Al-Khwarizmi Engineering Journal, Vol. 10, No. 3, P.P. 13- 24 (2014)

Al-Khwarizmi Engineering Journal

Using TermoDeck System for Pre-Cooling/ Heating to Control the Building Inside Conditions

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(Received 24 March 2014; accepted 13 July 2014)

Abstract

In this paper, experimental study has been done for temperature distribution in space conditioned with Ventilation Hollow Core Slab (TermoDeck) system. The experiments were carried out on a model room with dimensions of (1m ×1.2m ×1m) that was built according to a suitable scale factor of (1/4). The temperature distributions was measured by 59 thermocouples fixed in several locations in the test room. Two cases were considered in this work, the first one during unoccupied period at night time (without external load) and the other at day period with external load of 800W/m^2 according to solar heat gain calculations during summer season in Iraq. All results confirm the use of TermoDeck system for ventilation and cooling/heating purposes in arid and hot climate for its ease, simple and good comfort performance and to save energy and improve the overall energy performance of the building by reducing the peak load.

Keywords: *TermoDeck, Thermal storage, Ventilated hollow core slab (VHCS), Night Ventilation, Pre-cast concrete.*

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. 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) so in many literatures, the active hollow core slab system has different terminologies such as " TermoDeck system ", "advanced fabric thermal storage", and " thermally activated building system " (TABS) [1]. TermoDeck is a fan-assisted, heating, cooling and ventilation system that uses the high thermal mass of structural, hollow core slabs through which warmed or cooled fresh air is distributed as shown in Figure (1). 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 ceiling slabs; therefore the airflow will increase the convective heat transfer. Energy savings from this system have been reported to be between 13% and 70%, depending on the building type and the prevailing weather conditions [1,2].

By forming perpendicular coupling airways between the hollow cores, it is possible to form a 3 or 5 pass circuit through which supply air may pass. The TermoDeck system achieves good heat transfer between the incoming air and the concrete slab by ensuring turbulent airflow through the hollow cores. This is achieved by using a core air velocity of approximately 1m/s, which enables heat to be stored at a rate of between 10 and 40 W/m² of floor area ceiling , depending on the air temperatures involved [3].

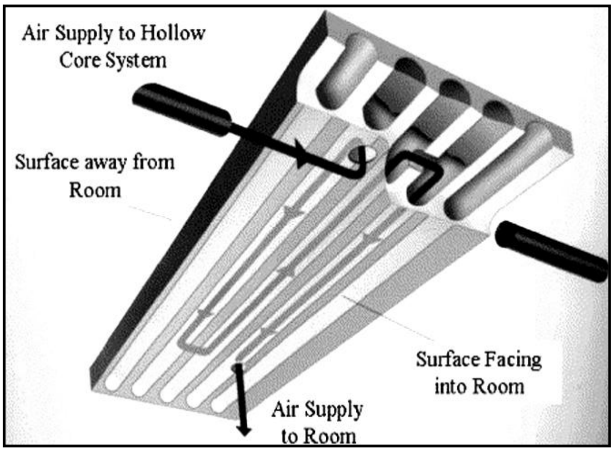


Fig.1. The TermoDeck system.

Various studies have shown the benefits of using ventilated slab systems. Shaw, et al. [4] reported that the active use of the thermal properties of the mass within the ventilated slab not only saved energy through reducing fan and coil power in peak time, but also had a thermal comfort advantage because the increased radiant heat transfer between the occupant and the space allows the occupants to feel cooler at the same air temperature.

Barnaby, et al [5] simulated the thermal behavior of a hollow core slab system and concluded the system could provide an energy reduction between 13% and 30% for the peak cooling load. Other studies have developed numerical models to simulate the thermal properties and estimate the system performance of hollow core slab systems under particular conditions.

Standeven et al. [6] presented a study on one of the existing buildings using TermoDeck, Elizabeth Fry Building at the University of East Anglia in UK. The monitored data showed that:

- Heating and cooling energy consumption is half that of a conventional building of the same type.
- Use of TermoDeck provides good levels of thermal comfort. Occupant satisfaction and productivity is high.
- Capital and maintenance costs are low.

Karlström [7], treated the modeling and testing of hollow core concrete elements for heat storage and heat distribution via the building construction thermally activated building system, TABS, using ventilated hollow core concrete element, this system is analyzed as well as optimized for effective use of low valued energy sources. This lead to a renewed environmentally friendly industrial building concept that provides good comfort to a low cost. Also confirm the biggest advantage of the system is the capability to store and distribute heat in the hollow core concrete elements which has a positive effect on energy use

Ren and Wright [8] introduced a transient simulation model for a three core ventilated slab using a lumped parameter thermal network model. When the heat transfer coefficient of the corner of the air path was assumed to be 50 times higher than the heat transfer coefficient in the straight sections of the core, the developed model showed acceptable accuracy when compared to measured data for a simple test room located in a large laboratory building.

Russell and Surendran [9] investigated the system performance through a two-dimensional (2D) finite difference model. In this study, when air at 16.9°C was assumed to be continuously circulated through three cores for 14 hours, the cooling potential of the system increased by 335 percent in comparison to a traditional slab configuration with night ventilation.

