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Experimental investigation of night ventilation for cooling a kitchen in hot dry summer conditions

Investigación experimental de la ventilación nocturna para enfriar una cocina en verano cálido seco

Ayala-Moreno Juan Pedro
Universidad de Sonora
Departamento de Ingeniería Civil y Minas, México
Correo: juan.ayala@unison.mx
https://orcid.org/0000-0002-7708-4113

Ayala-Moreno Alma Angelina
Universidad de Sonora
Departamento de Ingeniería Industrial, México
Correo: alma.ayala@unison.mx
https://orcid.org/0000-0001-9643-082X

Abstract

Passive design strategies in buildings have been lost over the years being replaced by active systems, which demand energy and contribute extensively to the environmental problems. Return to passive strategies in buildings design is a promising way for improving comfort and reducing energy demand. Passive strategies can be learned from traditional or old buildings in each climate zone. In this study the focus was on testing the performance of night ventilation for cooling a kitchen in an old building with high ceiling and high thermal mass, but under extreme summer conditions in a desert climate. The kitchen usually performs without air conditioning and it was monitored during June and July, the hottest months of the year. Each of the three established ventilation schemes were tested over a 7-day period: with windows closed day and night (A), with windows opened day and night with assisted night ventilation (B), and with controlled windows with assisted night ventilation (C). Based on the results of the three ventilation schemes it is seen that night ventilation together with controlled windows (ventilation scheme C) allows decreasing indoor average temperature about 3.6°C compared with the no ventilation scheme (ventilation scheme A). With no ventilation (ventilation scheme A) indoor maximum temperatures are more similar to outdoor maximum temperatures, around 2.7°C below. With night ventilation and controlled windows (ventilation scheme C), indoor maximum temperatures can be decreased by more than 1°C on average, thus around 4°C below outdoor maximum temperatures. Although night ventilation helped lower indoor temperatures under extreme summer conditions, it was not enough to achieve comfort during the usage hours even for acclimatized local people, which suggest the opportunity of application in transition periods, when temperatures are not extreme but still hot, giving the possibility of achieving the full effectiveness under hot but not extreme conditions.
Keywords: Night ventilation, natural ventilation, passive cooling, internal gain, thermal mass.

Resumen

Las estrategias de diseño pasivo en edificios se han ido perdiendo con el paso de los años desplazadas por los sistemas activos de climatización que demandan energía y contribuyen a los problemas ambientales. Regresar a estrategias pasivas en el diseño de edificios resulta prometedor para mejorar el confort y reducir la demanda energética. De los edificios antiguos o tradicionalmente adaptados al clima puede aprenderse sobre las estrategias pasivas que utilizan. Este estudio se enfocó en probar la ventilación nocturna para enfriar una cocina en un edificio antiguo, con techos altos y alta masa térmica, pero en condiciones extremas de verano en un clima desértico. La cocina usualmente funciona sin aire acondicionado y se monitoreó durante junio y julio, los meses más cálidos del año. Cada una de las tres configuraciones de ventilación establecidas se probó por un periodo de 7 días: con ventanas cerradas día y noche (A), con ventanas abiertas día y noche con ventilación nocturna asistida (B) y con ventanas controladas con ventilación nocturna asistida (C). Los resultados muestran que el esquema de ventilación C permite disminuir la temperatura promedio interior alrededor de 3.6°C en comparación con el esquema de ventilación A. Sin ventilación, las temperaturas máximas interiores son más similares a las temperaturas máximas exteriores, alrededor de 2.7°C por debajo. Con el esquema de ventilación C, las temperaturas máximas interiores pueden reducirse en promedio más de 1°C, esto es, alrededor de 4°C por debajo de las temperaturas máximas exteriores. Si bien la ventilación nocturna contribuyó a disminuir las temperaturas interiores en condiciones extremas de verano, no fue suficiente para lograr el confort durante las horas de uso, lo que sugiere la oportunidad de aplicación en periodos de transición, cuando las temperaturas no son extremas, pero sí cálidas, dando la posibilidad de lograr plena efectividad en tales condiciones.
Descriptores: Ventilación nocturna, ventilación natural, enfriamiento pasivo, ganancia interna, masa térmica.

Introduction

Passive strategies in buildings have been a traditional practice in architecture since ancient times. This traditional practice responds to regional climates and "is the result of hundreds of years of optimisation to provide comfortable shelters using local materials and known construction technique" (Izadpanahi *et al.,* 2021, p. 2). However, passive strategies in building designs had been lost over the years (Rogers, 2018) as a result of many processes, mainly technological and cultural (Santamouris, 2007; Bassoud *et al.,* 2021). It is a fact that many older buildings were designed with passive systems and perform better than more recent buildings (Rogers, 2018). Over the years, buildings were more and more dependent on energy to provide comfort. The energy challenge faced by the building sector is now focusing on efficiency. To make more energy efficient buildings is the goal. Air conditioning is one of the main reasons why energy consumption is increasing substantially and rapidly in the building sector (Santamouris, 2007). Research has shown passive strategies can contribute to energy conservation making buildings more efficient at the lowest cost (Santamouris, 2007; Givoni, 2011; Leo *et al.*, 2013; Solgi *et al.*, 2018; Bhamare *et al.*, 2019). This is why research interest in passive strategies has increased (Solgi *et al.*, 2018).

Among passive strategies, night ventilation appears to be one of the more promising strategies for cooling, improving comfort and reducing energy demand (Santamouris *et al.,* 2010; Santamouris & Kolokotsa, 2013; Solgi *et al.*, 2018). Even in hot dry climates comfort can be achieved naturally in buildings with night time ventilation (Givoni, 2011). Givoni affirms that this technique can be applied to any type of building and in hot dry climates is more effective because of the diurnal swing (maximum minus minimum temperature) of more than 8°C (Givoni, 1998; Givoni, 2011; Santamouris & Kolokotsa, 2013). Also, a high speed wind at night is not necessarily required because cross ventilation can be assisted by fans (Givoni, 2011).

