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Is it necessary to build airtight and to use heat recovery in order to achieve the energy efficiency of passive-energy building standard?

Essay on computer simulation

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Chapter 1

Introduction

Buildings account today for about 40% of the final energy consumption of the European Union, with a large energy saving potential of 22% in the short term (up to 2010) (Eicker,2002). Under the Kyoto protocol, the European Union has committed itself to reducing the emission of greenhouse gases by 8% in 2012 compared to the level in 1990. Buildings have a major role to play in achieving this goal.

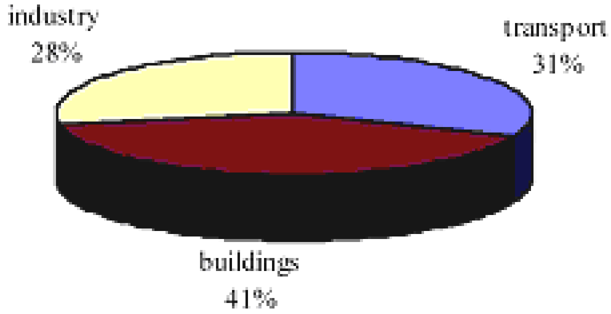

Figure 1.1: Distribution of energy consumption within the European Union with a total value of 10^{12} MWh per year (Eicker,2002).

1.1 Overview

In the last hundred years architecture has become increasingly scientific. New buildings are usually built to contain complicated, energy consuming technologies that enable them to maintain a comfortable interior environment under all ambient circumstances. Living and working in those artificial enclosures, people become detached from nature to such an extent that they forget to consider the sustainability[1] of their way of life. Recent progress in European governmental policy regarding environmentally appropriate lifestyles has awakened the issue of sustainability in the public consciousness. Building from local sources, using traditional methods, is becoming important again. This trend, in which tradition is supported by science, is further developed using computer technology. May this essay serve as an example.

To achieve or even approach the goal of sustainability, consumption must be reduced dramatically. The challenge is to minimize energy use during construction and ideally, bring the energy consumption of the home to zero.

1.2 Passive house standard

Since the oil crisis of the 1970's, the heating energy requirement, particularly of new buildings, has continuously fallen. If existing building standards are improved to meet the passive building standard, heating energy consumption can be lowered to less than 20 kWh/m^2 per annum.

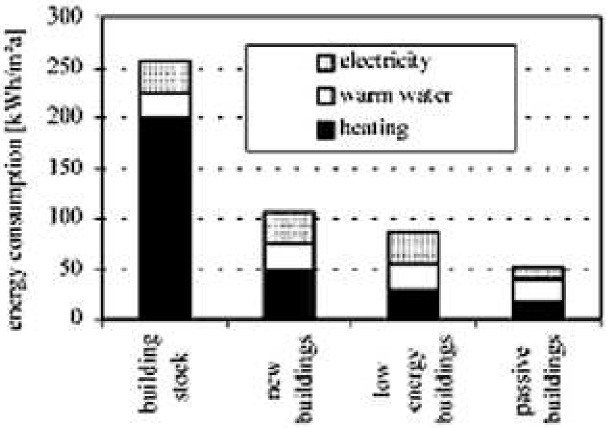

Figure 1.2: Energy consumption in residential buildings per square metre of heated floor space in Germany (Eicker, 2002).

The passive house has barely any need for heating, if properly managed. Its superinsulated, tight envelope insures that interior air warms up merely by the presence of people, electrical appliances and passive solar energy gain. Triple glazing and new window technologies enable the window to be a passive solar element and at the same time cause only low transmission heat losses. Common engineering practice indicates that a vital condition for achieving the passive

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[1] Sustainable means to use and replenish the earth's resources in a way that doesn't deplete the supplies.

house standard is an efficient, controlled form of ventilation with heat recovery (Voss, 2005).

Heat recovery means that polluted interior air is replaced by fresh air via a heat exchanger, where exiting interior air gives almost all of its heat energy to incoming exterior air over large area of thin conductive material that separates them. In order to work properly, heat recovery systems require air tightness. Heat recovery stops being efficient when doors or windows are left open, as the heat energy of the interior air is then dissipated and needs to be recreated. Therefore, additional heating for these houses is necessary. Heat recovery systems are expensive, and the mechanical ventilation connected to the heat exchanger needs electricity.

1.3 Questions

By using the IES Virtual Environment software[2], this paper will answer the following questions:

> *Is it possible to achieve the passive-energy building standard through design, using natural, ordinary and inexpensive materials, without heat recovery and without particular care about air tightness?*
>
> *Can the heat distribution of the house be effectively achieved by natural ventilation, by opening the windows?*

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[2] *Integrated Environmental Solutions Limited 2004 - Virtual Environment, VE Version 5.2.1, ¡http://www.iesve.com¿

Chapter 2

Software

2.1 IES package

IES Virtual Environment has all the elements necessary to create and assess a building design in terms of energy use. It provides assessments of natural and artificial lighting, air conditioning, natural ventilation, aerodynamics, heating, water, cost, evacuation, electric installations, life cycle analysis and more. With its rendering tool, IES can be used to create realistic snapshots of the modeled building.

In this paper, three parts of IES were utilized to design a family house based on its thermal performance:

- ModelIT - Building Modeler
- MacroFlo - Multi Zone Air Movement
- Apache - Thermal Calculation and Simulation Software

2.1.1 ModelIT

The primary idea (see chapter 4) was sketched in the form of a basic floor plan in ModelIT, a CAD program within IES. ModelIT allows the rapid execution of a simple three-dimensional model. It asks the positions of the openings (doors, windows and holes) in the walls, floor and ceiling for each room. The rooms' geometry can be easily modified and if necessary, divided with partitions.