Barton, et al. [10] developed a numerical tool using a two-dimensional finite difference model to investigate the thermal performance of a ventilated slab system. The theoretical results for both steady state and transient conditions showed that the corner sections of the cavity loop had little impact on the overall slab performance, while the bending or corner sections are regarded as important factor to the system performance by other studies [8]. They also theoretically evaluated the damping effect between a five core and a three core slab system.

Corgnati and Kindinis [11] proposed a numerical model of the slab system based on a finite difference model. The slab is similar to a heat exchanger in this model. The authors implemented their model within a simulation tool to investigate the performance of the free cooling potential and indoor thermal conditions in an office. Comparing a traditional ventilation system with the night ventilation operation, the hollow core ventilation system offered a more acceptable indoor temperature during the cooling period under various internal heat gains for a Mediterranean climate.

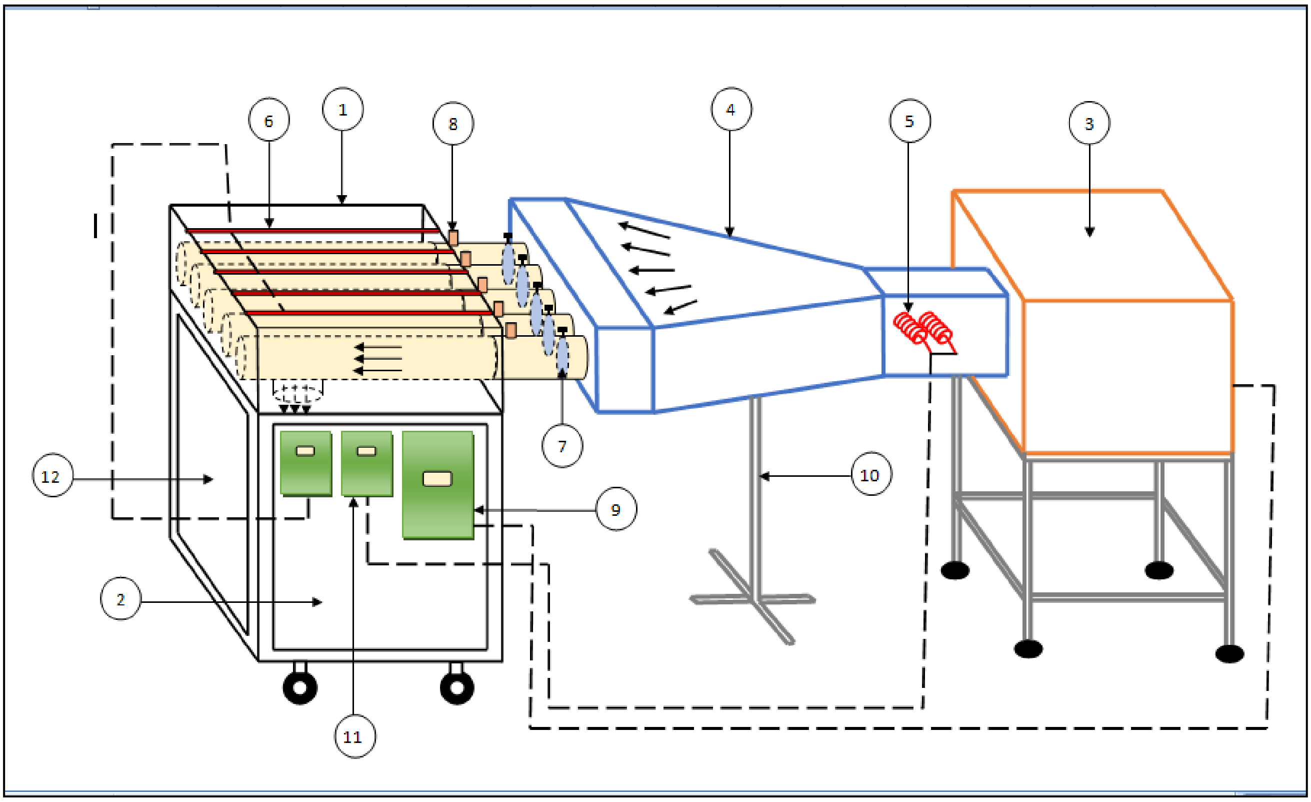
Recent research on ventilated slab systems using a hollow core slab indicates that energy savings can be achieved when the ventilated slab system is used as a thermal storage element to cool the building, and various numerical models have been developed to characterize the performance of the system. However, most experimental and theoretical model results are based on measured or simulated energy consumption for a particular space, day and climate condition. This does not allow any general conclusions to be made that would extend these results to different buildings, locations, and climate conditions. The most recent study about this system is published by Xinhua et al. [12] , where present a comprehensive review of the research and application of active hollow core slabs in building systems for utilizing low energy sources. They point out that the active hollow core slabs are widely used mostly in Europe for reducing energy consumption and improving indoor environment, their detailed performance investigations and evaluations are still rough and limited. In addition, it seems that there is no report on the researches and applications of these active slabs in Asia. More works on the active slabs are still needed for promoting these slabs to be used in low energy architectures wherever the climate is appropriate, and therefore the present study was carried out to fulfil their requirements.

2. Experimental Work

The TermoDeck system employed in this experimental equipment consist of a rectangular room with an air conditioner works as a conditioned unit, the schematic diagram for the whole apparatus shown in Figure (2). The test rig is used to study the effect of two operating parameters, the first one is "the core air velocity" and the second is "the inlet air temperature to the slab" to Determine the possibility of using TermoDeck system in arid climate especially in Iraq.