Despite the fact that literature can provide evidence that night ventilation is an effective strategy in most climate types, and recent research helps to improve it, optimization is still required, as for most passive strategies (Solgi *et al.*, 2018). Also, passive strategies can be learned from traditional or old buildings in each climate zone. To analyze those buildings can help optimize and inspire innovation in environmental design (Izadpanahi *et al.,* 2021).

The main interest of this study was to evaluate the performance of a real-world case of an old building with some optimal characteristics –like high ceiling and high thermal mass– but under extreme conditions. A high ceiling kitchen was selected in a high thermal mass residential building that usually performs without air conditioning, with internal heat gain from the kitchen appliances and in extreme hot climate with outdoor maximum temperatures above 40°C, although, considering acclimatized people. The focus was on the performance of night ventilation under all those mentioned conditions.

Materials and methods

The performance of night ventilation for cooling in hot dry summer conditions was evaluated in a high ceiling kitchen with internal heat gain of an old adobe residential building –built around 1900– situated in downtown Hermosillo, the main city in the Mexican zone of the Sonoran Desert. The climate classification for Hermosillo is BW(h') (INEGI, 2021) which is characterized by hot and arid conditions with intense sunshine and summer rain. The building is located at 29°05'13.0"N 110°57'03.6"W with an elevation of 217 meters above sea level.

All the kitchen walls are made of adobe and all the inner and outer surfaces are covered with mortar. The ceiling is of reinforced concrete covered with mortar on the inner surface and an insulation layer of earth (around 6 cm) and mortar on the outer surface. The floor is solid concrete with ceramic tiles on the inner surface. The door is of solid wood and the windows are of steel frames and simple glass of 3 mm thick.

As shown in Figure 1, the exterior wall of the kitchen is orientated east and has a width of 50 cm. The north wall is 35 cm width and is adjacent to a porch. The interior walls are south and west with 35 cm and 50 cm width, respectively. The kitchen has two windows, one on the east wall and one in the north wall. There is an orange tree that provides shade to the east wall window. The porch provides shade to the north wall window.

The area of the kitchen room is 9.90 m^2 with an average ceiling height of 3.30 m, which is 0.90 m higher than the common height for residential buildings in the city. The interior surface area interacting convectively with the interior space is about 61.38 m^2, respectively, 35.27 m^2 (57.46 %) of adobe walls, 9.90 m^2 (16.13 %) of concrete ceiling, 9.90 m^2 (16.13 %) of concrete floor, 2.10 m^2 (3.42 %) of solid wooden door and 4.21 m^2 (6.86 %) of glass windows.

Outside the kitchen there is a sidewalk of 2.40 m wide of concrete and then the street of hydraulic concrete with parked cars along the sidewalk. On the sidewalk, in front of the kitchen window, there is a

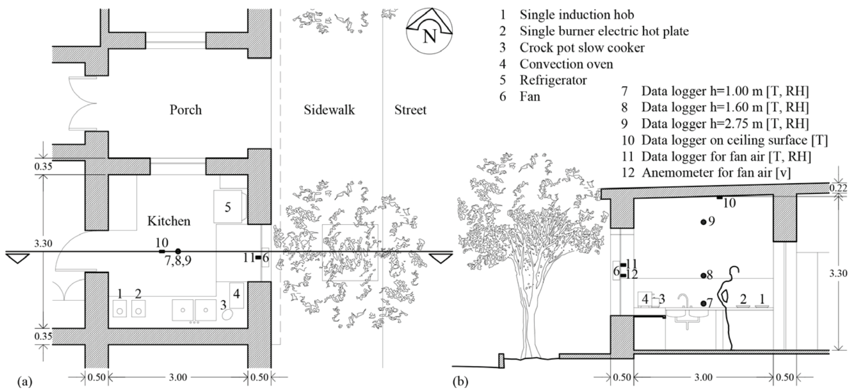

Figure 1. a) Horizontal and b) vertical sections of the kitchen with appliances and sensors positions and measured variables

planter of 1.44 m^2 with an orange tree of around a 3.5 m canopy diameter and 4 m height.

The average wind speed in the city is 2 m/s in June and July (UCLA Energy Design Tools Group, 2019). The low wind speed together with the obstructions of the windows, like the parked cars and the tree, did not favor natural cross ventilation. The effective area for ventilation with open windows is 1.55 m^2, representing 36.9 % of the windows area. The windows have security grills and mosquito nets obstructing the path of natural ventilation even more. To provide assistance for night ventilation (Givoni, 2011) a fan was installed as an impeller (from outside to inside) in the east window which is the one facing the outside.

A family of three people lives in the residential building, hence the kitchen was evaluated in use. The appliances of the kitchen that contribute to the internal heat gain are a single induction hob, a single burner electric hot plate, a convection oven, a crock pot slow cooker and a refrigerator (see Figure 1).

Experimental procedure

In order to investigate the influence of assisted night ventilation in a high thermal mass building, with internal heat gain and with high ceiling, three ventilation schemes were considered following Givoni (1998) to evaluate the thermal performance of the kitchen room:

- Ventilation scheme A: windows closed day and night.
- Ventilation scheme B: windows opened day and night, fan assisted ventilation at night.
- Ventilation scheme C: windows closed during the day and opened with fan assisted ventilation at night.

Each ventilation scheme was evaluated during a 7-day period. The ventilation scheme A, with windows closed day and night, was evaluated during the period from May 31 to June 6, 2022. The ventilation scheme B, with windows opened day and night with fan assisted ventilation at night, was evaluated from June 14 to 20, 2022. And the ventilation scheme C, with windows closed during the day and opened with fan assisted ventilation at night, was evaluated from July 5 to 10, 2022. Five days before each evaluation period, the ventilation scheme was already ongoing to minimize the influence, in the measurements, of factors beyond the established schemes. The evaluation periods were established in June and July because those months are the hottest of the year. During the study the hourly outdoor average maximum temperature recorded was of 39.7°C, being 37.9°C, 40.7°C, and 40.7°C the hourly outdoor average maximum temperatures for first, second and third period, respectively.

