434: CAVE DWELLING IN CHINA CLIMATIC CONDITIONS & MICROCLIMATIC EFFECTS

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Abstract

The loess belt mainly extending along the *Huang He* - Yellow River – has for a long time been a chance for people to cultivate and to inhabit there thanks to the fertility and to the consistency of the soil material. For a long time the large year temperature range has suggested people to carve their housing inside the ground.
Amongst several types, the famous *yao dong* – courtyard one – offers interesting thermo-hygrometry characteristics which make it more inhabitable than surface buildings.
The study of three houses has allowed to compare their performances by respect to the form of the courtyard and to point out the possible works able to improve the inhabitability. It has also saved this vernacular housing from the trend to fill them in and replace them by standard housing energetically greedy and environmentally noxious.
If the seasonal conditions inside this housing remain out of extremes by about 8°C more in winter and less in summer, the living conditions could be largely improved thanks to works of water tightness, insulating and careful behavior of the inhabitants.

Keywords : loess, yao dong - cave dwelling, energy, comfort

1. Introduction

The present energy demand and resource questions in China, the next important rural modernization plan, the nature and the reality of the existing cave dwelling in the Honan Province, and the specificity of this housing, particularly inside the loess areas, all these points of interest interlace to form the matter of this paper, stressing the environmental dimension of these questions.
Carefully respecting the living conditions of farmers and the environment, the cave dwelling faces the next rationalization proposals with anxiety and regret to see the lack of recognition of the high environmental value of this vernacular housing facing the serious present and future problems as regards energy, pollution, economy and comfort.
The will tries to demonstrate that it is possible to preserve the cave dwelling after punctual technical improvements in insulation, water-tightness, ventilation, in the scope of a global re-urbanization concept.
The last International Workshop on Folk-custom, Folk art and Folk Dwelling in the underground villages on the Loess Plateau in Shan County, China, organized by the School of Architecture & Center for Sustainable Towns and Villages in the Zhengzhou University and Oikodrom the Vienna Institute of Urban Sustainability, has gathered several participants from Austria, USA and France with Chinese teachers and students, to make proposals for the preservation and the improvement of the Yao Dong cave dwellings. This paper concerns the architectural part of this program.

2. The loess plateau

Carried by the wind from the Gobi desert for thousand years, the loess settled under the geological structures and covered large areas forming the loess belt mainly situated in the Houang Ho - Yellow River – a loop in the territories of Shaanxi, Shanxi and Honan, but also in Hebei, Ningxia, Inner Mongolia and Gansu (Fig. 1).
The loess offers two main advantages to the people who decided to stay in these places for more than 6 000 years:

- The soil fertility when coupled with rains
- The dry deposit and the water table - deeply buried under the loess layers-

have combined together to give the soil the stability convenient to carve caves

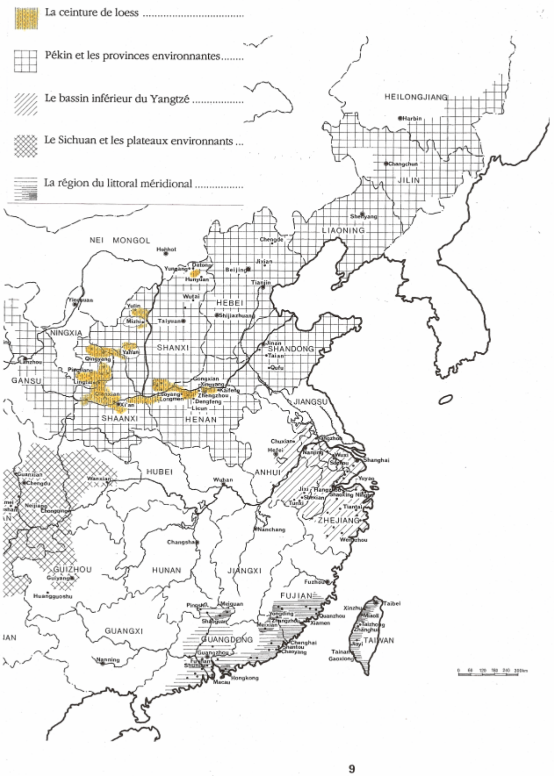

Fig 1. The loess belt and the Huang Ho loop
From "Architectures de Chine" Kang Chang & Werner Blaser [2]