2.1. Design of TermoDeck System

The hollow core concrete slabs can be manufactured in a range of geometries [10,13]. Figure (3) shows the geometry used in this study; (1000 mm length, 1200 mm width, 240 mm Height of the slab and the core diameter was 160 mm). Figure (4) shows the steps of manufacturing of TermoDeck system The holes are closed at the end by fiber wood material, so the air enter to the test room through elbow apart with the same diameter. Five convector heaters are placed in the upper face of the slab inside a grove with approximately 1000 mm length to emulate the solar heat gains during normal daily operation of the ventilated slab system. During these tests, the room heat gains were imitated by the convector heaters of approximately 800 W/m² output as the maximum solar heat gains during summer season at 21th July. All of the heaters are connected to current controller to provide the system with the required energy. The whole system are covered with two layers of glass wool insulation 20 mm thickness for each layer and (0.04 W/m.°C) thermal conductivity to prevent heat gain losses.



1	Termodeck system	4	Supply duct	7	Air damper	10	Stand
2	Test room	5	Duct Heaters	8	Hotwire position	11	Current control
3	Air conditioner	6	Termodeck Heaters	9	Control board	12	Room wall (polystyrene)

Fig. 2. Schematic diagram of the test rig.

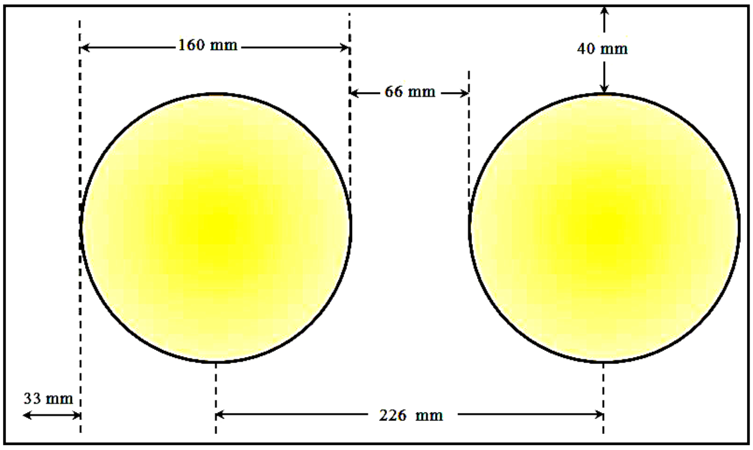


Fig. 3. TermoDeck cross-section core geometry.

Fig. 4. Steps of manufacturing the TermoDeck system

2.2. Experimental Apparatus Parts

The experimental room can be described as an isolated space with well insulated walls and floor by polystyrene with (100 mm) thickness in order to study the performance of the TermoDeck system. It represent an office test room with dimensions (L=4 m, W=4.8 m and H=3.75 m).

A Suitable scale factor was assumed to find the model dimensions: (l_m / l_p = 1/4). The model room dimensions accordingly are (L_m = 1200 mm, W_m = 1000 mm and H_m = 1000 mm) where the subscripts m and p refer to model and prototype, respectively. In this study the velocities are 1m/sec and 1.6m/sec for all test cases. Fifty nine thermocouples type K were used for the temperature measurements. These sensors are fixed as follows:

1. Fifteen thermocouples were fixed on the inlet, middle and outlet of hollow core slab channel to read air hollow core temperatures along the hole .
2. Fifteen thermocouples were fixed on the floor's ceiling of the slab under the hole to read inlet, middle and outlet air surface slab temperatures.
3. Twenty seven thermocouples were fixed inside the test room in three levels in order to read the air-conditioned space temperatures for room model.
4. One thermocouples are fixed at middle side slab in order to read side slab temperature.
5. The last thermocouple is for measuring the ambient air temperature.

2.3. Method of Testing

Two cases were taken in this work; the first case was with no external load (during the night period). The inlet air temperature, inlet velocity and internal load were varied in this case. The second case was done with 800 W/m² external load (during the day period) at a similar conditions for the first case. The measurement of the temperatures was taken every twenty minutes for the inlet air temperature through the slab. The slab surface temperature, the conditioned space temperatures and the slab side temperature were measured to study the performance of the TermoDeck system via the absorbed heat. According to the measurements, the performance for every case reaching the steady state in 90 to 150 minutes as a maximum. The measurements were taken for October 2013. The test room is located in a large laboratory (workshop) in university of Karbala therefore the test room's external environment is that of the test hall. The experimental cases are shown in Table (1).

Table 1,
Experimental test cases.

No. of Exp.	Inlet Core Velocity m/s	Inlet Core Temp. ºC	Ambient Temp. ºC	Internal Load W/m²	External Load W/m²
1	1	16	23.3	0	0
2	1.6	16	23.9	0	0
3	1	16	24.3	630	0
4	1.6	16	24.5	630	0
5	1	18	23.9	630	0
6	1.6	18	24.0	630	0
7	1	16	22.2	630	800
8	1.6	16	22.3	630	800
9	1	18	22.5	630	800
10	1.6	18	22.6	630	800

3. Results and Discussion

General, the parameters that affect the thermal performance of the hollow core slabs are classified into four categories. Two of these (Diameter and Thermal Mass) are determined in the design stage of the slab and the other two (Inlet air velocity and Inlet air temperature) are determined in the operation stage.

