Energy efficient rural houses pilot project in Heilongjiang Province of China

Robert Celaire - Concept Energy & Alain Enard - Architect, France

Background and partners

A pilot project of construction of energy efficient rural houses has been carried out and completed in the Northern Manchourian Province, of Heilongjiang, in the People's Republic of China.

This project is a component of the global Sino-French cooperation project on energy efficiency in buildings carried through the years 2000-2009 dealing with various subjects including institutional cooperation and industrial cooperation in energy efficient technologies along with the achievement of a few pilot projects, mostly in urban areas except for the project described here-after.

The cooperation partners of this energy efficient rural houses component have been:

- On the Chinese side, the Construction Commission of the Province of Heilongjiang, working with regional and village authorities; design and construction teams and with the Harbin Institute of Technology (HIT);
- On the French side, the FFEM (Fonds Français pour l'Environnement Mondial) or French Global Environment Facility as a donor agency with ADEME (Agence de l'Environnement et de la Maîtrise de l'Energie) or French Agency for Environment and Energy Efficiency as the project pilot with significant and well appreciated local support of the AFD (Agence Française de Développement) or French Development Agency.

The authors have been in charge of providing technical assistance to project including "hands-on" training to Chinese partners for project design and implementation. This work has been achieved through a large number of multi-years short-term field missions and distance backup advising. Their work has also lead to writing a small design assistance manual.

1. Project context and environment

1.1 Project location and climate

The Heilongjiang (Black Dragon) Province of China is located at the northeastern tip of China (between 44° and 54° North latitude) along the Russian border of Eastern Siberia. It covers a surface area of 445 000 km2. It experiences an extremely harsh climate with long cold freezing winters and short hot summers. This climate features:

- Huge yearly temperature amplitude (79℃ in Lindian county where this project started near Daqing- in 1980 between January min and June max)
- Average yearly temperature below +5℃
- Average January temperature from -18℃ to - 25℃
- Typical yearly 18℃ degree-days from 6000 to 7000
- Fairly dry climate - 430 mm of yearly rainfall in southern HLJ plain area
- High sunshine availability
- Winter North cold wind

- Short hot summer - average July 22℃

1.2 Current situation of rural housing in Heilongjiang

Rural housing typology

The total population of Heilongjiang (2006) is 38,2 millions people amongst which farmer's population (2006) is 17,9 millions (47%). Farmers live in 440 millions m2 of rural houses featuring:

- About 34% adobe brick walls with adobe & straw roof houses;
- Over 60% clay brick houses that tend to be replaced by progressively mud brick houses. They use tile roofs or more commonly metal tin roofs;
- A minority (few percent) other techniques use modern components or traditional methods (wooden-log walls covered with mud for instance in a few mountain areas). Amongst these houses only a small minority purposely include some energy efficiency designs (like a few straw bale houses).

Typical cost of clay houses are in the range of 60,000 to 80,000 Yuan (roughly 6000 to 8000 Euros)

Rural houses and energy efficiency

Main aspects of "modern" clay brick houses (and also of many old mud brick houses whenever possible) related to energy efficiency are the following:

- Favorable winter sun collecting because of southern orientation;
- Fairly good layout with respect to energy efficiency and passive solar design, with living space and kitchen in southern part of the house; storage and secondary spaces in the northern part ;
- large southern double windows allowing to collect large amount of abundant winter sunlight bringing comfort and covering a very significant part of the heating load of the households;
- Attic filled with insulating material limiting heat losses which is one of the main energy escape routes in a house. Insulating materials being wood chips, sawdust, straw, etc;
- Some houses have an air lock on entrance door.