2. Climate and bio-climate

Both influenced by the Siberian anticyclone in winter and by the monsoon in summer, the region is quite dry with cold dry winters and hot summers with few rains.
As observed on the Building Bioclimatic Chart of Xi'an (Fig.2 & 3), the cold dry 5-month winters from November to March, require insulation, inertia, sun radiation and heating.
The hot 5-month season from May to September requires insulation, inertia, ventilation and

SIAN (HSI-AN; SIKING) 34°03'N, 109°01'E 1197 ft 363 m.

Period - Bibliography 21	Temperature: Average daily Max.	Temperature: Average daily Min.	Temperature: Average of highest each month	Temperature: Average of lowest each month	Temperature: Absolute Max.	Temperature: Absolute Min.	Relative humidity: Average of observations at all hours	Precipitation: Average monthly fall	Precipitation: Maximum fall in 24 h	Precipitation: Average No. of days with 0.004 in or more
	°C	°C	degrees Fahrenheit				per cent	inches		
January	40	23	51	12	61	-13	72	0·3	0·2	3
February	46	29	59	17	65	8	69	0·3	0·7	4
March	61	41	80	30	90	22	62	0·7	0·4	5
April	73	52	91	40	100	28	64	1·8	0·9	7
May	83	64	98	52	109	43	64	1·9	1·0	7
June	92	73	103	62	112	57	58	1·8	1·2	7
July	93	78	105	68	115	59	69	3·9	2·3	9
August	91	76	101	66	112	61	79	3·9	2·4	10
September	80	65	93	53	102	32	78	2·3	1·5	10
October	69	54	81	41	100	32	75	1·6	1·5	8
November	56	38	68	28	77	18	76	0·5	0·8	4
December	44	28	54	17	66	1	72	0·3	0·3	3
Year	69	52	107	9	115	-13	70	19·3	2·4	77
No. of years	13	13	13	13	13	13	11	12	4	8

Fig 2. Climatological data of Xi'An

shading.

Two short inter-seasons in April and October require insulation, inertia and sun radiation.

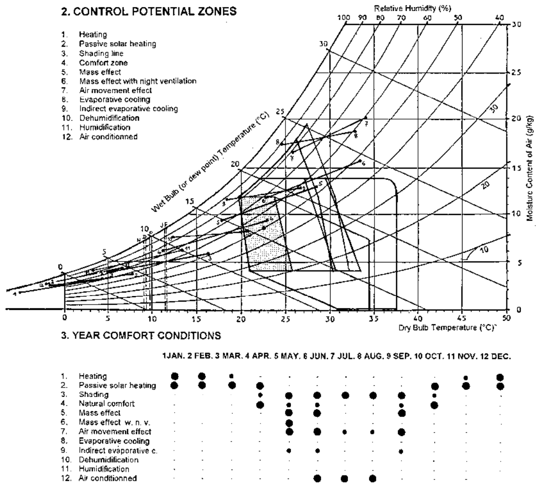

Fig 3. Building Bioclimatic Chart for Xi'An

3. Case studies

Three case studies have been chosen in the village of Miao Shan, close to the city of San Menxia by the Yellow River

Fig 4. Plan of the village Miao Shan

Three cave houses have been selected in the village according to the shape/orientation of the courtyard (Fig. 4) :

- A north-south oriented square (1)
- A north-south oriented rectangle (2)
- A east-west oriented rectangle (3)

This choice was done so as to observe the effect of the shape on the sun radiation results inside the courtyard.

3.1. Case study 1 : square plan

The courtyard has the form of a square longer (10.65 m) than large (8.43 m), with a depth close to 5.20 m.