For the experiments carried out in this work, the temperature distributions were plotted for different parameters. The temperatures variation with time were drown using Microsoft Excel program and they show the effect of variations of the inlet air velocity and inlet air temperature to the slab with time.

Figures (5) to (15) represent unoccupied period at night time (without external load).

Two inlet air velocities were considered, i.e. (1 and 1.6 m/sec). Figures (5) and (6) study the effect of inlet air velocity on the performance of this system. The flow in both cases is turbulent and a better air circulation is achieved with that air penetration in the room which leads to improve comfort. The results showed good heat removal achieved when the air inlet velocity is equal to (1m/s) with different external load, internal load and the supply core temperature.

The TermoDeck system achieves good heat transfer between the incoming air and the concrete slab by ensuring good thermal coupling must exist between the air and the hollow cores of the building. This is achieved by using a core air velocity of approximately 1 m/s. So, the indoor thermal environment can meet the requirements at that ventilation rate.

Figures (7) to (14) represent the effect of inlet air temperature on the performance of this system. The results referred the reduction in the room temperature by about (5.4°C to 6.5°C) when the inlet air temperature is 16°C and about (2.5°C to 2.8°C) at the inlet air temperature of 18°C according to the change in the core air velocity and internal load. The slab surface temperature reduced by about (4.3°C to 5.6°C) when the inlet air temperature is 16°C and about 2.7°C at the inlet air temperature of 18°C. However, the slab side temperature reduced by about (3°C to 5°C). The steady state condition occurs during about 80 minutes for the cases without external load.

Figure (15) shows the variation of slab side temperature with time at different cases with internal load equal to 630 W/m^2 at various inlet parameters. All previous results confirm the effectiveness of the night ventilation strategy to remove heat from this system and obtaining high temperature drop at lower outdoor temperature.

Figures (16) to (23) represent the occupied period at the day time (with external load of 800 W/m^2). At inlet air velocity equal to 1m/sec the room temperature reduced from (38°C to 20°C) at inlet air temperature equal to 16°C and from (38°C to 23.5°C) at inlet air temperature of 18°C. However the room temperature reduced from (37.5°C to 22°C) at inlet air temperature equal to 16°C and from (37.5°C to 24.5°C) at the inlet temperature of 18°C for air velocity of 1.6 m/sec.

Similarity, with inlet air velocity equal to 1m/sec, the slab surface temperature reduced from (41°C to 21°C) at inlet air temperature equal to 16°C and from (41°C to 24.5°C) at inlet air temperature equal to 18°C. The slab surface temperature reduced from (41°C to 23.5°C) at inlet air temperature equal to 16°C and from (41°C to 26.5°C) at inlet air temperature equal to 18°C with inlet air velocity of 1.6 m/sec. Finally the slab side temperature reduced about (11°C to 16°C) at various cases and the steady state condition occurs after approximately 140 minutes from starting point.

Figure (24), shows the variation of slab side temperature with time at various inlet conditions when external and internal load are equal to 800 and 630 W/m^2 respectively.

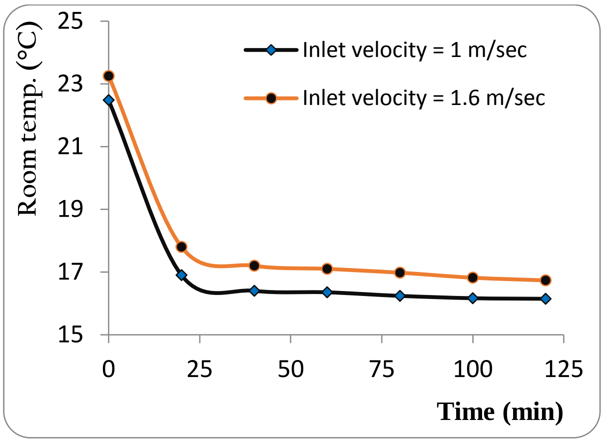


Fig. 5. Variation of room temperature with time at Tai = 16°C without loads.

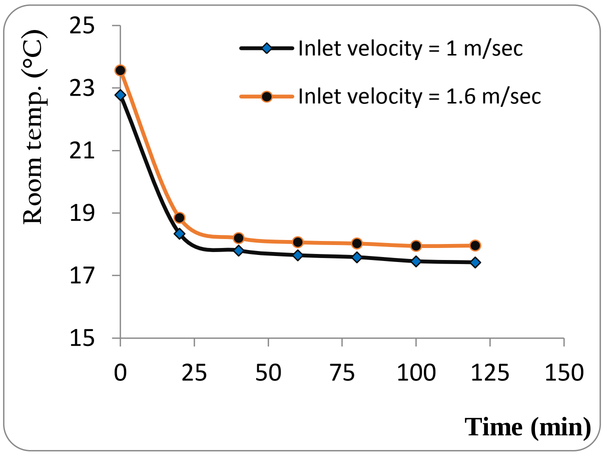


Fig. 6. Variation of room temperature with time at T_{ai} = 16°C without external load and the internal load = 630 W/m^2.