However most clay houses that are being built at the moment also feature some energy inefficient aspects such as:

- no wall insulation even though some of the houses use double wall with air cavity in between (in these cases the cavity is very seldom filled with some insulation);
- no floor insulation whatsoever leading to high discomfort (the "cold feet syndrome");
- no specific treatment of thermal bridges in construction;
- trend of using metal-plastic double-glazing, single windows which are less energy efficient than locally made single (or double) glazing double windows; that also used to be supplemented by an additional plastic film mounted for the winter;
- Large northern windows. Farmers like these large windows no matter what the orientation is, to let in light during the day-time, but these components are large energy losers in winter. In the "modern" clay brick houses there is a very little difference in window sizes whether these are on the Southern or Northern part of the house;
- no night-time movable efficient insulation is used to decrease heat losses from windows: no shutters, no thick and tight curtains or any other movable insulations are being used;
- last, but not least, there is no ventilation control in the house leading either to access the ventilation to allow proper combustion of stove (this access ventilation leading

itself to large heat losses and air streams, which is bad for thermal comfort of inhabitants) and/or plus the insufficient ventilation leading to very poor air quality in the houses, in some cases, to dangerous building up of CO due to incomplete combustion of coal.

Heating systems and heating fuels

Most houses use brick heating bed (and a few houses heating walls operating in the same way) or "*Khang*" heated by exhaust smoke from cooking stove located in the northern kitchen. The smoke is channeled through brick cavities located underneath these brick beds. This hot smoke progressively heats up this high mass of bed on which people sit in the daytime and sleep at night.

The stove is usually fired three times a day in winter so *khang* is irregularly heated up but its high thermal mass keep the house warm most of the day. Some houses have two *khangs*.

Some houses also use locally made metallic coal boilers connected to conventional thermo-siphon radiators system.

The heating fuels used are:

- Crop residues (straw, stems, small branches, corn stalks, etc) used mostly in the stoves at the beginning of the season and as long as they are available ;
- Wood collected form areas where ever available and is legal (mostly in mountain forest areas of Western Heilongjiang);
- Low quality coal (lignite with a low heat value of the order of 5500 Wh/kg – values provided by former HIT professor) which is used along with crop residues.

1.3 Social, economical and environmental impacts of energy inefficient housing

The main impacts of this inefficient housing are the following:

- Houses experience very poor thermal comfort conditions in winters: typically 4℃ to 12℃ in the middle of winter in main rooms and in some houses the morning temperatures being much lower;
- Houses also experience poor air quality due to inadequate ventilation (death due to CO poisoning being reported)
- High portion of farmers' budget is spent on coal purchase: typically 10% to 20% of income can be spent on buying fuel while coal prices have soared from 200 Yuans/ton to 400 Yuans/ton in the last few years.

In this respect it is interesting to point out that a large scale of surveys on energy uses that have been carried out in various areas of Heilongjiang showed that coal (lignite) consumption for houses of the same typology can range from 2 tons/year to 10 tons/year. Heat load calculations have showed that 10 tons/year would be the order of magnitude of heating consumption if houses were maintained at good comfort temperatures (in the range of 15℃ or 16℃): this means that when people cannot afford to spend more on coal they just have much poorer comfort conditions.

So typically poor farmers with income lower than 5000 Yuan/year will buy for instance 2 tons of coal/year (16% of family budget), while richer families who earn 20000 Yuan/year can buy for instance 6 tons/year (12% of family budget). Families have to be fairly rich to be able to afford the amount of coal they would need to experience comfort through the whole heating season.

One of the social consequences of these harsh living conditions is the large rural exodus of farmer families to urban areas at the moment when job offers are on a decline.

Last but not least, consequence of this situation is the environmental impact of lignite consumption, which is huge with an average of 5 tons/year of CO_2 emission for a typical house burning 3 tons coal yearly.

2. Project context

2.1 Project context and objectives

In spite of official decisions from the Chinese authorities to prioritize the development of rural areas in the future, the perspective of quick improvement of living conditions in terms of thermal comfort and sub-consequent coal consumption reduction in rural areas of Heilongjiang is limited.

The road of energy efficiency in the rural housing sector does not seem to be open yet. To give a relevant example, while energy efficiency standards exist for urban housing (being enforced only in a very small fraction of cases only) they do not apply to rural housing.

In the mean time very few and isolated actions of energy efficiency project on rural houses exist and they are not coordinated.