The rooms are carved inside the sides of the courtyard following an ogive shape, with a key 3.10 m high. The loess above the key vault is 2.10 m thick.

A paulownia tree is planted on the left side of the courtyard and a bush of roses grows in the middle.

The guest room faces the south; the kitchen and the family room are on the east side (Fig 5).

Fig 5. View inside the courtyard of the house 1 & plan

Bioclimatic survey 16 05 08 – 9:00 am, 2:35 pm (Fig. 6)

- The daily range inside the courtyard approaches 10°C & 20% H°, it crosses the comfort zone
- Inside the south facing guest-room it is only 2.1°C & 2% H°, remaining out of the comfort zone all day long, the entrance door remaining closed
- Thanks to the door opened during the day, the north facing room is a little more comfortable with about 4°C & 7% H°
- The range in surface mostly remains out of the comfort zone

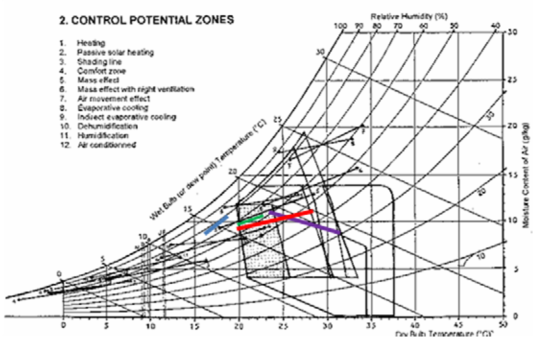

Fig 6. House 1 building bioclimatic chart

3.2. Case study 2: north-south rectangle plan

The courtyard has the form of a rectangle which length (14.77 m) is north-south oriented, with an east-west oriented width (5.50 m) (Fig 7).

The vertical dimensions are the same as in case study 1.

A pear tree is planted exactly in the middle of the narrow courtyard and a paulownia tree grows equidistant from the south-facing facade and the pear tree.

The guest room faces the south; the kitchen and the family room are on the east side.

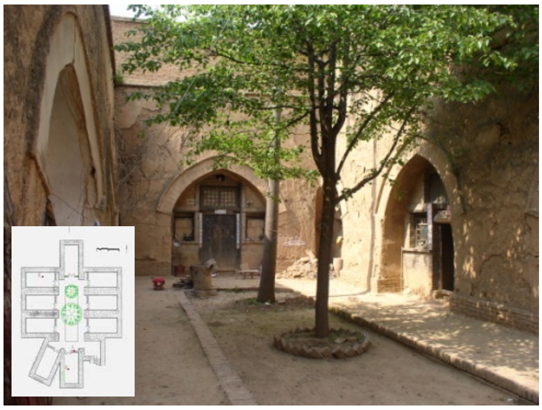

Fig 7. View from the bottom inside the courtyard of the house 2 & plan

Bioclimatic survey 16 05 08 – 6:00 am, 2 :00 pm (Fig 8)

- The daily range inside the courtyard reaches 9.6°C and 38% H°, it crosses the comfort zone
- Inside the west facing room the range is only 1.5°C & 3% H°, remaining out of the comfort zone all day long, the entrance door remaining closed
- The north facing room presents a better range with 2.4°C and 5% HE
- The range in surface remains mostly out of the comfort zone

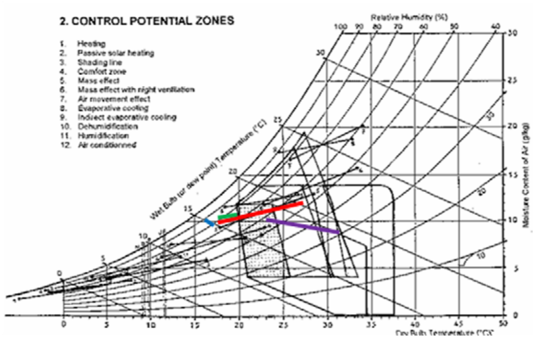

Fig 8. House 2 building bioclimatic chart

3.3. Case study 3 : East-west rectangle plan

The courtyard has the form of a rectangle which length (13.38 m) is east-west oriented, with a north-south oriented width (8.82 m). Its depth is close to 5.40 m.