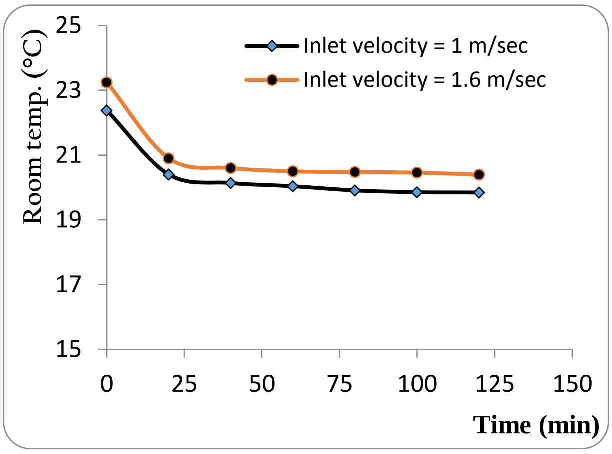


Fig. 7. Variation of room temperature with time at T_{ai} = 18°C without external load and the internal load = 630 W/m^2.

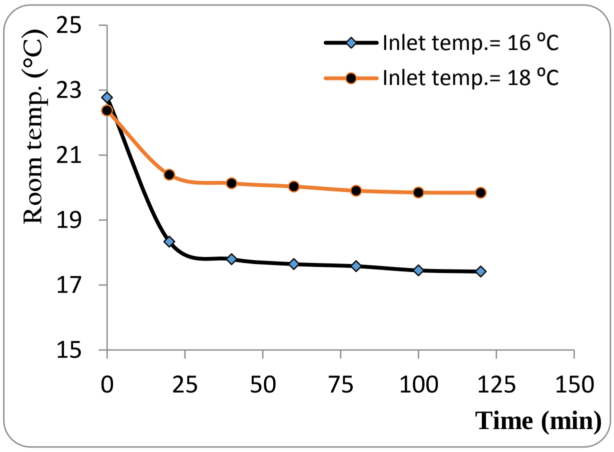


Fig. 8. Variation of room temperature with time at u_{ai} = 1m/sec without external load and the internal load = 630 W/m^2.

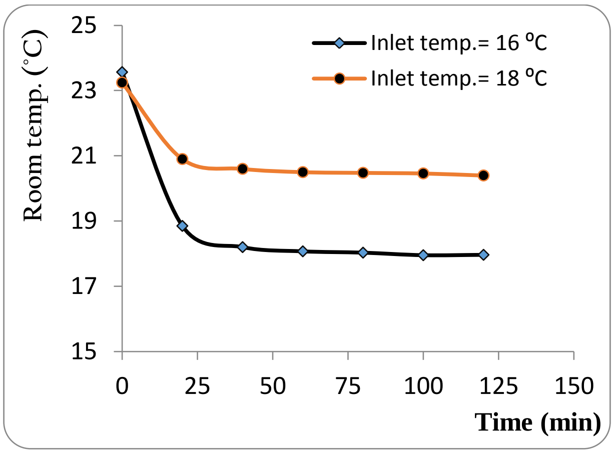


Fig. 9. Variation of room temperature with time at u_{ai} = 1.6m/sec without external load and the internal load = 630 W/m^2.

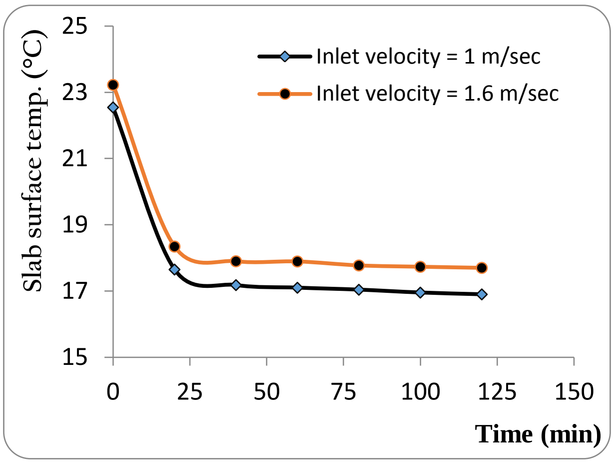


Fig. 10. Variation of slab surface temperature with time at Tai = 16°C without loads.

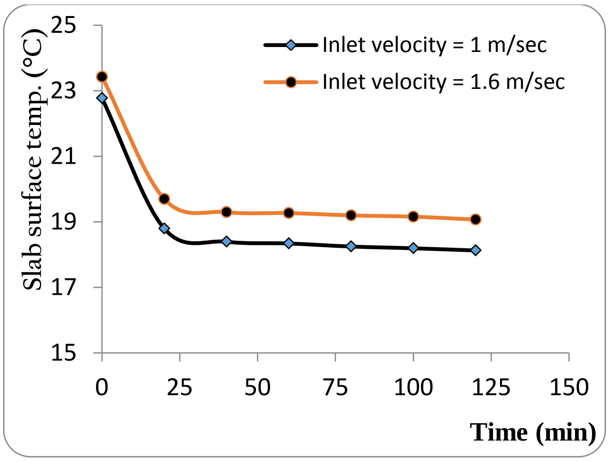


Fig. 11. Variation of slab surface temperature with time at Tai = 16°C without external load and the internal load equal to 630 W/m^2.