2.1.2 MacroFlo

MacroFlo comes into play when designing natural ventilation through windows. It considers the percentage of window opening, the level of air tightness (the infiltration through the cracks around windows) and window position in terms of vulnerability to wind pressure. The regime of window ventilation can be also specified, either based on a time schedule or on variables such as: threshold temperature, room moisture content, solar gain to room and carbon dioxide room concentration. Variables could be arranged to respect a time schedule, which could be set to vary within a day, week or a whole year.

2.1.3 Apache

What influences the thermal performance of the house?

- The local weather conditions.
- The insulation quality of the building envelope including windows and main door.
- The mass of all materials in the interior and its ability to store heat.
- The window area and its exposure to the sun.
- The infiltration through all possible cracks in the envelope.
- The mechanical or natural ventilation.
- The heat dissipated to an interior by inhabitants and electrical appliances.
- The choice of a heating / cooling system.

Once the figures related to above mentioned items are in its database, Apache performs a complex simulation. The thermal performance can be calculated for any period of time during one year and the calculation can be linked with MacroFlo (to include natural ventilation through windows) and with Suncast - Solar Shading Analysis (to include the effect of mutual surface shading on sunny days).

2.1.4 Vista - Results analysis

Vista is IES software that arranges the results of Apache thermal simulation into tables and graphs. The graphs show the development of a parameter on a time line. It can be viewed in detail in short time periods or over the whole simulation. For the results presented in tables, Vista offers three choices:

- One table gives a summary over each month and over the whole simulation period.
- Another option is to view the minimal, maximal and mean values of the desired parameter over the simulation time.
- Especially useful is the opportunity to follow the number of hours that a parameter reaches a certain limit (for an assessment of overheating for example, the matter of interest is the amount of time that the room temperature is raised over 25 degrees Celsius).

Chapter 3

Model

3.1 Materials and construction

The materials of the modeled house are exclusively from renewable sources. Their local availability was taken into account in order to minimize the embodied energy associated with transportation. Another aspect that influenced the choice of materials was their simplicity of use. The house should be easy to build for a moderately experienced self builder.

Though the model assessed by the computer simulation is simplified, it is useful to consider the construction in fairly great detail. This helps to assure that the simplification leads to as accurate results as possible. (The schema of two story load bearing straw bale structure used in the model is presented in Appendix 2.)

3.1.1 Ground floor and foundations

The main floor area was modeled as a suspended floor with 350mm thick straw bale insulation. The house is lifted from the ground. A structural horizontal timber frame supports the ground floor and the load bearing straw bale walls. It sits on piers of a recycled tire foundation (See Appendix 2 and 3). The tires are filled with rammed gravel and are placed on a rammed gravel bed.

Foundations were omitted from the modeling because they don't influence the thermal performance.

3.1.2 Ceiling and roof construction

The first floor structure is made of timber joists connected to a wall plate on top of load bearing straw bale walls. Above the wall plate, load bearing straw bales continue all the way up to the roof level. The roof plate crowns the walls, holds them in place and distributes the load of the roof evenly onto the walls. The roof consists of ceiling panels, timber joists, straw bale (350mm thick) thermal insulation with 30mm layer of clay plaster on top, ventilated air gap, timber decking, waterproof membrane and an extensive green roof.

The box-like spaces inside the wall and roof plates are tightly filled in with loose straw (see Appendix 2 and 5); therefore the insulation properties of a modeled wall are considered to be constant over the whole height of the building.

The roof assembly above the ventilated air gap wasn't considered in the modeling, because the layers above the air gap don't influence the roof's thermal performance.

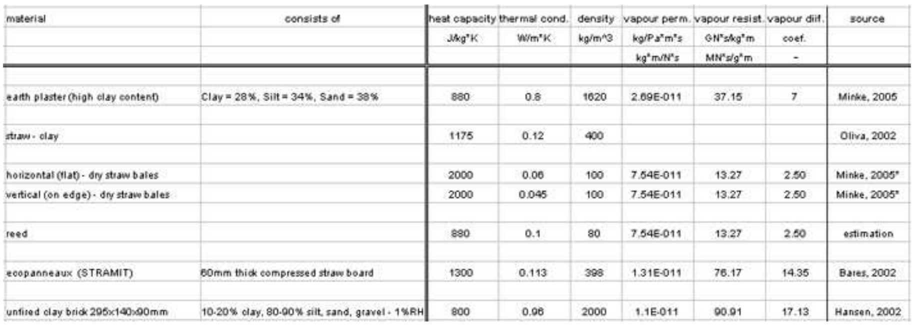
3.1.3 Walls

The walls are earth plastered load bearing straw bales. The overall thickness is 520mm. In order to protect the external earth plaster from driving rain, and the straw from a moisture problem, the second story of the wall is provided with a 600mm thick reed coating, similar to thatch. In this way the earth plastered wall under it (the first floor level) is given a necessary protective overhang. (See Appendix 5)

3.1.4 Material properties

The earth and timber is thought to be local.