In this respect the FFEM/ADEME project goals were:

- to demonstrate energy saving impacts of improved energy efficiency designs (minimum objective was 50% reduction of coal consumption);
- *to demonstrate comfort impacts of improved energy efficiency designs;*
- maintaining incremental construction costs to minimum while demonstrating the improved energy efficient designs;
- making use of components and technologies readily available in the Chinese market ;
- to transfer energy efficiency design know-how to local professionals and facilitate energy efficiency features acceptance by users;
- to provide inputs to HLJ Province Department of Construction to plan the promotion of energy efficient rural housing.

2.2 Pilot project content

The two stages of pilot project of energy efficiency improvement of Heilongjiang house design consisted in working with a local design teams to tackle the various issues of inefficient designs mentioned above while enhancing the positive aspects of traditional construction.

First step of the project lead to the construction of four pilot energy-efficient houses in Shengli village, of Daqing district, during the period of 2003-2005.

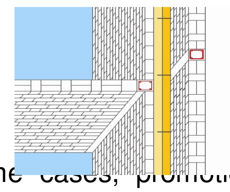
The second step lead to the construction of approximately 40 houses, amongst which 20 have been supported by the FFEM project, in the Heihe district during the years 2005-2007.

Hands-on training has been provided through the first step of the project while short-term monitoring of temperatures and fuel consumption has been carried for both project components.

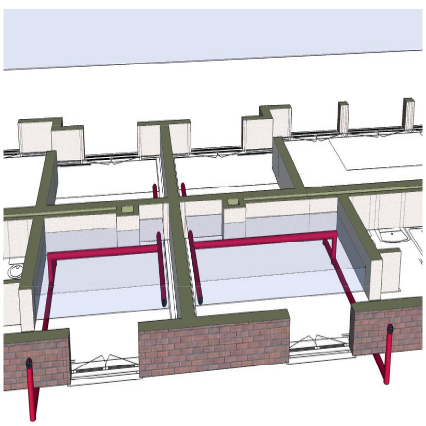
The non-exhaustive list of following designs, components and systems have been implemented through the various steps of the project (table below concern the houses 1,2 and 4 of the first stage of the project while houses 5,6 and 7 are base cases)

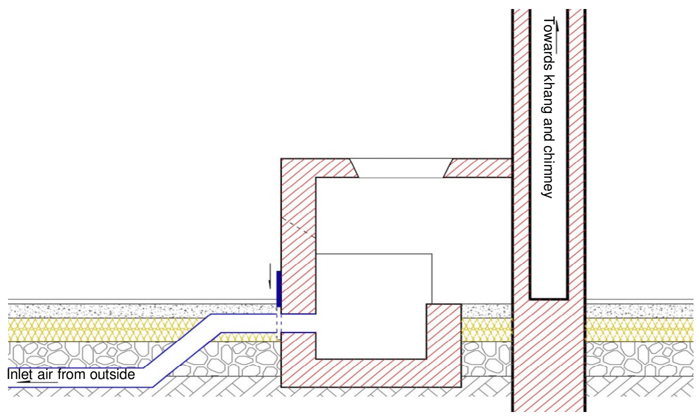
	Walls	Roof	Floor	Window	Ventil for Stove.
House 1 and 2	28 cm straw pannels	40 cm wood chips	80 mm EPS	Double plastic w/ curtains	Y
House 4	14 cm straw pannesl	Same as 1	80 mm EPS	Same as 1	Y
House 5	14 cm straw panels	Same as 1	N	Same as 1	Y
House 6 and 7	Double brick wall	Wood chips	N	Double wood	N

- wall insulation using various insulation materials (straw panels, EPS, etc)
- increase in ceiling insulation levels;
- floor insulation using mostly EPS;
- work on thermal bridge treatment with field training (During first stage of project in Shengli village)



- improved window design including the window size Decrease in northern rooms, triple glazing windows in some cases, promotion of night insulation shutters;
- improvement of inlet ventilation for stove combustion and trials of fresh hygienic air inlet in the main rooms through *khang* preheating;





2.3 Project monitoring results

• Lindian county, Daqing district houses

Site: Shengli village, Lindian county – 3 energy efficient houses (out of 4 built) plus 3 base cases have been monitored.

