International Journal of Energy and Environmental Engineering
a SpringerOpen Journal

ORIGINAL RESEARCH Open Access

Thermal comfort design of traditional houses in hot dry region of Algeria

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Abstract

The new architecture produced recently in the south of Algeria known as 'modern construction' following the trend of the northern cities, which have different climate, is completely non-adapted to the harsh climate of the south of Algeria and, therefore, has high-energy consumption. The Ksar of Kenadsa is considered among the most important old cities of the south-west region of Algeria by its cultural and religious dimensions. In this area, the traditional architecture has been built to achieve the comfort in hot season. The new constructed houses have been built following the north architectural design neglecting the very harsh climate of the south region of Algeria characterized by very hot and dry climate. To evaluate the thermal comfort of this modern housing, a comparative analysis for the existing traditional housing is carried out using TRNSYS software. The simulation results show that the modern typical house seems to be inappropriate for the desert climate. Indeed, except the use of air-conditioning in summer, there is no other solution which can ensure thermal comfort.

Keywords: Energy, Modern house, TRNSYS, Thermal comfort, Simulation

Background

Passive methods of achieving thermal comfort in buildings in various countries have been widely investigated [1-7]. Fanger has calculated the thermal comfort by introducing a basic comfort equation [8]. Indeed, those passive methods are the best solution to provide a healthy and energy-efficient indoor environment [9-12].

The new houses built during these last decades in Algeria particularly in the south, called modern construction, are high-energy consumer and are completely not adapted for the hot climate. Indeed, the high demand of housing combined with the poor economic management of the public authorities made that the qualitative aspect of the built houses was sacrificed to the profit of the quantitative aspect to solve the enormous deficit in housing. It was urgent to find immediate solutions, resulting in the importation of new housing models, completely unsuitable for the climatic, cultural, and social contexts of the region [13].

Algeria has a traditional architectural heritage which can be noticed through the knowledge in the construction field based on vernacular architecture integrating climatic data and local resources. In the south west of Algeria (hot and dry climate), the traditional architecture had developed an empirical knowledge, particularly oriented to the achievement of the comfort in hot season [14]. The users' comfort was ensured by a combination of several passive strategies of thermal control, which are the results of a thorough knowledge of the climatic conditions.

The comfort requirements have changed, but the current architectural design does not answer these new needs. These climates are characterized by long and severe hot seasons. For this reason, the buildings must be designed according to the summer requirements. Those of the winter will be satisfied consequently [15].

The city of Kenadsa is characterized by long periods of overheating where discomfort is strongly felt. The aim of this study is to evaluate the thermal comfort of the modern constructed houses. A comparison analysis within the existing traditional housing is carried out using simulation by means of TRNSYS software.

Geographical location and climatic data

Kenadsa is located in the south west of Algeria about 20-km west of Bechar city and from 950-km south west of Algiers, at the altitude of 806 m, latitude of 31°38′N, and longitude of 2°15′W [16]. It lies at the bottom of a valley by

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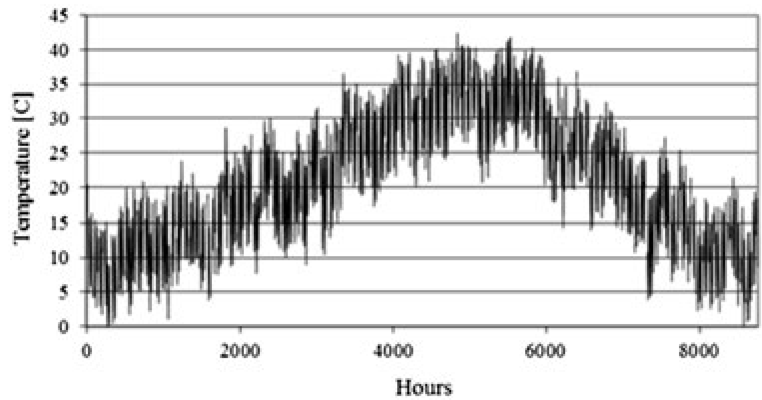

Figure 1 Monthly distribution of the outside temperature.