Measurements

The kitchen room was equipped with data loggers to measure and record dry bulb temperature and relative humidity. A total of five data loggers were used to collect indoor data and one to collect outdoor data.

The outdoor dry bulb temperature and relative humidity were measured and recorded by an Elitech data logger located 15 m from the kitchen. The indoor dry bulb temperature and relative humidity of the kitchen room were measured and recorded likewise by three Elitech data loggers located in the center of the room, respectively, at a height of 1.00 m, 1.60 m, and 2.75 m. The ceiling interior surface temperature was measured and recorded by an Elitech data logger with external sensor glued to the surface and covered with a paper tape (Givoni, 1998). The fan indoor air dry bulb temperature and relative humidity were measured and recorded likewise by an Elitech data logger with external sensor fixed 1 cm inside the mosquito net.

The temperature accuracy of the data logger according to the manufacturer data sheet was ± 0.5°C (Table 1). However, the six Elitech data logger were tested un-

Table 1. Technical specification of the instrumentation used in this study

Parameter	Instrument	Accuracy	Range
Dry bulb temperature/ Relative humidity	Elitech data logger	± 0.5°C ± 3 % RH	– 30°C to + 60°C 10 % to 99 % RH
Dry bulb temperature/ Relative humidity	Elitech data logger with external sensor	± 0.5°C ± 3 % RH	– 40°C to + 85°C 10 % to 99 % RH
Air velocity	Smart Sensor digital anemometer	± 5 %	0.3 m/s to 30 m/s

der the same conditions and all of them gave the same temperature within a maximum uncertainty of ± 0.1°C.

For controlling windows and assisted night ventilation the parameters shown in Figure 2 were set. For controlling windows, if indoor temperature is higher than outdoor temperature, the windows must be opened matching an every 10 minutes schedule, if the condition do not present, windows must remain closed. For controlling fan, if indoor temperature is higher than outdoor temperature plus 1°C the fan must be on matching an every hour schedule, if the condition do not present, fan must remain off.

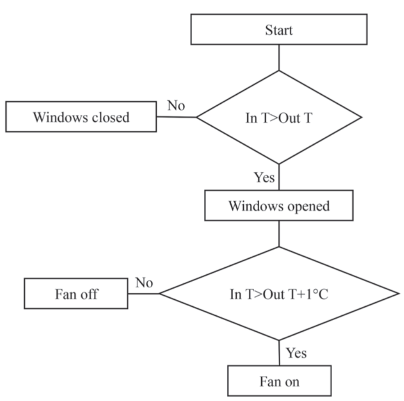

Figure 2. Parameters for controlling windows and fan for assisted night ventilation

The indoor temperature used to make the described changes is the one from the data logger positioned at 1.60 m height. This height was established considering the thermal comfort of the people using the kitchen in a standing working posture.

The measurements were conducted under the described conditions and following the settled parameters. Measurements were taken at 2-minute intervals. Later the data were averaged for hourly values (Givoni, 1998).

In order to achieve a high air change rate a powerful fan was selected to compensate for the efficiency drop caused by the mosquito net. Measurements of the air speed of the fan placed in the window with and without mosquito net were performed in 9 points twice and the average was used to calculate the air flow rate and the air change per hour (ACH). The measurements of the air speed were performed with a digital anemometer with an accuracy of ±5 % according to the manufacturer data sheet (Table 1). The calculated average speed with mosquito net was 3.44 m/s and without mosquito net was 4.92 m/s. It was found that the mosquito net in the window obstructs around 30 % of the air flow rate of the fan. The calculated ACH with the mosquito net in the window was 45 air changes per hour.

The internal heat gain data were recorded by the persons using the appliances in the kitchen. The recorded data were date, start and end time, and the power rating for the operation of the appliance. Refrigerator internal heat gain was not included in the analysis because it is taken as a constant thus has no impact on temperature fluctuations. Internal heat gain from the artificial lighting was considered negligible because it was rarely used since there was good natural lighting while using the kitchen. Also, the internal heat gain from the persons using the kitchen was considered negligible because of their limited permanence. Therefore, and given that the internal heat variable was used to analyze its correlation with the indoor temperature and not for heat transfer calculations, the electrical appliances consumption, in Wh, is taken as the independent variable of internal heat gain.

Results and discussion

The results are presented and discussed in five sections. In the first three sections the results are presented and discussed through the three ventilation schemes and with the analysis focused on the temperature taken at 1.60 m height. In the fourth section the results are presented and discussed comparing the three ventilation schemes. In the last section the results are presented and discussed analyzing stratification. All the temperature data presented in the following discussion are hourly values.

Ventilation scheme A: windows closed day and night

During this period from May 31 to June 6, 2022 the kitchen was monitored with windows closed day and night. Figure 3 shows indoor air temperature at three heights (1.00 m, 1.60 m, and 2.75 m), ceiling inner surface temperature, outdoor temperature, and outdoor daily averages, together with the internal heat gain from the appliances.

This monitoring period was characterized by outdoor moderately high maximum temperatures of 37.9°C on average, not reaching 40°C, and wide diurnal swing from 13°C to 16.6°C. The results show an indoor temperature diurnal swing of 2.4°C on average, which is short as it is common in other similar experimental studies (e.g. Givoni, 1998; Geros *et al.*, 1999), in addition, indoor temperatures fluctuate in a range from 32.1°C to 36.3°C, which is high. The indoor average temperature was about 3.7°C above the outdoor average temperature (see Table 2). The outdoor and indoor air temperature curves show clearly in Figure 3 the wide gap between outdoor and indoor minima, the average difference is 9.6°C, as shown in Table 2. The average difference between outdoor and indoor maximum temperatures is 2.7°C.