The material properties were either taken from IES system database or from table 3.1 .



material	consists of	heat capacity	thermal cond.	density	vapour perm.	vapour resist.	vapour dif.	source
		J/kg*K	W/m*K	kg/m^3	kg/Pa*m*s	GN*s/kg*m	coef.	
					kg*m/N*s	MN*s/g*m	-	
earth plaster (high clay content)	Clay = 28%, Silt = 34%, Sand = 38%	880	0.8	1620	2.69E-011	37.15	7	Minke, 2005
straw - clay		1175	0.12	400				Oliva, 2002
horizontal (flat) - dry straw bales		2000	0.06	100	7.54E-011	13.27	2.50	Minke, 2005*
vertical (on edge) - dry straw bales		2000	0.045	100	7.54E-011	13.27	2.50	Minke, 2005*
reed		880	0.1	80	7.54E-011	13.27	2.50	estimation
ecopanneaux (STRAMIT)	60mm thick compressed straw board	1300	0.113	398	1.31E-011	76.17	14.35	Bares, 2002
unfired clay brick 295x140x90mm	10-20% clay, 80-90% silt, sand, gravel - 1%RH	800	0.96	2000	1.1E-011	90.91	17.13	Hansen, 2002

Table 3.1: Tables of project constructions are provided in Appendix 6.

3.2 Weather data

The data representing Prague's (Czech Republic) local weather conditions were taken from Apache database.

3.3 Others

Chapter 5 introduces more variables, especially the ones that were modified for thermal performance optimization.

Chapter 4

Primary idea

The conservatory creates a courtyard open to the south side. The courtyard is an intermediate buffer between the main interior space and ambient environment.

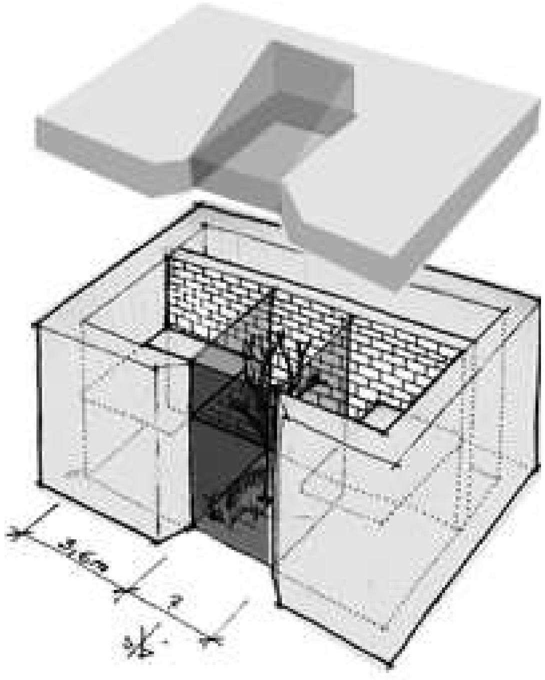


Figure 4.1: Primary idea consists of an integrated conservatory into the rectangular building plan. The question is: *How wide the conservatory should be in order to insure ideal thermal performance?* Note how the second floor stands back from the glazing, so that the sunshine through the roof can penetrate deep into the first floor inerior (see also fig. 5.6).

All the internal glazing faces the courtyard in order to minimize heat loss through the windows. To achieve a sufficient level of daylight, the adjacent rooms are not deeper than 3.6m and the walls facing the courtyard are fully glazed.

Despite the modest volume of its rooms, the interior has an airy and sunny feeling to it. The views expand over the central courtyard joining the space over the whole width of the house together visually.

The back courtyard wall is solid. This heavy partition divides heated living space and unheated service space. It runs the whole width of the house and is made of unfired clay brick to give the lightweight building a sufficient thermal mass. It's ability to buffer summer overheating is scrutinized by simulation in the first part of following chapter.

Chapter 5

Simulation

The simulation was done in two phases. In the first phase four modifications of the primary idea were tested for their thermal performance. In the second phase the most successful modification was developed into a family house with the lowest possible heating energy demand.

5.1 Assessment

The thermal performance was assessed by calculating:

- The amount of energy needed to heat the building to 19 degrees Celsius (the interior temperature set by Apache as default) over the course of one year.
- The number of hours annually that the modeled rooms overheated over 25 degrees Celsius.

5.2 First simulation phase

5.2.1 Questions

> *What is the optimal width of the conservatory to allow sufficient passive solar gain, while avoiding heat loss through its glass?*
>
> *How thick needs the heavy weight partition be to prevent the overheating of interior spaces?*

5.2.2 Variables

The glass facing outside environment from the conservatory is an ordinary double glass selected from the Apache database as ”double glazing domestic” with U = 2.8 W/m^{2}K. The glazing between the conservatory and interior also comes from the Apache database. It is a "low-e double glazing (2002 regs)" with U = 1.95 W/m^2K. The conservatory floor is created by a layer of large stones. Unlike the suspended floor of the rest of a building, the conservatory floor is connected with the ground. The layer of stones is 900mm deep. It gives thermal mass in order to prevent the overheating of the conservatory during summer. The conservatory is neither cooled nor heated. It is classified by Apache as an "unheated separated dwelling conservatory".

The two adjacent rooms were modeled with a thermostat attached to a heater, to insure that the interior temperature wouldn't drop below 19 degrees Celsius in a course of a year. The cooling profile was switched off, so in the summer, the temperature is expected to be quite high due to direct solar radiation.

