure 5 reveals that VS system reduces the daily peak load (a) and keeps the indoor environment more comfortable (b and c). The VS also maintains lower MRT (d) in the open space office zone through the day, which is the main reason for the occupants to feel less hot.

## 5. Conclusion

The authors herein strived to investigate the impact of VS system (applied to an office building) on the cooling energy reduction and thermal comfort augmentation. It is also aimed to reveal the possible best practice of VS system by observing the outcomes for different length and diameter hollows and different air mass flow rates. The results demonstrated that VS system is a functional passive measure for attenuating the cooling energy requirements and increasing thermal comfort. It is found that space without VS system requires 14.7 % more cooling energy. In addition, VS system leads to attain a more comfortable space with lower PMV, PPD and MRT values. It is also unveiled that doubling the hollow length and diameter without changing the flow rate is trivial in terms of reducing cooling energy and increasing comfort. If however, the flow rate is doubled the effect of VS system further increases. Thus, the authors propose that the flow rate through the slab should be doubled for the best practice for the building considered herein. The open space office zone has the VS system only on its roof. Certainly if the space involves the VS on the floor in addition to the roof, the cooling energy will further reduce and the comfort will further increase. For best practice, air flow rate through the slab should be doubled, however the fan energy consumption for the increased air flow rate should be further investigated.

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