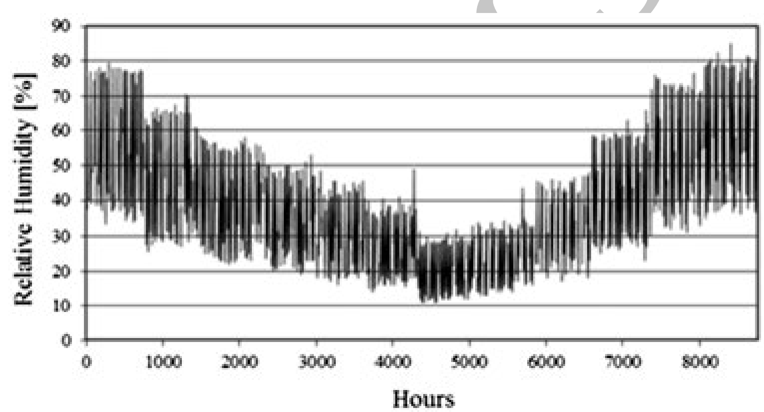

Figure 2 Monthly distribution of the relative humidity.

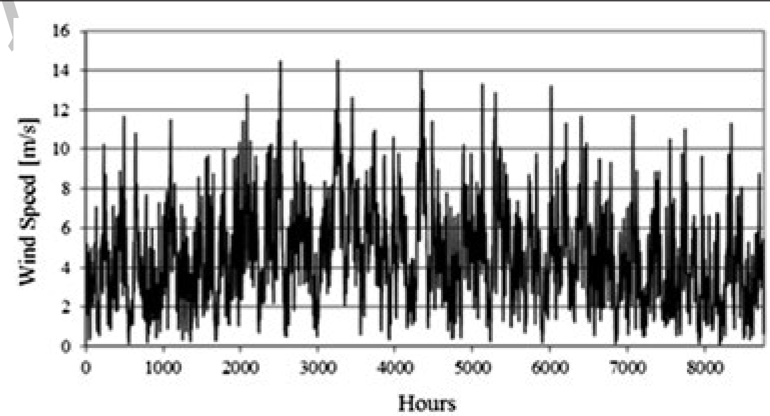

Figure 3 Monthly distribution of the wind speed.

Figure 4 Ksar of Kenadsa.

a mountainous relief, surrounded by a cliff called Barga which is composed of white rocks (silica sandstone) and fine sand in the north and the west, which offers an optimal protection against the harsh climate.

The monthly distribution of the air velocity, the temperature, and the relative humidity of the city are shown in Figures 1,2 and 3, respectively. These figures indicate that most part of the year is outside the comfort zone, except some periods of the months of September, October, March, and April. Another zone includes November to February where the building may require heating to ensure the comfort of the occupants. The third