5.2.3 Simulation I.

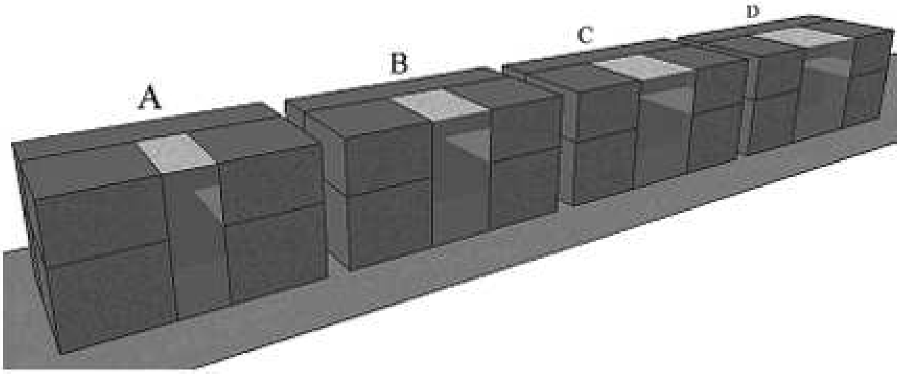


Figure 5.1: The four modifications of the primary idea A,B,C,D were tested simultaneously. From ModelIT

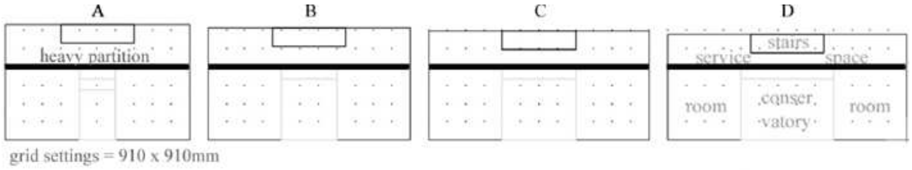
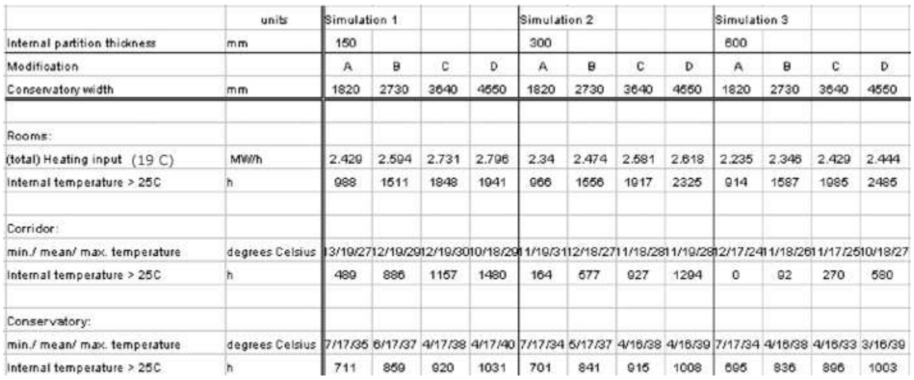


Figure 5.2: Four modifications - floor plans. Service space has in all cases the same volume.

The orientation is the same in each case. The volumes of interior rooms are unchanged; however, the percentage of glazing to outside varies and thus the whole conservatory is of varying widths.

5.2.4 Results

Heating energy demand



	units	Simulation 1				Simulation 2				Simulation 3			
Internal partition thickness	mm	150				300				600			
Modification		A	B	C	D	A	B	C	D	A	B	C	D
Conservatory width	mm	1820	2730	3640	4550	1820	2730	3640	4550	1820	2730	3640	4550
Rooms:													
(total) Heating input (19 C)	MWh	2.429	2.594	2.731	2.796	2.34	2.474	2.581	2.618	2.235	2.346	2.429	2.444
Internal temperature > 25C	h	988	1511	1848	1941	966	1556	1917	2325	914	1587	1985	2485
Corridor:													
min./ mean/ max. temperature	degrees Celsius	13/19/27	12/19/29	12/19/30	10/18/29	11/19/31	12/18/27	11/18/28	11/19/28	12/17/24	11/18/26	11/17/25	10/18/27
Internal temperature > 25C	h	489	886	1157	1480	164	677	927	1294	0	92	270	580
Conservatory:													
min./ mean/ max. temperature	degrees Celsius	7/17/35	6/17/37	4/17/38	4/17/40	7/17/34	5/17/37	4/16/38	4/16/39	7/17/34	4/16/38	4/16/33	3/16/39
Internal temperature > 25C	h	711	859	920	1031	701	841	916	1008	695	836	896	1003

Table 5.1: Parameters and a summary of results for all four models with different partition thickness over one year.

Figure 5.3 shows that the annual heating energy demand of living quarters adjacent to the conservatory increases from case A to case D. This indicates that when the conservatory is larger, more heating is required to maintain the temperature of 19 degrees Celsius in the rooms adjacent to conservatory. The rate of the increasing energy demand of adjacent rooms slows with increasing conservatory width.

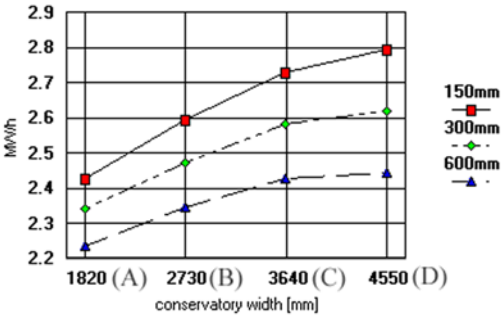


Figure 5.3: Annual heating demand of living quarters for varying conservatory width and different partition thickness.

If one compares the minimal temperature profiles in the interior of the different-sized conservatories (see the table 5.1), the reason for such behavior becomes obvious. During the winter, temperature drops to a lower level inside the model with a bigger conservatory, because the thermal losses through the larger glazed areas are more significant. It is indeed in the winter that the rooms need the most energy to heat up.