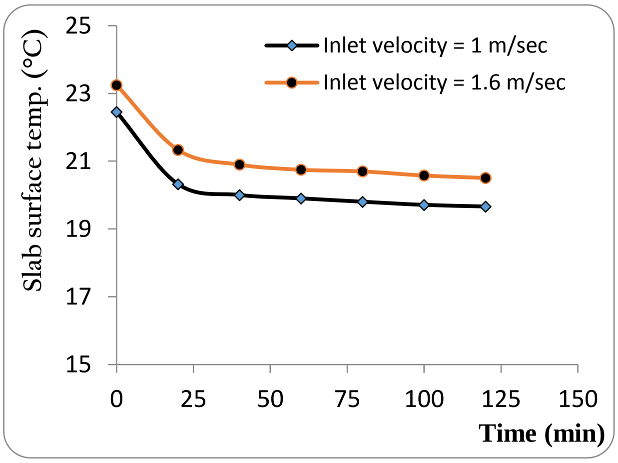


Fig. 12. Variation of slab surface temperature with time at Tai = 18°C without external load and the internal load = 630 W/m^2.

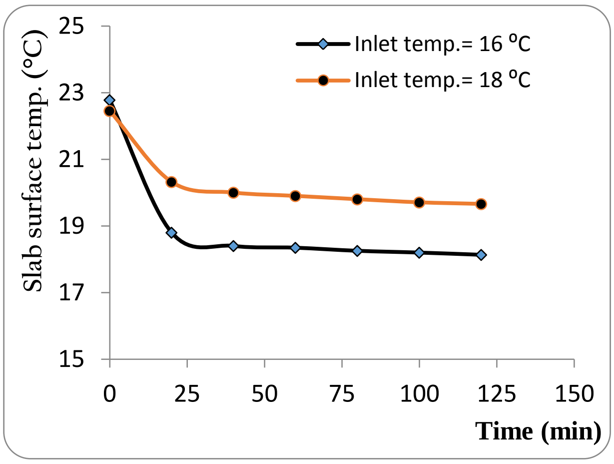


Fig. 13. Variation of slab surface temperature with time at uai = 1m/sec without external load and the internal load = 630 W/m^2.

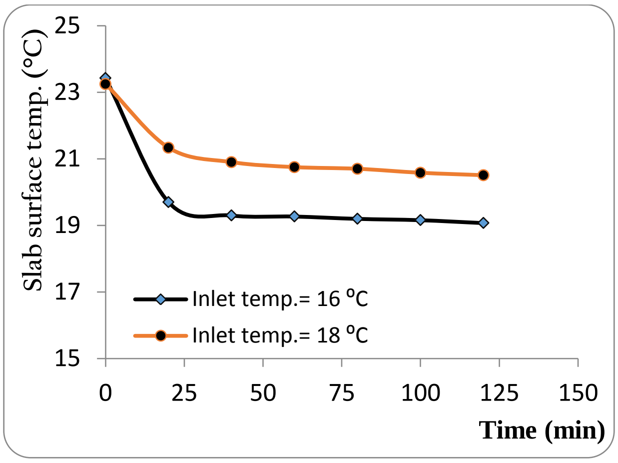


Fig. 14. Variation of slab surface temperature with time at uai = 1.6m/sec without external load and the internal load = 630 W/m^2.

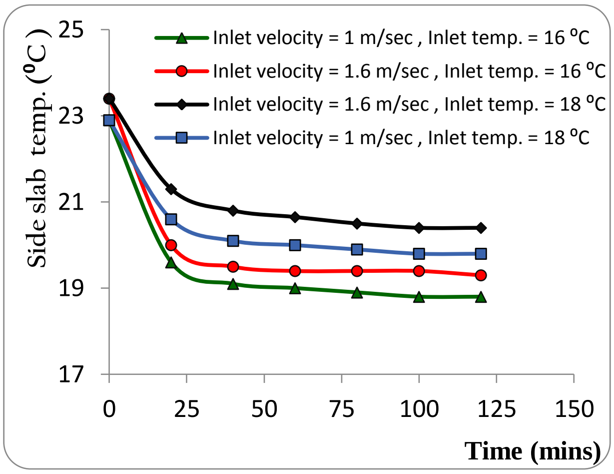


Fig. 15. Variation of slab side temperature with time without external load and the internal load equal to 630 W/m^2.

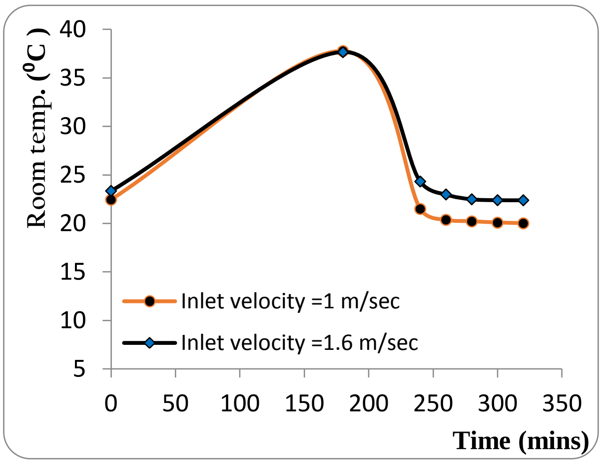


Fig. 16. Variation of room temperature with time at Tai = 16°C with external load= 800W/m2 and the internal load = 630 W/m^2.