The monitoring campaign (March 2004) was achieved by the local team with specifications and guidance from the authors. The campaign measures were:

- Ambient temperatures
- Wood, straw and coal consumption with manual scale

The tables below show the result of monitoring which testify that energy consumption per temperature difference (Wh/DD) were 2 to 4 times lesser for the energy saving houses than for the base cases. In addition to this, the first sample of energy efficient houses has been built with only 3 to 12 % incremental costs when compared. In the mean time, even though exhaustive multi-questions survey has not been accomplished, satisfaction from users has shown to be high:

- we don't have cold feet anymore said one of the users
- in one of the most insulated houses (house2) the lady owner went through the whole first winter by using only crop residues and without having to buy any coal which lead to tremendous savings.

	Average	Straw	Coal	Gas	Total consum.	Wh/DD-m2
	°C	kg	kg	m3	kWh	
House 1	8,5	156	10,5		604	15
House 2	10,0	373	0,0		1306	29
House 4	11,3	343	103		1767	35
House 5	10,2	716	99		3051	65
House 6	12,4		275	185	3733	76
House 7	15,1	489	266		3175	78

Houses	Surface area (m2)	Cost (Yuans /m2) (*)	Increment costs (%) w/r to 5
1 and 2	124	870	12
3 and 4	124	800	3
5	124	780	0
6	112	500 (1990)	- 35
7	79	500 (1990)	- 35

• Heihe district houses:

Forestry villages of Daling, Daping, Sandaogou
Monitoring campaign (January 5th through 29th, 2006) of 4 houses with simultaneous measurements on one old house nearby used as reference case (but temperatures have not been measured in the last one).
The monitoring dealt with:

- Heat transfer through the walls (U value measurement);
- ambient temperatures;
- Measurement of wood, straw and coal consumption/

The table below reports monitoring for three houses - two energy efficient and one conventional, and the figures show once again that energy efficient houses use 2 to 4 times less fuel than the conventional ones.

Even though temperatures could not be monitored in the old house we know from experience that during such cold periods average temperatures are rather below than 10°C in such old houses, thus difference of energy consumption per degree per day between energy efficient and base case would have been even greater. Satisfactions from users have been reported well and good by Heihe construction team but we could not verify this information by ourselves. In the mean time, incremental costs when compared to base case conventional houses for construction of this second set of energy efficient houses has been very high and not significant (over 50%) due to many reasons including difficulties in using local materials for insulation and high unit costs for components

Monitoring of rural houses in Heihe Region				
		Sandaogou new house	Daping new house	Sandaogou old
Surface area of house m2		82	84	80
House main orientation : South, East , etc..		South	South	South
Family living in house : YES or NO		N	Y	Y
What heating systems		Khang, heat.wall, radia	Khang, heating wall	Khang, heat wall, radia
How many times a day fuel is fed in stove		many times	many times	many times
Monitor period : 1st and last days in January		Janu 5-Janu29 2006	Janu 5-Janu29 2006	Janu 5-Janu29 2006
Weather during monitoring		sunny	sunny	sunny
Average wood consumption/day			23,88	
Average straw consumption/day		22,6		48,56
Average coal consumption/day		13,44		35,52
Total en consumption kWh/day (*)		145,75	83,58	351,70
Average consumption kWh/m2-day		1,78	1,00	4,40
Average external temp during monitoring		-20,76	-20,76	-20,76
Description insulation wall		12 cm EPS	18 cm EPS	490 mm brick
Description insulation roof		12 cm EPS+30cm wood	18 cm EPS+30cm w	30 cm wood
Description insulation floor		10 cm EPS	12 cm EPS	no insulation
Description windows		double plastic	triple plastic	double wood
Monit mini in South living room		3,5	6,8	
Monit average temperature in south living		12,6	16,5	
Monit average temperature in north kitchen		11,1	17	
Monitored average temperature in North bedroom		11,9		
Monitored average temperature in North toilet		7,2		
Monitored average temperature in south bedrom			7,2	
Average temperature in all rooms		10,7	13,6	
Average temperature in main rooms: living +bedroom		12,3	11,9	
(*) Asumptions : 3,5 kWh/kg for wood, 3,0 kWh/kg for straw and 5,8/kg for coal				