Overheating

By increasing the conservatory width, the amount of thermal mass expands proportionally. The heavy clay brick partition gets longer and the area of stones in the conservatory floor becomes larger. At the same time, as the percentage of external glazing increases the internal space opens up to sunshine. Furthermore the number of overheating hours will be influenced by the thickness of unfired clay brick partition. It is expected that the thicker the partition, the greater the heat absorption, and thus the smaller the number of overheating hours. The first round of simulation utilized a partition 150mm thick, the second had 300mm, and the third had a 600mm thick partition.

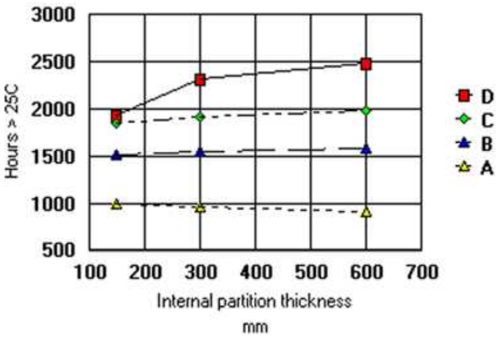


Figure 5.4: Overheating hours in rooms.

In the narrow, canyon-like, conservatory (case A), the sun is shaded by the roof. Case D, with the largest conservatory, overheats for three times as many hours annually than case A.

The expected decrease of overheating time due to the additional thermal mass (brick partition thickness) happened only in case A - with the narrowest conservatory. The living rooms in cases B,C,D overheat more frequently, despite the increasing partition mass.

Figure 5.5 shows the temperature development in the upper living room over one week during August. Dotted black lines show all four cases with a 600mm partition, and gray lines with a 150mm partition. This graph shows also the peaks of the solar gain. At the beginning of graph, when the solar gains reach the highest values, the different partition thicknesses follow an almost identical temperature pattern. When there is extensive sunshine, the temperature in the upper living room isn't affected by thermal mass. On the18th, 19th and 20th of August, the upper living room receives a lot of solar gain. On the 21st the sun is behind the clouds and at that time the thermal mass starts to work. The 600mm partition has some stored heat, while the 150mm one cools down faster. On the

23rd and 24th, the 600mm thick partition causes higher temperatures in cases B,C, and D, which lead to overheating. Thermal mass has a negligible effect on case A, because the case A receives the smallest amount of solar radiation.

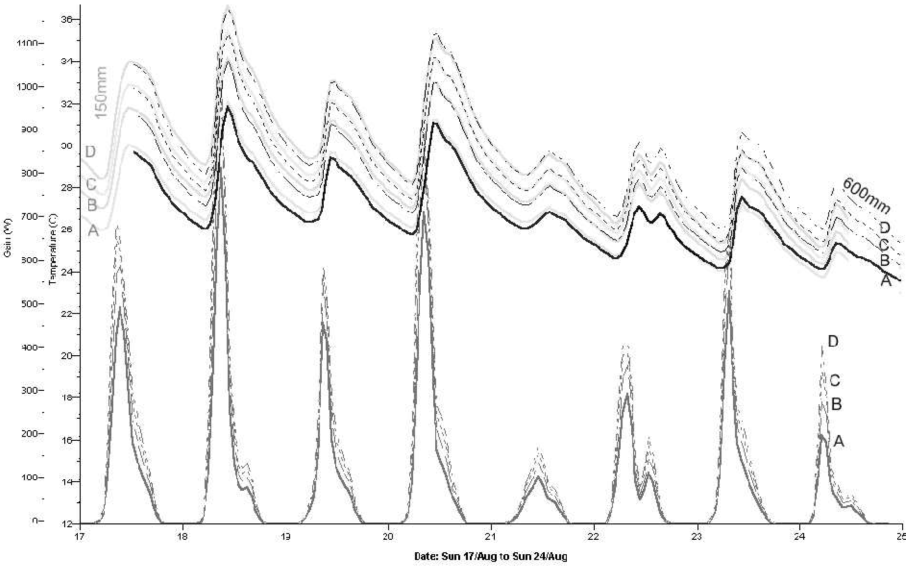


Figure 5.5:

5.2.5 Conclusion - simulation I.

Case A, with the narrowest conservatory, requires the lowest heating energy input. The same case overheats the least. It makes sense to follow the primary idea further by developing case A.

Figure 5.4 shows that to prevent annual overheating, the thickness of the partition isn't significant. However, by looking at Fig. 5.3, some savings could be achieved by keeping the partition 300mm rather than 150mm thick. The effort to build a 600mm thick partition isn't justified.

The calculation of daylight factor should have been included in the assessment of conservatory width as well. Although IES package includes software to calculate the daylight factor, the computer received a warning. The calculation would exceed its remaining memory capacity. However; in order to maximize the access of the ground floor to light, the second floor stands 910mm back from the glazed wall, creating a loft like space (see fig. 5.6).