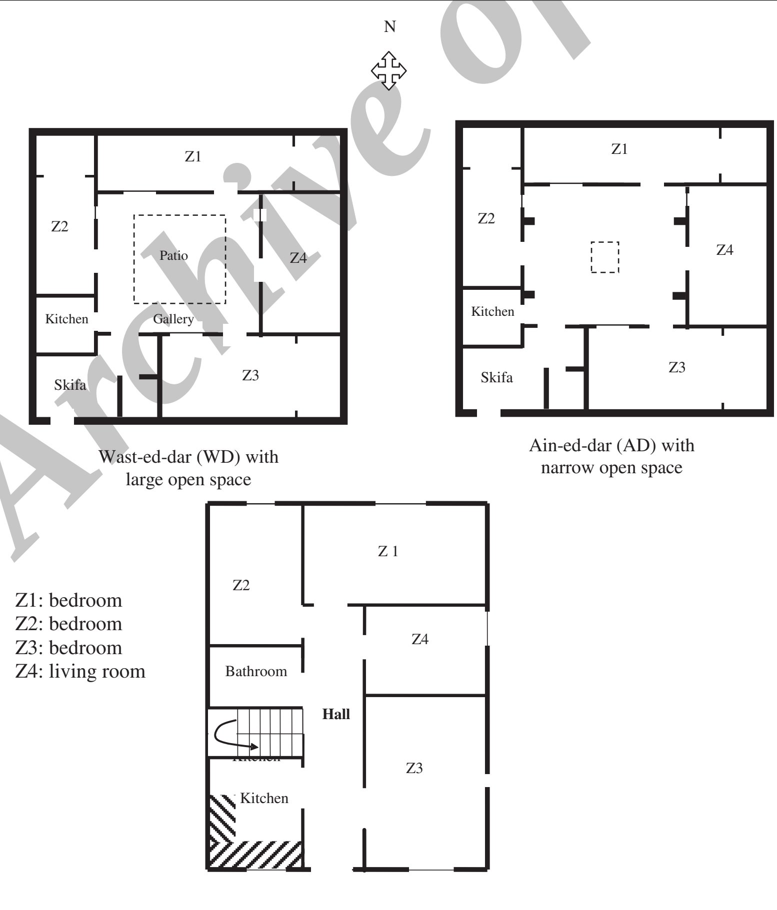

Figure 5 Model houses.

zone from May to September presents a period of hot season. The insolation exceeds 3,500 h/year, and the direct solar radiation may reach 800 W/m^2 on the horizontal surface. In summer, the temperature in the shade exceeds 40°C, and the amplitude between the day and the night is approximately 15°C, whereas the relative humidity remains low at about 27% [17].

Thermal characteristics and architectural aspects

The city is settled near the oasis to benefit from the effect of cooling by evaporation. The urban fabric appears in a form of a horizontal, dense, and compact model having a double effect of protection of the intense solar radiation in summer and the prevailing hot and cold winds (see Figure 4).

The Ksar is accessible by a route called 'derb' which is presented in the form of a labyrinthine course, which indicates the dynamics of the course during displacement. This course which is a long narrow street is shaded during the day, except when the sun is high in the sky. These streets are protected by the projection of rooms built in cantilever above the road.

The house, known under the terminology of 'dar', is the house of the family where several families having their parental relations cohabit. It consists of four elements: bab (entry door), skifa (chicane), central space, and bit (room).

The general orientation of the house is towards the east. The questions of the orientation illustrate the convergence of the climatic, cultural, and religious considerations.