As can be seen in Figure 3, through variations in temperature, internal heat gain from the appliances contributes to a faster increase of indoor temperature. It is more evident in the second, fifth and sixth days with a higher internal heat gain.

Ventilation scheme B: windows opened day and night, fan assisted ventilation at night

During the second period from June 14 to 20, 2022 the kitchen was monitored with windows opened day and night and with fan assisted ventilation at night time, following the established parameters to control the switching on and off of the fan. Figure 4 shows indoor air temperature at three heights (1.00 m, 1.60 m, and 2.75 m), ceiling inner surface temperature, fan air temperature, outdoor temperature, and outdoor daily averages, together with the internal heat gain from the appliances.

During this monitoring period the outdoor maximum temperatures were high, of 40.7°C on average, and the diurnal swing was from 9.2°C to 16.1°C. It can be seen in Figure 4 that indoor temperature patterns are more similar to outdoor temperature patterns, therefore, the indoor temperature swing is wider than with closed windows (ventilation scheme A), with an average difference of 6.6°C. The indoor average temperature was close to the average outdoor temperature, with a difference of about 0.8°C above the outdoor average temperature (see Table 2). The average difference between outdoor and indoor maximum temperatures is 2.9°C.

Under this ventilation scheme, internal heat gain from the appliances although contributes to increase indoor temperature, does not significantly affect the temperature patterns, unless there was a high internal heat gain from the appliances or a not so high outdoor temperature, like in third and fifth days, respectively.

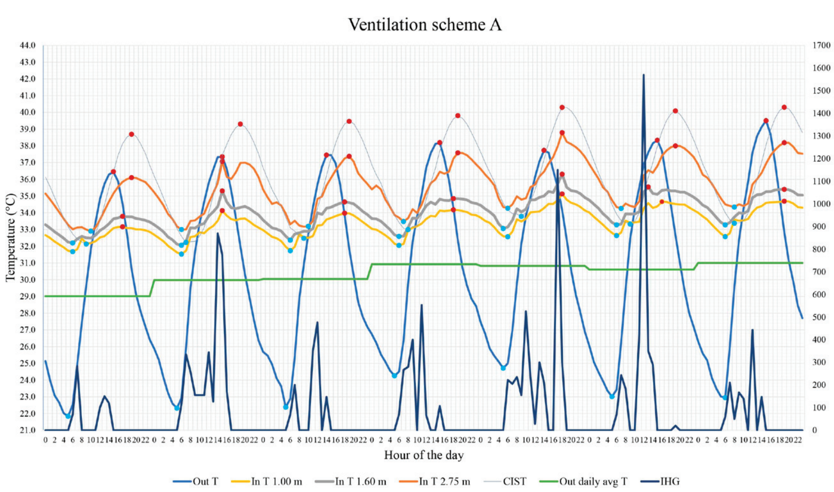

Figure 3. Indoor and outdoor air temperature, ceiling inner surface temperature and internal heat gain as a function of time of the kitchen with ventilation scheme A, during the period from May 31 to June 6, 2022

Table 2. Differences between indoor and outdoor average, minimum and maximum temperatures from the three monitoring periods

		Average	Minimum	Maximum		
		In T 1.60-Out T	In T 1.60-Out T	In T 1.60-Out T	Diurnal swing	Internal heat gain
	JDN	(°C)	(°C)	(°C)	(°C)	(Wh)
Ventilation scheme A	151	4.1	10.4	– 2.6	14.6	723
	152	3.6	9.7	– 2.0	15.0	3460
	153	3.6	10.0	– 2.8	15.1	1243
	154	3.1	8.3	– 3.3	13.9	1743
	155	3.8	8.4	– 1.4	13.0	3566
	156	4.0	10.3	– 2.8	15.3	3152
	157	3.6	10.3	– 4.1	16.6	1217
	Average	3.7	9.6	– 2.7	14.8	2158
Ventilation scheme B	165	0.9	3.2	– 3.1	12.7	2992
	166	0.2	3.6	– 4.2	16.1	1363
	167	– 0.3	3.0	– 4.6	15.9	5032
	168	0.8	2.6	– 2.1	10.5	3456
	169	1.4	3.1	– 1.1	9.2	1967
	170	1.4	3.3	– 2.2	11.8	877
	171	1.2	3.0	– 2.9	12.4	2769
	Average	0.8	3.1	– 2.9	12.6	2636
Ventilation scheme C	186	0.0	2.8	– 4.2	12.8	1043
	187	0.3	3.4	– 2.6	14.8	3461
	188	0.1	3.3	– 4.3	12.7	1723
	189	– 0.1	2.7	– 4.5	12.3	2318
	190	0.4	2.1	– 3.5	10.6	2715
	191	0.2	3.0	– 5.0	13.2	2607
	Average	0.1	2.9	– 4.0	12.7	2311

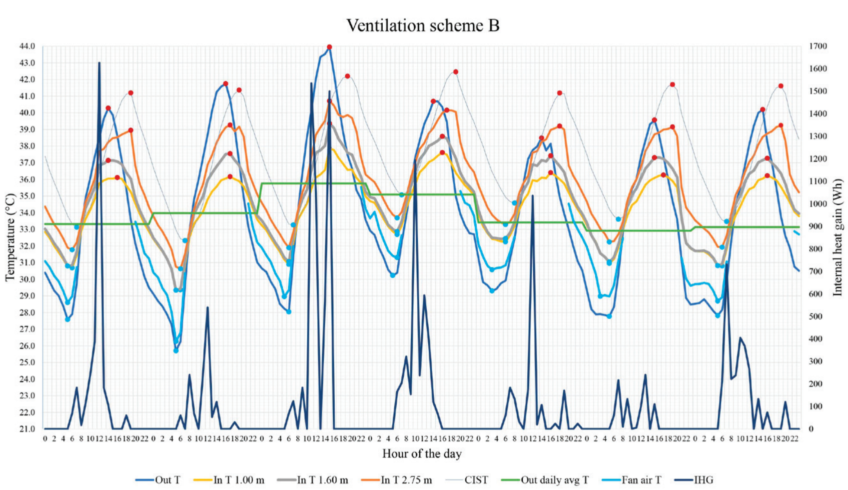

Figure 4. Indoor and outdoor air temperature, ceiling inner surface temperature and internal heat gain as a function of time of the kitchen with ventilation scheme B, during the period from June 14 to 20, 2022