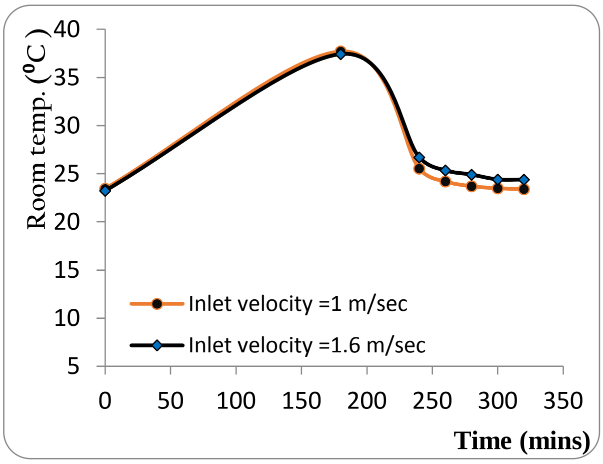


Fig. 17. Variation of room temperature with time at Tai = 18°C with external load= 800W/m^2 and the internal load = 630 W/m^2.

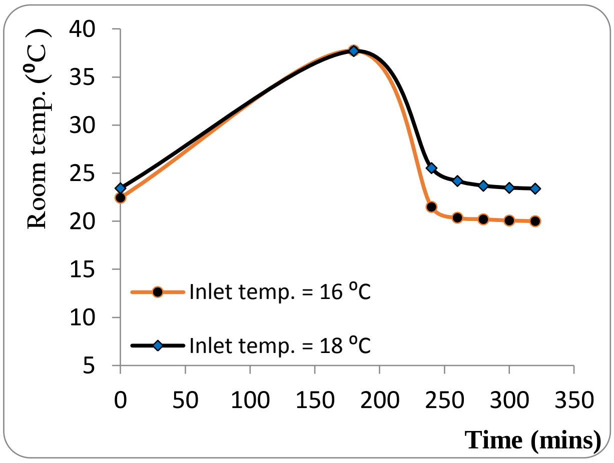


Fig. 18. Variation of room temperature with time at uai = 1m/sec with external load= 800W/m^2 and the internal load = 630 W/m^2.

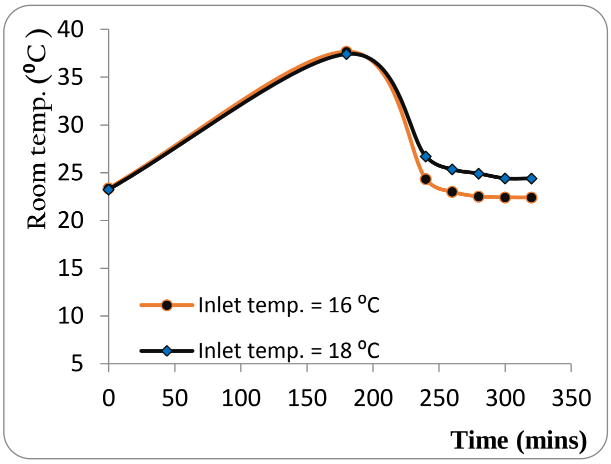


Fig. 19. Variation of room temperature with time at uai = 1.6m/sec with external load= 800W/m2 and the internal load = 630 W/m^2.

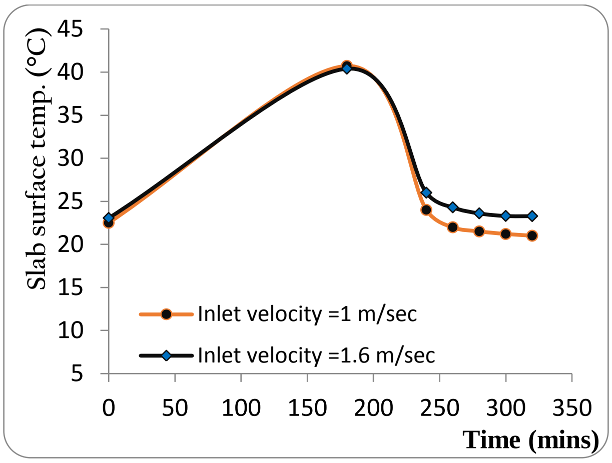


Fig. 20. Variation of slab surface temperature with time at Tai = 16°C with external load= 800W/m^2 and the internal load = 630 W/m^2.

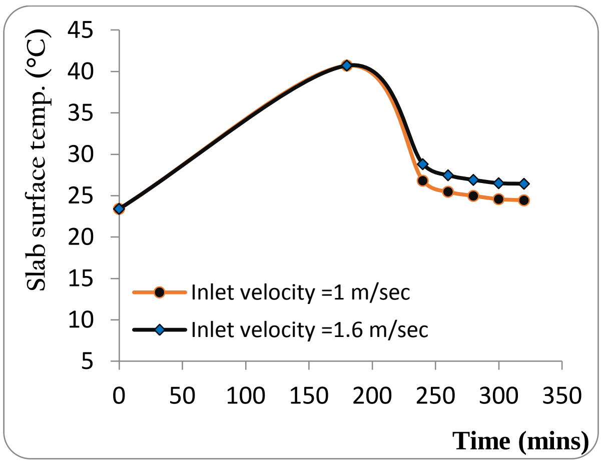


Fig. 21. Variation of slab surface temperature with time at Tai = 18°C with external load= 800W/m^2 and the internal load = 630 W/m^2.