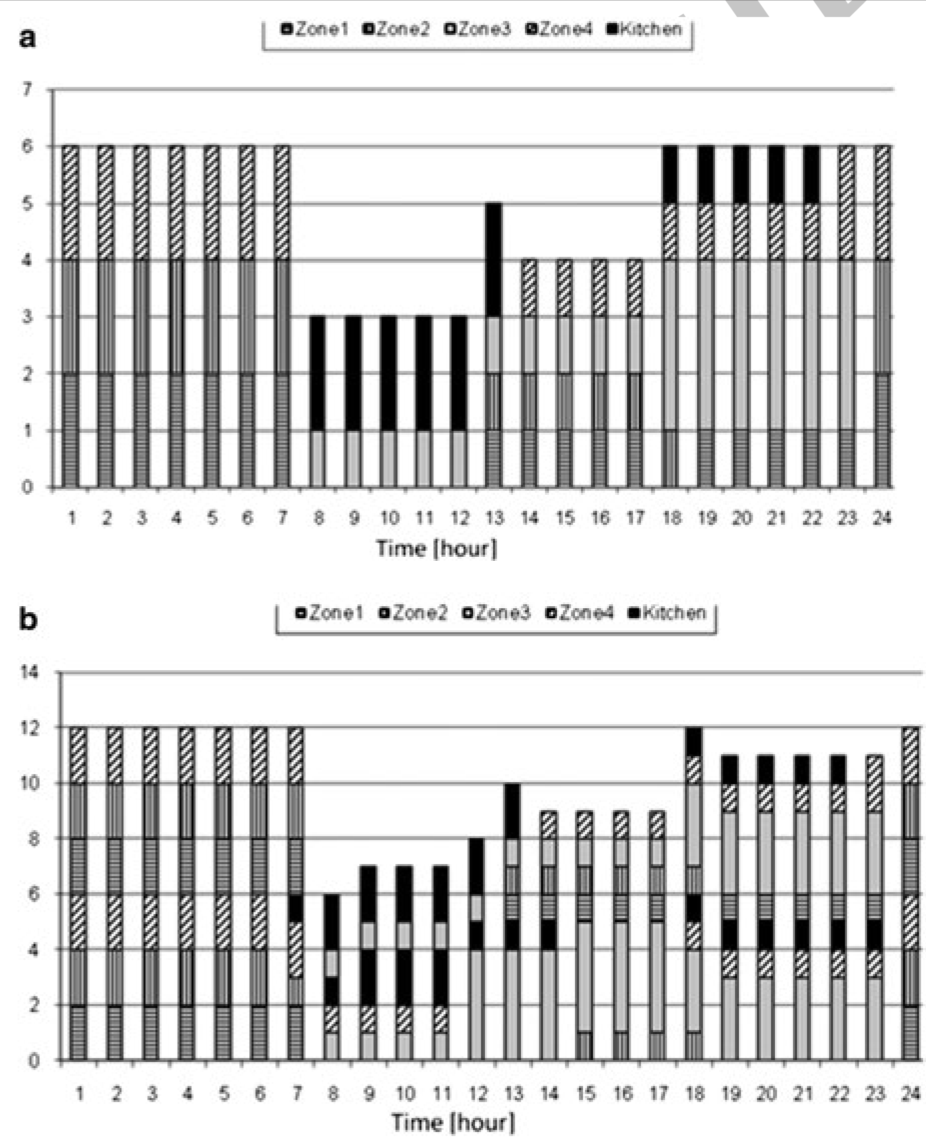

Figure 6 **Occupation scenarios of the different zones ((a) weekday occupation and (b) weekend occupation).**

Moslem directs their prayers and thoughts through the direction of qibla (means the direction towards Mecca). We have to distinguish two different shapes of central space. The models studied are shown in Figure 5 for the traditional housing, wast-ed-dar (WD) and ain-ad-dar (AD), and the modern housing (MH). WD has a large central space open to the sky. On the other hand, AD presents a narrow central open space (1 m × 1 m) which also opens to the sky.

The houses were completely turning inward. The walls that overlook the outside, particularly on the street (derb), are blind. All openings of the rooms are towards the inner courtyard, and the windows are long and narrow. This shape is very effective to obscure the sunrays. A very thick wall made a significant shadow over the opening. There are generally small openings for ventilation situated on the wall opposite to the courtyard near the ceiling and which remain always open during the summer.

Simulation

The aim of this paper is to examine the positive points as well as the failures of this type of housing. Detailed simulation have been carried out using the computer program TRNSYS. TRNSYS is a simulation environment and an open modular structure for the transient simulation of system used to validate new energy concepts. A TRNSYS project is typically set up by connecting components graphically in the simulation studio [18].

In the first step, we have introduced the geometrical description and the thermo-physical characteristics of the construction materials currently used in this region. The models studied are shown in Figure 5 for the traditional housing, WD and AD, and the MH. For the traditional housing, the exterior walls are made with stone of thickness of 40 cm, the interior partition walls are composed of 30-cm adobe, and the roof is in adobe of 17-cm thickness with a wooden false ceiling of 4 cm. The window glazing is clear glass of 4-mm thick. For the modern construction type, the exterior walls are made of double layer of 20-cm hollow perpend, the partition walls are in hollow perpend of 15 cm, and the roof is in hollow blocks of 17 cm. For each type of constructions, the floor is on full ground in a concrete slab with tiling of 2 cm. Since our aim is to assess

Table 1 Percentage of hours in year obtained by classification of the temperatures