The vertical dimensions are the same as the previous one with small differences.
Two paulownia trees are planted close to the north side of the courtyard facing the south.
The family room faces the south; the kitchen faces the north and the guest room faces the west (Fig. 9).

Fig. 9 View from the bottom inside the courtyard of the house 3 & plan

Bioclimatic survey – 16 05 08, 6 :00 am, 2 :00 pm (Fig. 10)

- The daily range inside the courtyard reaches 10.5°C & 34% H°, crossing the comfort zone during the day.
- With 3°C and 2% H° range, the family room facing south could be more comfortable if the humidity was lower.
- The room facing west is much less uncomfortable with a 1.5°C and 3% H° range.
- The range in surface remains mostly out of the comfort zone

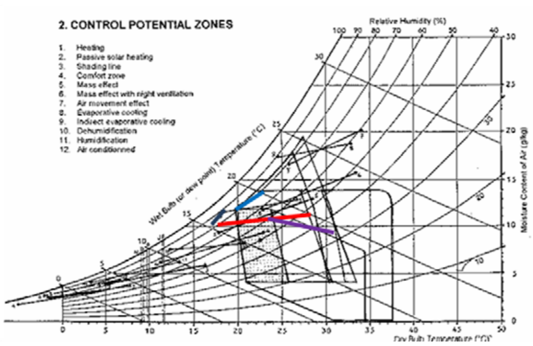

Fig 10. House 2 building bioclimatic chart

3.4. Comparisons

The light thermo-hygrometry measure campaign which was leaded during 24 hours inside the three case study houses has given the following main results (Fig. 11) :

- In all the cases mostly in the morning, the courtyards are cooler than the ground-floor in surface, thanks to the patio and the burying effect,
- The carved courtyards can have a daily range around 10°C, higher than the surface one (8°C) with a higher relative humidity
- The caved rooms T°/H° remain nearly the same all day long
- The squares, large and narrow depending on their width, are successively the hottest and the less hot courtyards
- The closing or opening of the room doors directly influences the inner microclimate of the rooms
- The courtyard of house 1 is the most comfortable
- The south facing rooms remain out of the comfort zone, especially when the door is closed (house 1)
- The north facing room of house 1 gains comfort thanks to the open door

	courtyard	south	North	west
H 1	20 – 28 °C 65 – 45 %	16 - 18 77 – 79	19 – 23 68 – 61	
H 2	17 - 27 83 - 56		17 – 18 79 - 82	16 - 17 86 - 83
H 3	17 - 27 81 - 47	19 - 22 80 – 78		17 - 18 86 - 89

Fig 11. Thermo/hygrometry measures at 6:00 am & 2:00 pm

3.5. Sun radiation inside the courtyards

It varies depending on different parameters:

- The proportions of the courtyard
- The orientation of the courtyard according to the sun
- The depth of the courtyard
- The orientation of the room
- The trees planted inside the courtyard

The comfort conditions stressed in the building bioclimatic chart show for each month when and if the shading (in the hot season) or the sun radiations are required (Fig. 12, 13, 14).

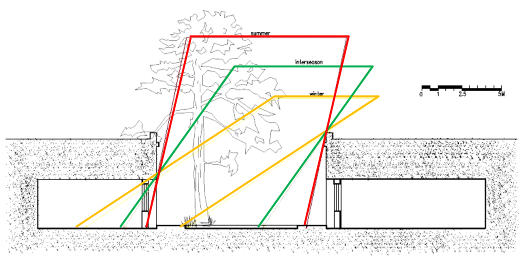

Fig 12. House 1,seasonal sun radiation at noon

The use of caducous leaves trees allows to answer these alternative conditions, either when the tree has lost its leaves or when it has recovered them.