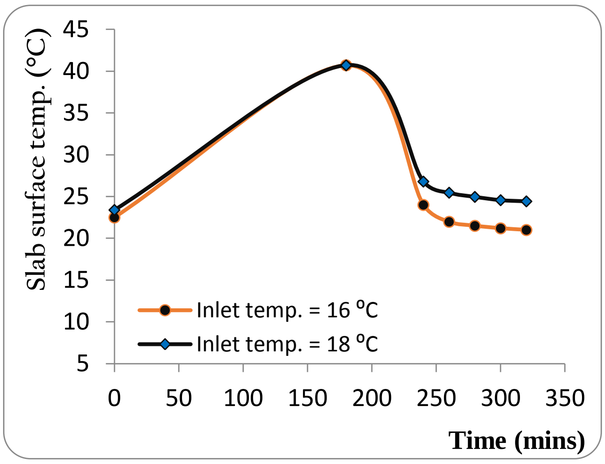


Fig. 22. Variation of slab surface temperature with time at uai = 1m/sec with external load = 800W/m^2 and the internal load = 630 W/m^2.

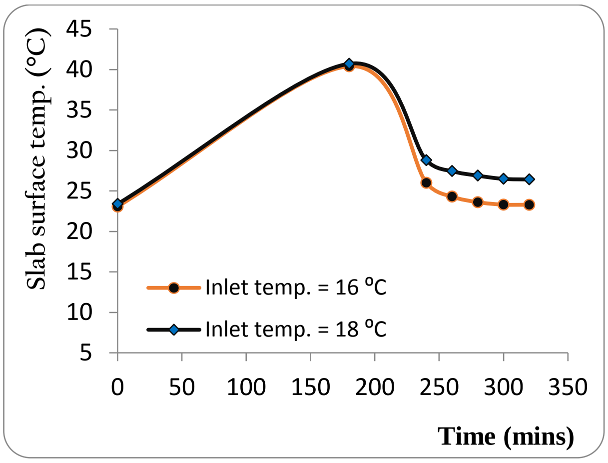


Fig. 23. Variation of slab surface temperature with time at uai = 1.6m/sec with external load= 800W/m^2 and the internal load = 630 W/m^2.

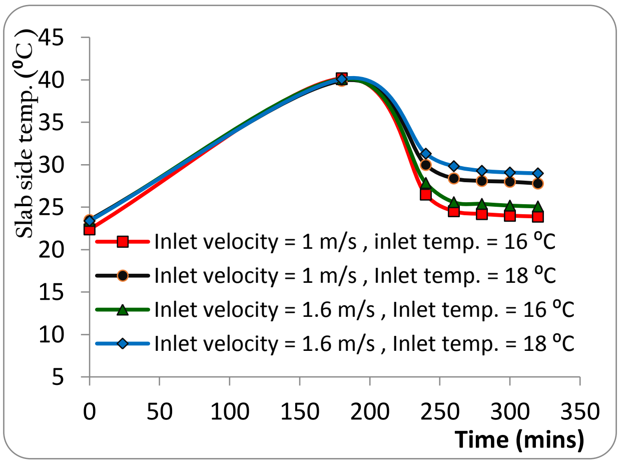


Fig. 24. Variation of slab side temperature with time at external load= 800W/m^2 and the internal load = 630 W/m^2.

4. Conclusions

From the results of the present work, the following conclusions are deduced:

1. The experiments showed during load period that thermal comfort always can be achieved with inlet core temperatures between (18°C and 20°C) with air inlet velocity of 1m/s, for high external load of about 800W/m^2.
2. The effect of air inlet velocity and air inlet temperature to the slab was very significant especially when the air inlet temperature decreases from (18°C to 16°C) and the results showed that the high heat removal take shorten time to reach to the steady state condition when T_{ai}=16°C and u_{ai}=1m/s.
3. The night ventilation strategy was found to be effective to remove heat in all present cases without loads if the outdoor temperature is lower than the indoor temperature .
4. Applying the TermoDeck system with ventilation technique during the day or night times, was able to control the space condition, by cooling the ceiling of the building to remove the stored heat from the building.
5. This cooling technique is suitable for all the applications especially for buildings which need fresh air at all times as this system provide the buildings with treated (tempered) fresh air without any load on the capital cooling system.

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إستخدام نظام الترمودَك للتبريد/ التسخين الأوّلي للسّيطرة على الظروف الداخلية للبناية

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الخلاصة

تم في هذا البحث اجراء دراسة عملية لتوزيع درجات الحرارة في حيّز مكيَّف بنظام تهوية البلاطة المجوفة (ترموديك). أُجريَت التجارب على انموذج مصغّر لغرفة بأبعاد (1m×1.2m×1m)، والذي بُنِيَ على أساس مقياس رسم مناسب هو (1\4) . تم قياس توزيع درجات الحرارة بوساطة تثبيت (59) مزدوجاً حراريا في مناطق و مقاطع متعددة. أُخذت حالتان في هذا العمل صُنِّفت على اساس عدم انشغال الحيز أي خلال فترة الليل (دون وجود حمل خارجي) والاخرى خلال فترة النهار أي بوجود حمل خارجي مقداره ($800W/m^2$) وفقا لحسابات الكسب الحراري الشمسي الناتج من الاشعاع الشمسي خلال فصل الصيف في العراق .جميع النتائج أكّدت إستخدام نظام الترموديك لأغراض التهوية والتبريد/التسخين في أجواء الاقاليم الجافة لبساطتها واداءها الجيد من حيث الراحة الحرارية وخزنها للطاقة و تحسين اداء الطاقة الكليّة للبنايةعن طريق تقليل الحمل الاعظم.