House type	Zone	*Tmax Tmin* (°C)	34°C < *T* (%)	32°C < *T* < 34°C (%)	30°C < *T* < 32°C (%)	18°C < *T* < 30°C (%)	15°C < *T* < 18°C (%)	*T* < 15°C (%)
WD	Zone 1 (north)	35.71 7.63	1.08	5.81	7.12	42.35	13.34	30.30
	Zone 2 (west)	36.20 7.10	1.71	5.97	7.21	42.81	11.95	30.36
	Zone 3 (south)	36.72 7.72	3.35	6.14	6.49	44.06	14.18	25.91
	Zone 4 (east)	36.25 7.73	1.98	6.21	7.05	43.73	12.32	28.60
AD	Zone 1 (north)	33.54 3.07	0	2.94	10.39	44.50	11.73	31.76
	Zone 2 (west)	34.23 3.32	0.12	4.58	10.20	42.5	11.80	30.89
	Zone 3 (south)	35.36 3.49	1	8.16	7.7	42.96	12	27.08
	Zone 4 (east)	34.32 3.42	0.5	6	9.26	43	11.50	29.95
MH	Zone 1 (north)	38.69 6.7	16.59	5.78	5.17	36.64	9.58	26.23
	Zone 2 (west)	38.86 6.78	16.67	5.91	5.41	41.8	9.73	25.85
	Zone 3 (south)	39.63 8.19	17.44	5.44	5.94	39.01	11.56	20.52
	Zone 4 (east)	39.50 8.45	19.81	4.97	6.25	35.99	11.15	21.82

AD, ain-ad-dar; MH, modern housing; WD, wast-ed-dar.

and compare the thermal comfort of three different housing, therefore the same condition of occupant is set for the three dwellings. We have chosen the most realistic scenario of occupation considering six people as shown in Figure 6.

The metabolic energy of the inhabitants has been taken as 1.5 met during 8:00 am to 11:00 pm in summer and 8:00 am to 9:00 pm in winter and 1 met at night. For summer and winter, 0.5 and 1.5 clo have been considered as thermal resistance of their clothing, respectively.

The relative air speed is about 0.1 m/s. Infiltration is defined as an input according to the model of ASHRAE; the number of change per hour (ACH) is given by [19] in the following:

$$ACH = K_1 + K_2(T_{zone} - T_{amb}) + K_3 V_w \quad (1)$$

where T_{zone}, T_{amb}, and V_{w} are the zone temperature, ambient temperature, and wind speed, respectively. K_1, K_2, and K_3 are the empirical constants that depend on the airtightness for different construction qualities. Regarding the windows, in summer, the shutters and glazing are closed at daytime and open at night. In winter, the shutters are open during day and closed at night; the glazing being always closed. The free internal gains are due to the equipments (refrigerator, cooker, TV, and PC), and the lighting power are 20 W/m^2 for each room. TRNSYS was run hourly using a typical metrological year data recorded on the site of Bechar. We should mention here that the simulation has been done during a whole year and the ASHRAE model was used when the windows are closed. The solar radiation model available in the TRNSYS library (type 109) has been used assuming the surroundings to be black. The corridors have been modeled as thermal zones; therefore, no air movement is considered there.

Results and discussion

The objective of the simulation is to assess the level of climate adaptation of two traditional habitats. In the previous research, it has been found that the typical modern house seems to be inappropriate for a desert climate, and in the summer, the two traditional houses remain most effective to the heat problem for the two types of building materials

Table 2 Percentage of hours in year obtained by classification of the temperatures

House type	Zone	*T*max *T*min (°C)	34°C < *T* (%)	32°C < *T* < 34°C (%)	30°C < *T* < 32°C (%)	18°C < *T* < 30°C (%)	15°C < *T* < 18°C (%)	*T* < 15°C (%)
WD	Zone 1 (north)	36.76 5.72	2.85	6.08	6.49	42.57	13.03	28.97
	Zone 2 (west)	37.45 5.30	3.78	5.92	6.62	42.20	11.15	30.33
	Zone 3 (south)	37.67 5.43	5.43	5.33	6.35	42.69	12.89	27.30
	Zone 4 (east)	37.5 5.72	4.25	5.81	6.67	42.71	12.08	28.48
AD	Zone 1 (north)	34.23 2.63	0.09	3.27	8.91	44.18	11.65	31.89
	Zone 2 (west)	34.76 2.74	0.43	4.21	8.59	43.78	11.72	31.27
	Zone 3 (south)	36.09 2.80	1.82	6.18	7.10	43.93	11.95	29.01
	Zone 4 (east)	34.98 2.84	0.66	5.31	8.24	43.84	11.52	30.42
MH	Zone 1 (north)	37.17 9.02	15.50	7.37	2.64	39.76	10.87	23.91
	Zone 2 (west)	37.14 9.23	15.98	6.94	3.07	39.88	10.71	23.42
	Zone 3 (south)	37.69 11.99	17.37	6	6.11	44.58	16.58	9.34
	Zone 4 (east)	38.72 11.70	22.84	2.89	9.17	38.61	12.56	13.91