Ventilation scheme C: windows closed during the day and open with fan assisted ventilation at night

During this period from July 5 to 10, 2022 the kitchen was monitored with windows closed during the day and opened during the night with fan assisted ventilation at night time, following the established parameters to control the windows and the switching on and off of the fan. The monitoring original period was 7 days –as established– from July 5 to 11, 2022 and data were measured and recorded the 7 days but a storm event during the night of July 10 to 11 compromised the data because the outdoor and fan sensors recorded water temperature instead of air temperature. Therefore, the last day –July 11– was excluded from the analysis because data were altered from the storm event. Figure 5 shows indoor air temperature at three heights (1.00 m, 1.60 m, and 2.75 m), ceiling inner surface temperature, fan air temperature, outdoor temperature, and outdoor daily averages, together with the internal heat gain from the appliances.

This monitoring period was characterized by outdoor high maximum temperatures, of 40.7°C on average, and a diurnal swing from 10.6°C to 14.8°C. The indoor average temperature was close to the average outdoor temperature, with a difference of about 0.1°C above the outdoor average temperature (see Table 2). The indoor temperature swing is about 5.8°C. As shown in Figure 5, indoor patterns follow outdoor patterns in the minimum temperatures but not in the maximums. Patterns for the maximum temperatures seem like a plateau, which means that night ventilation is contributing to decrease the indoor temperature peaks. The average difference between outdoor and indoor maximum temperatures is 4°C.

In Figure 5, the influence of internal heat gain from the appliances on indoor temperatures can be seen. When internal heat gain is moderate variations are visible but do not modify the plateau pattern of indoor temperatures. Instead, when internal heat gain increases, the influence is more marked, forming peaks of maximum indoor temperatures, as can be seen in the second day of the period.

Comparative analysis

Table 2 summarizes the data from the three monitoring periods focused on the temperature taken at 1.60 m height. It can be seen that night ventilation helps decrease the difference between indoor and outdoor average temperatures, since with no ventilation (ventilation scheme A) indoor average temperature is on average 3.7°C higher than outdoor average temperature, and with controlled windows and night ventilation (ventilation scheme C) the average difference is only of 0.1°C. The contribution of night ventilation is more evident in the decrease of indoor minimum temperatures. It can be seen that with no ventilation (ventilation scheme A) indoor minimum temperature is on average 9.6°C above outdoor minimum temperature and with night ventilation the difference can be reduced by over 6°C. On the other hand, with no ventilation (ventilation scheme A) indoor maximum temperatures are more similar to outdoor maximum temperatures, around 2.7°C below. With night ventilation and controlled windows (ventilation scheme C), indoor maximum temperatures can be decreased by more than 1°C on average, thus around 4°C below outdoor maximum temperatures.

These results show that, even under extreme hot conditions, night ventilation helps decrease indoor temperatures because is working together with high thermal mass which is characterized by a high thermal capacity (inertia) storing heat and hence blocking heat transfer (Hadji *et al.*, 2020). It can be seen that, even with

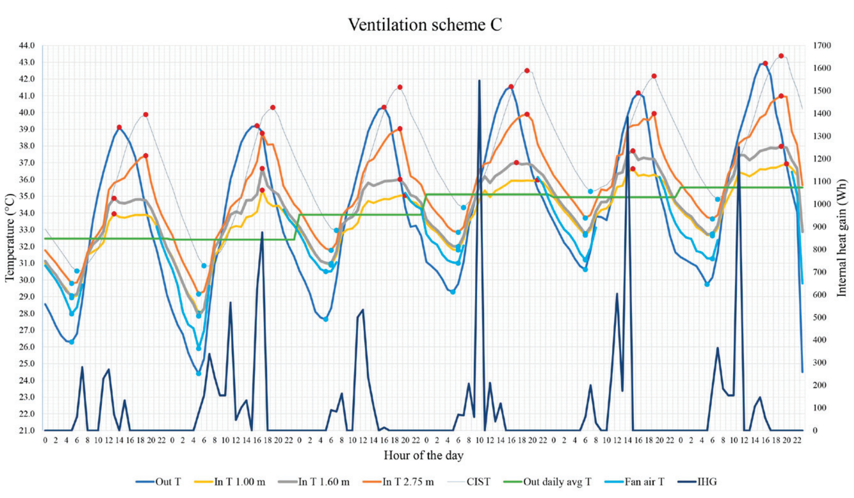

Figure 5. Indoor and outdoor air temperature, ceiling inner surface temperature and internal heat gain as a function of time of the kitchen with ventilation scheme C, during the period from July 5 to 10, 2022

the least favorable ventilation scheme (A), the indoor maximum temperatures are lower than the outdoor maximum temperatures probably because of the influence of the high thermal mass of the adobe walls and the wide diurnal swing. Thermal mass, storing heat, softens maximum temperatures as well as the minimums, and the wide diurnal swing causes, during night time together with radiative cooling, inducing low temperatures to the building envelope storing them because of its high thermal mass. In Givoni's (1998) experiment the maximum temperatures of all tested buildings with different mass levels and windows closed (like ventilation scheme A) result above the outdoors' maxima, but they presented a lower difference as the thermal mass increased. It must be noted that the higher mass building tested by Givoni (1998) has solid concrete walls of 10 cm width insulated externally with rigid foam and plastered. That is why a 50 cm adobe wall produces a more significant effect on lowering temperatures.