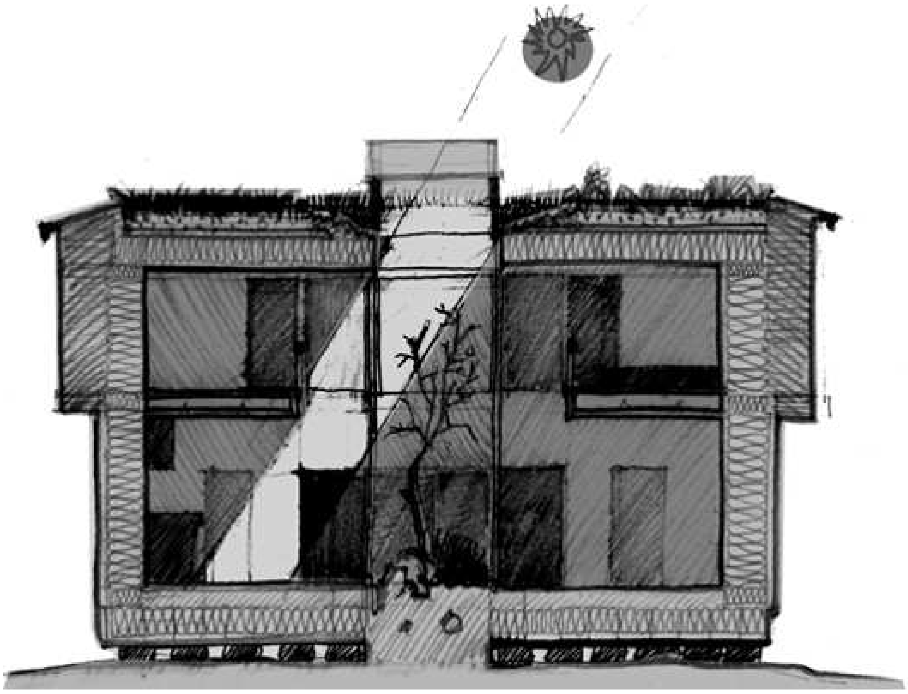
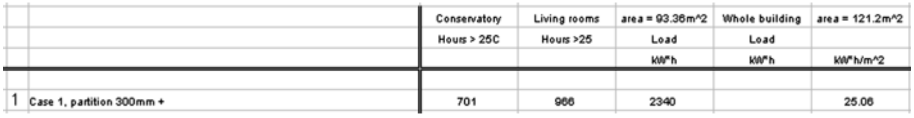


Figure 5.6: Cross section, family home

5.3 Second simulation phase

5.3.1 Simulation II.

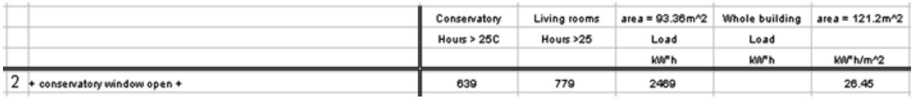
The second simulation phase was done in 13 steps. Following tables monitor the model evolution from a basic case A of the primary idea into the family home with an annual heating demand of the passive building standard without use of a heat recovery system.



		Conservatory	Living rooms	area = 93.36m^2	Whole building	area = 121.2m^2
		Hours > 25C	Hours >25	Load	Load	
				kW*h	kW*h	kW*h/m^2
1	Case 1, partition 300mm +	701	966	2340		25.06

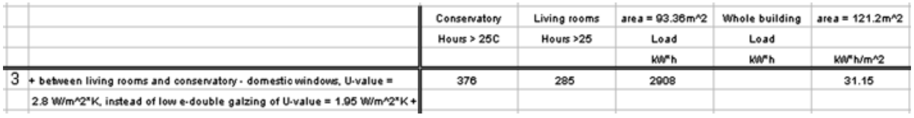
Case A, with 1820mm wide conservatory and 300mm thick partition between the unheated and heated interior spaces, was taken as a starting point for this simulation. The goal is to reduce overheating in living rooms (living quarters) and bring down the heating energy demand.

An openable roof and a large door into conservatory were created. They were then set to correspond to a time schedule, which opens them every morning



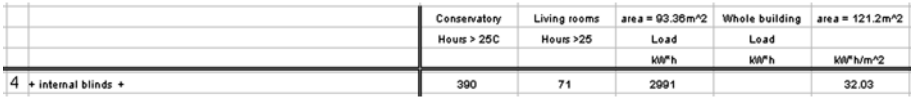
		Conservatory	Living rooms	area = 93.36m^2	Whole building	area = 121.2m^2
		Hours > 25C	Hours >25	Load	Load	
				kW*h	kW*h	kW*h/m^2
2	+ conservatory window open +	639	779	2469		26.45

from 6:30 to 8:30 and every afternoon from 16:00 to 22:00. The threshold opening temperature was set to 22 degrees Celsius. If the temperature inside the conservatory hadn't risen above 22 degrees Celsius by 6:30 or just before 16:00, the opening would remain shut. This way, the conservatory works well as a buffer zone and the opening schedule fits into the daily routine of an average family. However, there is still some overheating occurring in the living rooms.



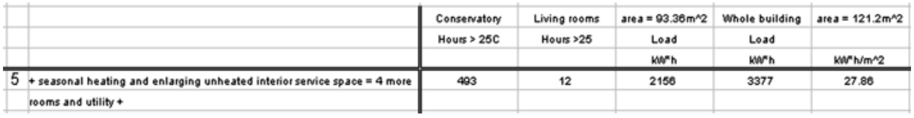
		Conservatory	Living rooms	area = 93.36m^2	Whole building	area = 121.2m^2
		Hours > 25C	Hours >25	Load	Load	
				kW*h	kW*h	kW*h/m^2
3	+ between living rooms and conservatory - domestic windows, U-value =	376	285	2908		31.15
	2.8 W/m^2*K, instead of low e-double galzing of U-value = 1.95 W/m^2*K +					

When the expensive low-e double glazing of large glazed areas between the conservatory and living quarters (with U = 1.95 W/m^{2}K) were replaced by ordinary "domestic double glazing" (with U = 2.8 W/m^{2}K) the result was a big drop in overheating, followed by an increase of energy heating demand. The inferior insulating qualities of glass amplify the buffering effect of conservatory. The conservatory becomes the most important element in the overall thermodynamic house design.