Traditional houses made of hollow perpend and modern house of adobe and stone. AD, ain-ad-dar; MH, modern housing; WD, wast-ed-dar.

tested (stone and adobe) (see Tables 1 and 2) [16]. However, the compactness of urban fabric is one of the main characteristics of the ksourienne fabrics in south Algeria.

To understand the effect of the urban compactness on the thermal behavior of the housing, a simulation of the three houses for more compact urban fabric was performed. Different scenarios of compactness have been investigated in this research. However, one case which consists in one house having two similar houses on both sides of the house is presented in this paper. The simulation results are illustrated in Table 3.

As it is shown by Table 3, the two traditional constructions present a small increase in the interval of hours of comfort (18°C < T < 30°C), and the maximal temperature is less than that obtained for the other cases. On the other hand, the minimal temperature is higher compared to the first case. For WD house, the average interval of the hours when T > 34°C has decreased from 2.03% to 0.98%, and there is a slight increase of percentage of hours when 30°C < T < 32°C from 6.96% to 7.02%. The average percentage of the hours when T < 15°C has not changed. However, we notice an increase in number of the hours when temperature is 15°C < T < 30°C from 12.94% to 14.25%.

Good results are obtained for AD house. There is an absence of temperatures higher than 34°C except for the south room. The percentage of hours of comfort (18°C < T < 30°C) presents an average of 48.48% which is much higher than the first case (43.24%). The compactness of the urban fabric gives a low percentage of hours with 32°C < T < 34°C equal to 1.49% with a decrease of 3% compared to the first case. However, for the modern house, we notice a great increase of hours when T > 34°C from 17.62% to 20.24% and a decrease in the interval of comfort from 38.36% to 34.65%. Therefore, the compactness of the urban fabric does not have a significant effect on the improvement of thermal comfort for the modern house made with hollow perpends.

We changed the construction material, and we carried out the simulation for the three houses keeping the same compactness but using the hollow perpend for traditional

Table 3 Percentage of hours in year obtained by classification of the temperatures for more compact urban fabric

House type	Zone	*T*max *T*min (°C)	34°C < *T* (%)	32°C < *T* < 34°C (%)	30°C < *T* < 32°C (%)	18°C < *T* < 30°C (%)	15°C < *T* < 18°C (%)	*T* < 15°C (%)
WD	Zone 1 (north)	34.97 9.64	0.33	4.34	7.39	43.65	16.07	28.13
	Zone 2 (west)	35.43 8.43	0.73	4.62	7.39	43.66	13.36	30.21
	Zone 3 (south)	35.95 8.11	2.13	5.97	6.18	43.71	14.24	27.76
	Zone 4 (east)	35.47 8.51	0.75	5.18	7.15	44.10	13.35	29.45
AD	Zone 1 (north)	33.30 3.41	0	0.33	5.60	50.28	12.34	31.44
	Zone 2 (west)	33.86 3.46	0	0.60	6.89	49.28	12.20	31.02
	Zone 3 (south)	34.80 3.43	0.22	4.13	9.26	46.03	11.88	29.07
	Zone 4 (east)	33.81 3.51	0	0.91	8.43	48.11	11.96	30.58
MH	Zone 1 (north)	38.49 7.44	18.20	5.29	5.04	35.85	10.34	25.28
	Zone 2 (west)	38.81 8.37	21.24	3.11	7	34.16	11.73	22.73
	Zone 3 (south)	39.14 8.61	20.90	3.65	6.63	34.47	11.50	22.85
	Zone 4 (east)	38.76 8.49	21.36	3.10	7.14	34.12	11.72	22.55

AD, ain-ad-dar; MH, modern housing; WD, wast-ed-dar.

constructions and adobe and stone for modern one. The results are presented in Table 4. As it can be seen, the material used affects slightly the overall thermal performance of WD housing in the comfort zone (30°C < T < 18°C). However, better performances have been obtained for AD housing for the same comfort zone.