To describe the strength of the relationship between the variables linear correlation coefficients were obtained. Correlation coefficients summarize both the direction of that relationship and its strength, the values are bounded between – 1.0 and + 1.0 inclusive, the negative or positive sign indicates the direction, and the absolute value indicates magnitude or strength association (Whitford, 2005).

Table 3 shows the most significant simple and multiple linear correlation coefficients found between indoor temperatures and the independent variables such as outdoor temperatures and internal heat gain from the appliances. For each monitoring period the most significant variables were different.

For the monitoring period with windows closed day and night (ventilation scheme A) the most significant variable that influences the indoor average temperatures was the average temperature from the day before that, together with the internal heat gain from the appliances, influences the indoor maximum temperatures, as can be seen in Table 3 and in Figure 6. The strong correlation between indoor average temperature with outdoor average temperature of the day before may be due to the effect of the adobe walls high thermal mass which delay on time the effect of outdoor on indoor temperatures.

Figure 7 and Table 3 show that in the second monitoring period with windows opened day and night with night ventilation (ventilation scheme B) the outdoor minimum temperatures highly influence the decrease of indoor minimum temperatures with linear correlation coefficients above 0.95.

For the monitoring period with controlled windows and night ventilation (ventilation scheme C) also outdoor minimum temperatures highly influence the decrease of indoor minimum temperatures with linear correlation coefficients above 0.91, as shown in Table 3. A higher influence can be seen in Figure 8 with very similar effect between indoor and outdoor average temperatures, with linear correlation coefficients above 0.97 (Table 3). For indoor maximum temperatures, are outdoor average temperatures together with internal heat gain from the appliances that influence the most, with linear correlation coefficients above 0.96 as shown in Table 3.

According to the linear correlation data between indoor temperatures and the independent variables parameters, presented in Table 3, formulas could be developed to predict the indoor behavior as a function of several variables in order to optimize the natural ventilation control.

Stratification

High ceiling is characteristic of traditional buildings in the city along with vents on the top of walls to exhaust hot air through. In the studied building the vents do not exist –or were lost over the years–, so hot air accumulates in the upper level of the room. Measurements at different levels of the kitchen room were part of the experiment settings as a way to test the thermal stratification of the high ceiling kitchen. The obtained patterns of the three ventilation schemes are previously presented in Figures 3, 4 and 5.

Figure 3 shows that the period with windows closed day and night (ventilation scheme A) was characterized by mild undulations of the indoor temperature at the lower levels (at 1.00 m and 1.60 m height) and more marked undulations of the indoor temperature at the upper level (at 2.75 m height). Maximum indoor temperatures at 2.75 m were closer or even higher than maximum outdoor temperatures. The marked undulations and the high temperatures in the upper level can be explained by the stratification effect that is more clearly appreciate when windows are closed (ventilation scheme A) where the indoor air moves exclusively by stratification since the hotter the air the lesser its density and therefore tends to rise to the ceiling. This stratification effect allows to remove the indoor hottest air from the zone (horizontal) where the users develop their activities, thus highlighting the success of interior spaces with high ceilings as a passive cooling strategy.

During the second period with windows opened day and night with nigh ventilation (ventilation scheme B), indoor temperature patterns in Figure 4 look similar to each other and are similar to outdoor temperature patterns. There is a difference between levels; there is a wider difference between maximum temperatures and

Table 3. Simple and multiple linear correlation coefficients between indoor temperatures and the independent variables

		Independent variables							
		Simple correlation coefficients					Multiple correlation coefficients		
	Indoor temperatures	Out avg T DB	Out avg T	Fan air T	Out min T	IHG	Out avg T DB & IHG	Out avg T DB & Fan air T	Out avg T & IHG
Ventilation Scheme A	Avg 1.00 m	0.91							
	Avg 1.60 m	0.91							
	Avg 2.75 m	0.90							
	Avg CIST	0.94							
	Min 1.00 m	0.77							
	Min 1.60 m	0.78							
	Min 2.75 m	0.83							
	Min CIST	0.86							
	Max 1.00 m	0.83				0.41	0.93		
	Max 1.60 m	0.62				0.63	0.91		
	Max 2.75 m	0.91				0.26	0.94		
	Max CIST	0.93				0.17	0.93		
Ventilation scheme B	Avg 1.00 m	0.73		0.91				0.97	
	Avg 1.60 m	0.66		0.85				0.94	
	Avg 2.75 m	0.64		0.84				0.94	
	Avg CIST	0.70		0.86				0.90	
	Min 1.00 m				0.98				
	Min 1.60 m				0.98				
	Min 2.75 m				0.96				
	Min CIST				0.95				
	Max 1.00 m		0.88						
	Max 1.60 m		0.94						
	Max 2.75 m		0.91						
	Max CIST		0.58						
Ventilation scheme C	Avg 1.00 m		0.97						
	Avg 1.60 m		0.98						
	Avg 2.75 m		0.98						
	Avg CIST		0.98						
	Min 1.00 m				0.97				
	Min 1.60 m				0.97				
	Min 2.75 m				0.96				
	Min CIST				0.91				
	Max 1.00 m		0.72						0.97
	Max 1.60 m		0.62						0.97
	Max 2.75 m		0.82						0.96
	Max CIST		0.96						0.97

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Figure 6. Daily average and maximum temperatures of the monitoring period with ventilation scheme A