		Conservatory	Living rooms	area = 93.36m^2	Whole building	area = 121.2m^2
		Hours > 25C	Hours >25	Load	Load	
				kW*h	kW*h	kW*h/m^2
4	+ internal blinds +	390	71	2991		32.03

Another step in reducing the interior overheating is to put a light canvas under the glazed roof and behind the glazed external conservatory wall. The curtain serves as an internal shading device. The time schedule is set to remove it from October till March. The curtain doesn't block the light completely. A shading coefficient was set to 0.65 (ranges from 0 to 1, when 0 means completely dark). It also doesn't add to the insulating quality of adjacent glazing.



		Conservatory	Living rooms	area = 93.36m^2	Whole building	area = 121.2m^2
		Hours > 25C	Hours >25	Load	Load	
				kW*h	kW*h	kW*h/m^2
5	+ seasonal heating and enlarging unheated interior service space = 4 more	493	12	2156	3377	27.86
	rooms and utility +					

Up to now, the heating regime has followed a schedule offered by Apache called "Domestic heating (min)". It simulates a thermostat which switches on the heating every day at 6:30 until 8:30 and at 16:00 until 22:00 to maintain the interior temperature at 19 degrees Celsius. The heater won't be turned on if the room temperature exceeds 19 degrees. That is why in spring, summer and autumn, when the solar heat gain starts to dominate the load, the heating is off most of the time. However, further reduction of the heating energy input was done by setting the schedule seasonally, with the heating completely off from May till October, without any significant interior temperature drop.

A further reduction of overheating was achieved by integrating case A into a livable house space. (See the Figure 5.7). On the first floor: an entry hall with a staircase, guest room, bathroom, utility room and pantry were added to fit into a square floor plan. The second floor loft-like rooms expanded into two studies with separate WC's, a common bathroom and a hallway.

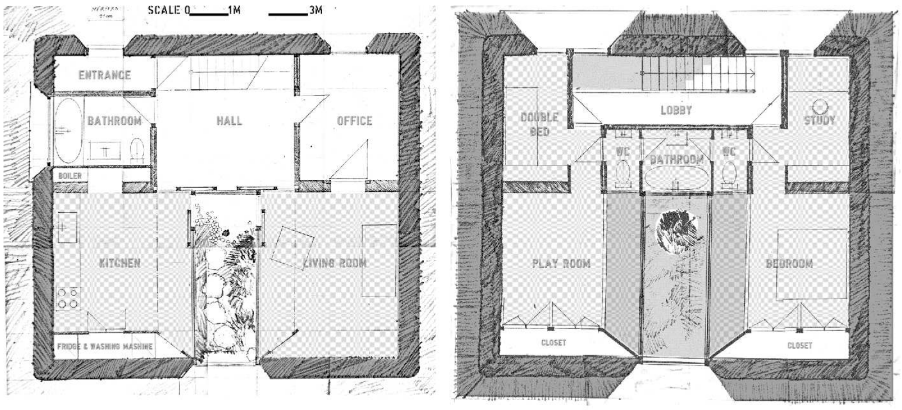
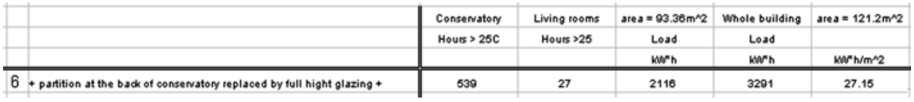
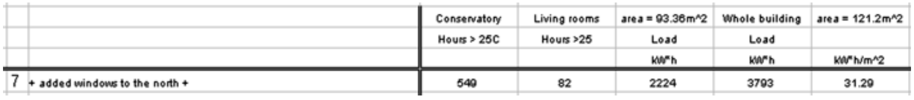


Figure 5.7: First and second floor plans of the extended primary idea to family home. The checkered area represents the open, heated space. The kitchen, living room and 2nd floor bathroom are directly heated.



		Conservatory	Living rooms	area = 93.36m^2	Whole building	area = 121.2m^2
		Hours > 25C	Hours >25	Load	Load	
				kW*h	kW*h	kW*h/m^2
6	+ partition at the back of conservatory replaced by full hight glazing +	539	27	2116	3291	27.15

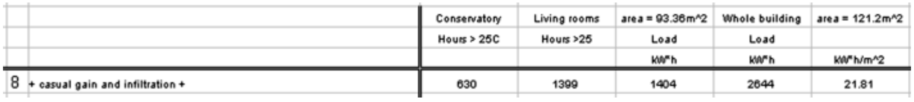
A solid partition at the back of the conservatory, between the conservatory and the unheated space, was replaced by full height glazing. The hall on the ground floor and upstairs bathroom include a fully glazed wall facing the conservatory courtyard with "domestic double glazing" with U = 2.8 W/m^{2}K.



		Conservatory	Living rooms	area = 93.36m^2	Whole building	area = 121.2m^2
		Hours > 25C	Hours >25	Load	Load	
				kW*h	kW*h	kW*h/m^2
7	+ added windows to the north +	549	82	2224	3793	31.29

The window orientation plays a crucial role in the thermal behavior of this lightweight, superinsulated house. All the additional windows, except the one in the bathroom downstairs, were oriented to north. Any other orientation would add significantly to overheating. Properties of all additional windows were taken from Apache database as a "low-e double glazing (2002 regs)" with U = 1.95 W/m^{2}K.