One can observe that in the three cases the depth of the courtyard has no incidence on the sun radiation to the south facing facade

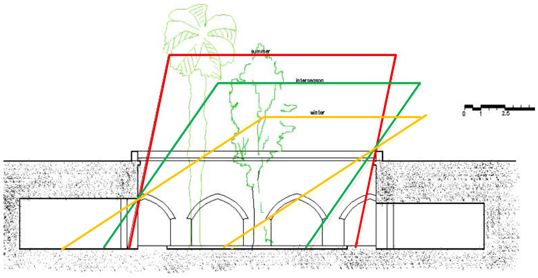

Fig 13 House 2

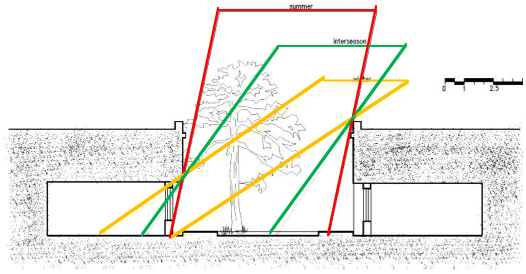

Fig 14 House 3

3.6. General micro-climatic features

- The rooms have a short range near 2-3°C a day
- The courtyards have a long range 8-10°C a day like the outside surface temperature, usually lower than 4-5°C by respect to this last one.
- During the May mid-season one can observe a maximum range of <u>10°C</u> between the courtyard and the rooms.
- In summer the temperature in the courtyard can reach a maximum 38°C and 25°C in the rooms, so a range close to <u>13°C.</u>
- In winter, as the temperature reaches a minimum - 8°C in the courtyard, it is +8°C in the rooms, so a range of <u>16°C.</u>
- The medium range between the courtyard and the caved rooms is stabilized at <u>10 °C.</u>

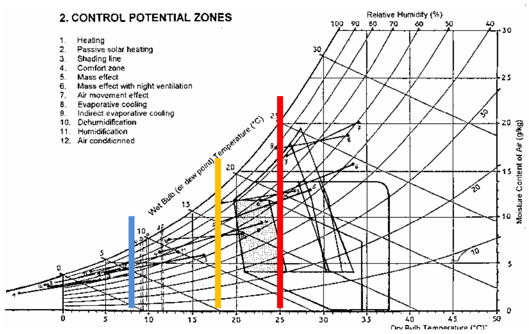

Fig 15. Seasonal limit temperatures inside carved rooms

In the extremes it increases to 16°C in winter and 13°C in summer, due to the inertia of the loess mass to become colder or warmer, as observed during the day time. The total range is 17°C (Fig. 15).

3.7. Impact of the design on the micro-climate

3.7.1. Shape of the courtyard

The winter sun penetration needs a long north-south dimension (Fig. 16)

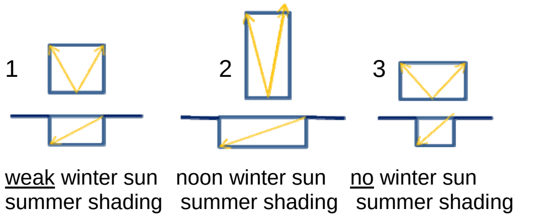

Fig 16 : Sizes of courtyards 1, 2 & 3

3.7.2. Thermal mass

The roof is about 2.20 m thick and the courtyard is between 5.20 and 5.50 m deep.
The time that the ground mass takes to keep the warmth (in summer) or to loss it (in winter) delays the passive cooling and heating of the houses

3.7.3. Tree shading

The position of the tree(s) is important to ensure shading in summer and a correct ambience inside the living rooms when the sun radiation is too strong (Fig. 17)

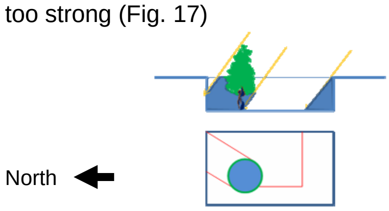

Fig 17. Tree position

4. Conclusion & recommandations

4.1. Improving the terraces water tightness

To protect the loess mass against rain- water, to prevent the absorption of water by the loess mass above and around the carved rooms and to avoid the humidity negative effects and discomfort in winter and during the inter-seasons (Fig. 18).