Traditional houses made of hollow perpend and modern house of adobe and stone. AD, ain-ad-dar; MH, modern housing; WD, wast-ed-dar.

For the modern construction house with stone and adobe, we notice a slight decrease in the number of hours in thermal comfort zone. On the other side, this type of construction presents very high percentage of hours with T > 34°C equal to 36.32%. The heat stored during the day cannot be restored overnight, and the thermal inertia of the construction materials and the free internal gains contribute in the increase of the discomfort. However, this has a significant role on the winter conditions with the percentage of the hours of 0.02% when T < 15°C. This type of construction for a compact urban fabric does not ensure a good air renewal and passive refreshments. For a compact urban fabric, the air velocity is lower, and the outside temperature is higher.

Conclusion

The simulation results show that the modern typical house seems to be inappropriate for the desert climate. Indeed, except the air-conditioning in summer, there is no other solution which can ensure thermal comfort. For the two other traditional houses, in summer, they remain more effective to face the heat problem for the two types of building materials tested (stone adobe and hollow perpend).

The WD house has very important natural ventilation, but it offers less comfort than the AD type. It remains to optimize its components: patio dimension, width of the galleries, use of vegetation, and water (fountain and pond). The phenomenon of nomadism allows a comfortable use of inhabited space according to the days and seasons. It consists in shading the maximum of the outside surfaces. As a future work, we will investigate the effect of the urban fabric compactness on the cooling and heating consumptions.

Table 4 Percentage of hours in year obtained by classification of the temperatures for more compact urban fabric

House type	Zone	*T*max *T*min (°C)	34°C < *T* (%)	32°C < *T* < 34°C (%)	30°C < *T* < 32°C (%)	18°C < *T* < 30°C (%)	15°C < *T* < 18°C (%)	*T* < 15°C (%)
WD	Zone 1 (north)	36.33 7.41	2.89	5.93	6.65	43.74	14.88	26.98
	Zone 2 (west)	36.94 6.45	2.76	5.84	6.71	42.71	11.89	30.04
	Zone 3 (south)	37.13 5.96	4.52	5.51	6.43	41.99	12.45	29.08
	Zone 4 (east)	36.82 6.77	2.97	6.07	6.75	42.95	11.83	29.47
AD	Zone 1 (north)	33.38 2.98	0	0.88	7.64	47.59	12.06	31.81
	Zone 2 (west)	33.87 3.01	0	1.32	8.04	47.13	12.03	31.47
	Zone 3 (south)	34.74 2.91	0.25	4.29	7.51	46.24	11.67	30.03
	Zone 4 (east)	33.71 3.04	0	1.51	8.91	46.65	11.83	31.08
MH	Zone 1 (north)	41.41 15	37.51	7.5	7.21	40.54	7.24	0
	Zone 2 (west)	41.08 15	36.50	6.96	7.77	40.87	7.89	0
	Zone 3 (south)	40.75 14.91	34.41	5.71	8.77	42.40	8.60	0.09
	Zone 4 (east)	41.18 15	36.89	6.88	7.69	36.20	7.22	0

Competing interests
The authors declare that they have no competing interests.

Acknowledgments
The authors acknowledge the University of Bechar for providing support to finalize this paper.

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Authors' contributions
MK and NF carried out the calculation and drafted the manuscript. Both authors read and approved the final manuscript.

Received: 11 February 2012 Accepted: 17 May 2012
Published: 17 May 2012

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doi:10.1186/2251-6832-3-5
Cite this article as: Khoukhi and Fezzioui: **Thermal comfort design of traditional houses in hot dry region of Algeria.** *International Journal of Energy and Environmental Engineering* 2012 **3**:5.