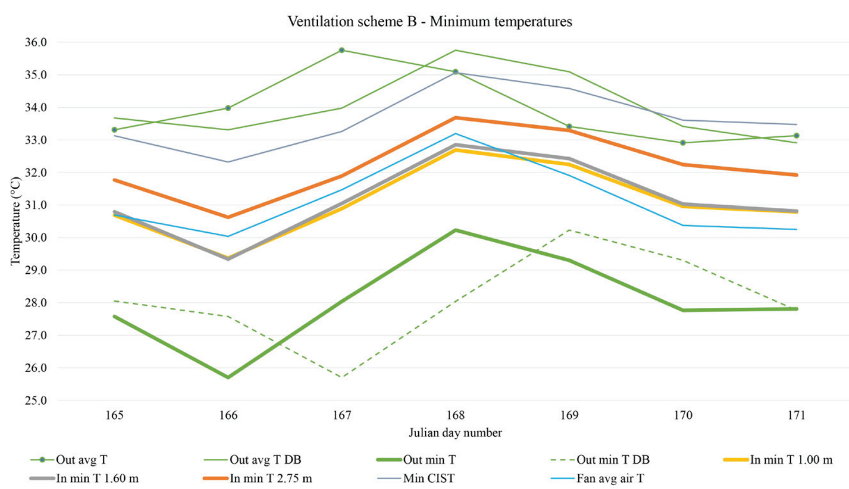

Figure 7. Daily minimum temperatures of the monitoring period with ventilation scheme B

Figure 8. Daily average and maximum temperatures of the monitoring period with ventilation scheme C

a shorter difference between minimum temperatures when night ventilation is ongoing. The rises of temperature are very similar at the three indoor temperature levels together with the outdoor temperature. Temperature drops follow a similar pattern between the three indoor temperature levels together with the outdoor temperature and fan air temperature but with a delay in time.

Figure 5 shows the period with controlled windows and night ventilation (ventilation scheme C). This period was characterized by the plateau pattern of the indoor maximum temperatures, but only in the lower levels and not in the upper level that shows a pattern mainly similar to the outdoor temperature pattern.

In the second and third periods with night ventilation (ventilation schemes B and C), it can be seen in Figures 4 and 5 that assisted night ventilation contributes to a more uniform temperature distribution at the lower levels (at 1.00 m and 1.60 m height) during the assisted ventilation time. However, although assisted night ventilation contributes to an evident decrease in the indoor temperature at the upper level, the temperature behavior at 2.75 m height show that minimum temperatures are still always higher than the ones of the lower levels, with an average difference of 1°C.

Table 4 summarizes the temperature differences between the three levels. It can be seen that the minimum differences occur during the monitoring periods with night ventilation. As can be seen in Figures 4 and 5, the minimum differences between levels occur while night ventilation is ongoing, that is, when the temperatures are low. The behavior of the temperatures at the lower levels (at 1.00 m and 1.60 m height) is very similar when night ventilation is ongoing. But, according to the behavior of the higher level, the minimum differences between the 2.75 m and 1.60 m levels occur during the rises of temperature. On the other hand, Figures 3, 4 and 5 clearly show that the maximum differences between levels occur coincidently when maximum temperatures occur. This gives an idea of the benefits of high ceiling in hot climates and why it is a traditional strategy to help achieve comfort in naturally ventilated spaces.

Table 4. Minimum, maximum, and average differences between the three measurement levels of the indoor temperatures from the three monitoring periods

		T 1.60-1.00			T 2.75-1.60		
	JDN	Min	Max	Avg	Min	Max	Avg
Ventilation scheme A	151	0.1	0.7	0.5	0.4	2.4	1.4
	152	0.4	1.2	0.7	0.4	2.7	1.5
	153	0.1	0.8	0.6	0.3	2.8	1.5
	154	0.2	0.8	0.6	0.3	2.7	1.6
	155	0.5	1.2	0.7	0.7	2.8	1.7
	156	0.4	1.0	0.7	0.4	2.8	1.6
	157	0.2	0.9	0.7	0.4	2.8	1.7
	Average	0.3	0.9	0.6	0.4	2.7	1.6
Ventilation scheme B	165	0.0	1.1	0.5	0.2	2.9	1.2
	166	– 0.1	1.5	0.6	0.1	2.3	1.2
	167	0.1	1.5	0.7	0.1	2.3	1.1
	168	0.1	1.0	0.5	0.4	2.8	1.1
	169	0.1	1.0	0.5	0.4	2.6	1.2
	170	– 0.1	1.2	0.5	0.3	2.5	1.3
	171	0.0	1.1	0.5	0.5	2.9	1.3
	Average	0.0	1.2	0.5	0.3	2.6	1.2
Ventilation scheme C	186	– 0.1	1.0	0.4	0.2	2.7	1.1
	187	– 0.2	1.3	0.5	0.4	2.8	1.2
	188	0.0	1.1	0.5	0.5	3.0	1.3
	189	0.1	1.1	0.6	0.6	3.0	1.4
	190	0.1	1.1	0.5	0.5	2.7	1.3
	191	– 0.3	1.2	0.6	0.5	3.0	1.5
	Average	– 0.1	1.1	0.5	0.4	2.9	1.3

Conclusions

In this study the focus was on testing the performance of night ventilation in a real-world case under extreme summer conditions. That is why a kitchen, which usually performs without air conditioning, was selected. The real-world case was an inhabited residential old building with high ceiling and high thermal mass that are traditional strategies used to help achieve indoor spaces comfort in the local desert region.

Three ventilation schemes: with windows closed day and night (ventilation scheme A), with windows opened day and night with assisted night ventilation (ventilation scheme B), and with controlled windows with assisted night ventilation were tested (ventilation scheme C). Based on the results of the three ventilation schemes it is seen that night ventilation helps decrease indoor temperatures compared with the no ventilation scheme. This contribution of night ventilation together with controlled windows allows matching indoor with outdoor average temperatures, that is, decreasing indoor average temperature by about 3.6°C compared with the no ventilation scheme. Also helps to decrease indoor maximum temperatures by about 1.3°C compared with the no ventilation scheme.

The study has some limitations. Regarding internal heat gain, this study, being in a real-world case, is limited to the actual specific usage patterns of the kitchen appliances and any change in usage time, usage power, schedule or other not only affect the thermal performance but the correlations between variables. Therefore, it is not possible to generalize. Other limitation is that, with only experimental study, comparisons between ventilations schemes cannot be done accurately because the independent variables, as the outdoor conditions or the internal heat gain, are not strictly corresponding. Even though an experimental study in a real-world case provides important results, a numerical model needs to be performed in further studies to complementary results and more accurate comparisons to optimize the tested strategies and identify more possibilities.