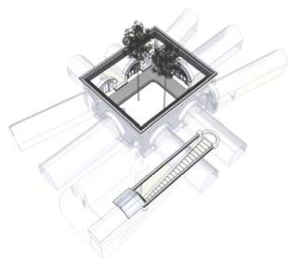

Fig 18. Terraces above carved rooms

4.2. Insulating the facades of the rooms towards the courtyards.

These are the main sources of coldness in winter and of warmth in summer.
Actually the fixed bottom windows (1), the door windows (2) and the impost windows (3) are either paper or single glazing closed ; double glazing is required to limit the heat and cool loss, keeping wooden frames (fig 19).
The brickwork bottom (4) and upper (5) walls are weakly insulated, they require covering joinery frames and inner insulation to prevent thermal bridges. The wooden door panels (6) have also to be insulated to complete the global insulation of the facade.

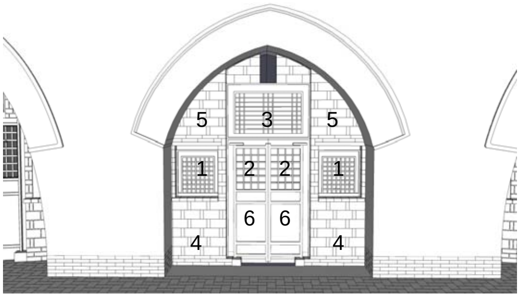

Fig 19. Guest room facade towards the courtyard

4.3. Preferring to live in the south facing rooms in winter and north facing ones in summer

So as to take advantages from sun radiation in the first case & shading in the second one(fig 20).

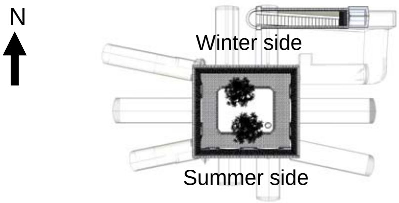

Fig 20. Quadrangle seasonality

4.4. Insuring a constant control of the apertures

Close the doors during extreme seasons, so as to keep inner warmth during winter nights and days and to be protected from the outer warmth during summer daytime, but open the doors at night to

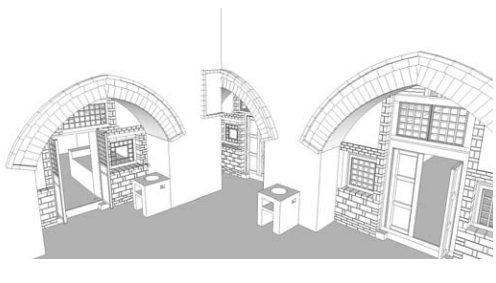

Fig 21. Joinery systems of doors

provide ventilation.
Open doors is possible during inter-seasons and usual summers so as to provide a constant ventilation.
The existing system of outside doors/windows and inner wooden shutters allows many combinations adapted to the season and to the time of the day (fig 21).

4.5. Ventilation

Create a double seasonal ventilation device from the bottom facade to the high back of the rooms so as to promote a cross ventilation through the carved room.
Air inlets are to be created inside the bottom of the doors and air outlets on the back-top of the vault to allow a basic ventilation all year long (small ones) and a summer night ventilation (larger ones) (fig 22)

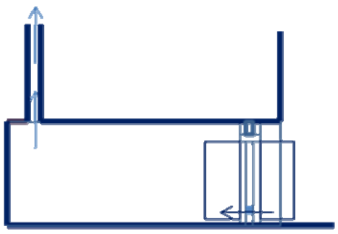

Fig 22. Cross ventilation

5. Acknoledgements

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