3. Conclusion and perspectives

3.1 Lessons learned

This modest pilot project of energy efficient rural houses in the very cold Province of Heilongjiang has showed:

- Potential fuel reduction factors in energy efficient houses of roughly 2 to 4 times when compared to conventional houses, that can lead, in some cases, to the exclusive use of renewable fuels (crop residue) with subsequent substantial savings extremely significant for low income families;
- Comfort improvement with increased average temperatures in the houses .We can even certainly say that, up to a certain extent, part of fuel savings have been "spent" on increased comfort;
- Farmers satisfaction (surveys achieved in the first stage of project in Shengli show it);
- Energy efficient housing can be cost effective, with incremental costs in the range of 10% and very short paybacks due to fuel savings, provided enough detailed design work with the local teams and appropriate follow up during construction can be done (including "hands-on" training, for instance, for thermal bridge avoidance or ventilation implementation). This kind of work could be done during the first stage of project (the 4 houses in Shengli), which enhanced the use of local materials and detailed work with local teams leading to building up trust and a spirit of "working together". It could not be replicated in the second stage of project in Heihe area where the project had been much more spread out and the real exchange work on designs between Chinese partners and French experts has been limited and possibilities of following up construction extremely difficult.

3.2 The long road for developing a culture of energy efficiency

This project created great expectation from local farmers, local teams and authorities for scaling up the development of energy efficient and more comfortable rural houses in northern China

However “bottle necks” are numerous and include the non-exhaustive following list of:

•Political and economical constraints:

- the fact that no energy efficiency standards exist for rural houses while they exist for urban buildings so there cannot be some kind of regulatory push;
- the fact that people have to pay for their fuel in rural areas while in the cities they pay directly only 10% of energy cost (around 3 to 4 Yuans/m2) for heating, the rest being covered but their employer which can be itself subsidized;
- there are no subsidies from central or provincial governments for energy efficient housing and only a few local initiatives exist to subsidize energy efficient rural houses;
- there are no organized financial policies that could allow short and mid-term loans for energy efficient designs.

• Technical difficulties linked to the lack of know-how, availability of affordable materials and components, etc.

•Sociological difficulties linked to the acceptance of some essential energy efficiency options to which people are not used e.g., ventilation systems, use of efficient nighttime insulation on windows, etc.

However the challenge is huge and it is a win-win-win one:

-Environmentally: over one million rural houses built yearly in Northern China and there is a (conservative) potential of 1.5 tons of coal saving for each of them, knowing that all Northern provinces of China are concerned: Jilin, Liaoning, Inner Mongolia, etc adding up to the rural population of over 100 million. And this is not to mention other very cold regions of China which are the Western Provinces which also experience harsh climates and where similar actions could be implemented.

-Socially: better comfort conditions can prevent rural exodus from the cold Chinese rural areas to cities;

-Economically: at the level of farmers, local and global level coal saving is good for families’ budgets; local economy and national economy.

So we suggest that this situation is tackled by huge and long-term efforts to establish:

- consistent regulatory and financial policies supporting energy efficient rural housing;
- appropriate technical policies : training, research, etc;
- awareness policies: information action of various key actors about the benefits of energy efficient designs;
- long term field demonstration projects formatted like the first stage of FFEM / HLJ Province project in Shengli.

For instance setting up a typical 1000 energy efficient house projects in Lindian county featuring, at an experimental level, the various regulatory, financial and technical policies listed above would be a good way to expand the very promising efforts started in Lindian county and learn lessons for quick up scaling efforts at Provincial level.

Preliminary terms of reference of such a project will be developed and submitted to French and Chinese authorities by the authors.

4. Acknowledgements

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