Under the extreme conditions of high outdoor temperatures and high internal heat gain from the kitchen appliances, passive strategies as the ones tested –natural ventilation together with high ceiling and high thermal mass– are not enough to achieve comfort during the usage hours even for acclimatized local people, that is about at a temperature of 32.2°C (Marincic *et al.*, 2012). But optimization is still possible, additional passive strategies such as solar chimneys or green roofs can be incorporated (e.g. AboulNaga & Abdrabboh, 2000; Jiang & Tang, 2017) or, as a last resort, a mix mode with active cooling systems can be used achieving a lower impact than with only common active systems (e.g. Darmanis *et al.*, 2020). Another possibility that the results suggest is the opportunity for application in transition periods, when temperatures are not extreme but still hot. If the results corroborate the effectiveness of the tested passive strategies even under extreme summer conditions, but they were not enough to achieve comfort, there is still possibility of achieving the full effectiveness under hot but not extreme conditions.

Nomenclature

T	Temperature (°C)
RH	Relative humidity (%)
v	Air velocity (m/s)

Abbreviations

ACH	Air change per hour	Avg	Average
CIST	Ceiling inner surface temperature (°C)	In	Indoor
DB	Day before	Max	Maxima/maximum
IHG	Internal heat gain (Wh)	Min	Minima/minimum
JDN	Julian day number	Out	Outdoor

References

AboulNaga, M. M., & Abdrabboh, S. N. (2000). Improving night ventilation into low-rise buildings in hot-arid climates exploring a combined wall-roof solar chimney. *Renewable Energy*, 19(1-2), 47-54. https://doi.org/10.1016/S0960-1481(99)00014-2

Bassoud, A., Khelafi, H., Mokhtari, A. M., & Bada, A. (2021). Evaluation of summer thermal comfort in arid desert areas. Case study: Old adobe building in Adrar (South of Algeria). *Building and Environment*, 205. https://doi.org/10.1016/j.buildenv.2021.108140

Bhamare, D. K., Rathod, M. K., & Banerjee, J. (2019). Passive cooling techniques for building and their applicability in different climatic zones-The state of art. *Energy and Buildings*, 198, 467-490. https://doi.org/10.1016/j.enbuild.2019.06.023

Darmanis, M., Çakan, M., Moustris, K. P., Kavadias, K. A., & Nikas, K.-S. P. (2020). Utilisation of mass and night ventilation in decreaasing cooling load demand. *Sustainability*, 12(18). https://doi.org/10.3390/su12187826

Geros, V., Santamouris, M., Tsangrasoulis, A., & Guarrancino, G. (1999). Experimental evaluation of night ventilation phenomena. *Energy and Buildings*, 29(2), 141-154. https://doi.org/10.1016/S0378-7788(98)00056-5

Givoni, B. (1998). Effectiveness of mass and night ventilation in lowering the indoor daytime temperatures. *Energy and Buildings*, 28(1), 25-32. https://doi.org/10.1016/S0378-7788(97)00056-X

Givoni, B. (2011). Indoor temperature reduction by passive cooling systems. *Solar Energy*, 85(8), 1692-1726. https://doi.org/10.1016/j.solener.2009.10.003

Hadji, F., Ihaddadene, N., Ihaddadene, R., Betga, A., Charick, A., & Logerais, P. O. (2020). Thermal conductivity of two kinds of earthen building materials formerly used in Algeria. *Journal of Building Engineering*, 32, 101823. https://doi.org/10.1016/j.jobe.2020.101823

INEGI. (2021). Aspectos geográficos: Sonora. Aguascalientes: INEGI.

Izadpanahi, P., Mahmoudi Farahani, L., & Nikpey, R. (2021). Lessons from sustainable and vernacular passive cooling strategies used in traditional iranian houses. *Journal of Sustainability Research*, 3(3). https://doi.org/10.20900/jsr20210014

Jiang, L., & Tang, M. (2017). Thermal analysis of extensive green roofs combined with night ventilation for space cooling. *Energy and Buildings*, 156, 238-249. https://doi.org/10.1016/j.enbuild.2017.09.080

Leo, D. G., Shiva, S. M., & Maiya, M. P. (2013). Passive alternatives to mechanical air conditioning of building. A review. *Building and Environment*, 66, 54-64. https://doi.org/10.1016/j.buildenv.2013.04.016

Marincic, I., Ochoa, J. M., & del Río, J. A. (2012). Confort térmico adaptativo dependiente de la temperatura y la humedad. *ACE: Architecture, City and Environment*, 7(20), 27-46. http://dx.doi.org/10.5821/ace.v7i20.2572

Rogers, K. (2018). *Building reuse: Sustainability, Preservation, and the Value*. Seattle: University of Washington Press.

Santamouris, M. (2007). *Advances in passive cooling*. London: Earthscan.

Santamouris, M., & Kolokotsa, D. (2013). Passive cooling dissipation techniques for buildings and other structures: The state of the art. *Energy and Buildings*, 57, 74-94. https://doi.org/10.1016/j.enbuild.2012.11.002

Santamouris, M., Sfakianaki, A., & Pavlou, K. (2010). On the efficiency of night ventilation techniques applied to residential buildings. *Energy and Buildings*, 42(8), 1309-1313. https://doi.org/10.1016/j.enbuild.2010.02.024

Solgi, E., Hamedani, Z., Fernando, R., Skates, H., & Orji, N. E. (2018). A literature review of night ventilation strategies in buildings. *Energy and Buildings*, 173, 337-352. https://doi.org/10.1016/j.enbuild.2018.05.052

UCLA Energy Design Tools Group. (2019, January). Climate Consultant 6.0. UCLA.

Whitford, A. B. (2005). Correlations. In encyclopedia of social measurement (pp. 523-529). Elsevier. Retrieved on https://doi.org/10.1016/B0-12-369398-5/00149-3

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