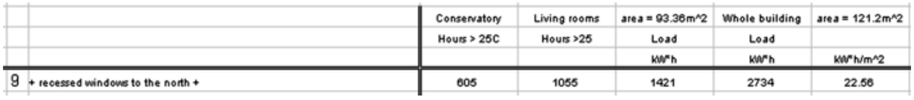
In MakroFlo, all windows were given cracks along their perimeter with a crack flow coefficient 0.15 l/(s*m*Pa$^{0.6}$)



		Conservatory	Living rooms	area = 93.36m^2	Whole building	area = 121.2m^2
		Hours > 25C	Hours >25	Load	Load	
				kW*h	kW*h	kW*h/m^2
8	+ casual gain and infiltration +	630	1399	1404	2644	21.81

To complete the picture, casual gains and infiltration were added to the model. The Apache default infiltration parameter of 0.5 air changes per hour was activated. Some sources say that for the ideal environment, infiltration of 1 ac/h is necessary in a residential space. According to Show (1987) 0.5 ac/h represents an average level of infiltration in double story, low energy houses. It insures a healthy environment, especially as the interior plastered with earth, functions as an excellent humidity buffer (Padfield 1998).

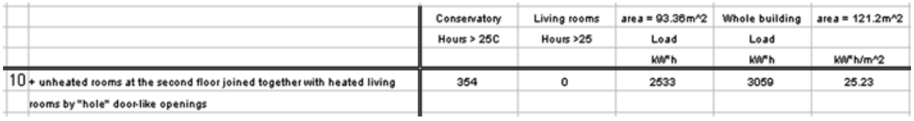
As for casual gains in family home, Apache doesn't offer an easy solution. Thermal gain created by the presence of people is usually taken into consideration in public buildings planned for a greater number of people, like schools, offices, etc.. In a superinsulated family house even the presence of few people could decrees the annual heating demand. Apache asks for the number of people per square meter with a limitation. The density of 0.5 person per 1 m^2 is the lowest number Apache allows. The house area is 121.5 m^2, which means that Apache allows a minimum of 60.75 people in the house. Even though an average 120 -110 W (CIBSE, 1999) of latent heat gain is generated by a *seated working or standing, walking person* in our case one person will generate 7.4 W. If number of 60.75 people generated 7.4 watts, the consequent casual gain over the whole house area will be 450W, which corresponds to a latent heat gain produced at average by four people.



		Conservatory	Living rooms	area = 93.36m^2	Whole building	area = 121.2m^2
		Hours > 25C	Hours >25	Load	Load	
				kW*h	kW*h	kW*h/m^2
9	+ recessed windows to the north +	605	1055	1421	2734	22.56

Even the north facing windows receive some direct solar radiation in summer. In order to avoid it completely, the windows in thick straw bale walls were set in deep recesses. Apache can specify recesses in its local shading devices setup menu for glazed constructions.

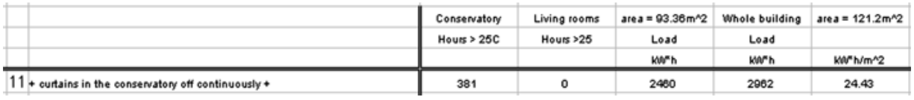
All rooms, except the kitchen, living room and second floor bathroom are unheated. Two studies upstairs are part of a large open space. They receive



		Conservatory	Living rooms	area = 93.36m^2	Whole building	area = 121.2m^2
		Hours > 25C	Hours >25	Load	Load	
				kW*h	kW*h	kW*h/m^2
10	+ unheated rooms at the second floor joined together with heated living rooms by "hole" door-like openings	354	0	2533	3059	25.23

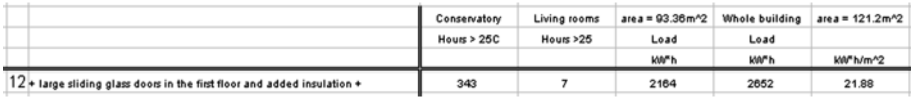
heat via a permanently open door from the heated living room or kitchen. The ability to open the north facing windows in both studies helps to ventilate the overall living space. The opening schedule is the same as the one for the external conservatory door (see the step 2). The only difference is that the opening threshold temperature is 20 degrees Celsius.

By now, overheating in living rooms was reduced to zero and the annual energy heating demand of the house came very close to the passive-energy standard.



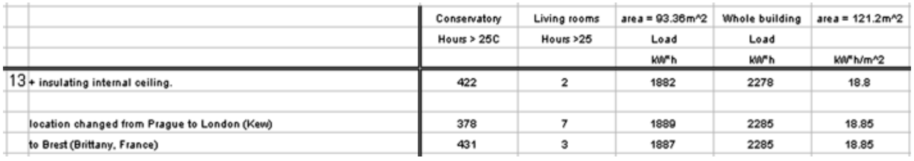
		Conservatory	Living rooms	area = 93.36m^2	Whole building	area = 121.2m^2
		Hours > 25C	Hours >25	Load	Load	
				kW*h	kW*h	kW*h/m^2
11	+ curtains in the conservatory off continuously +	381	0	2460	2962	24.43

The curtain from step 4 can now be canceled. The heating energy demand drops further and overheating remains at 0.



		Conservatory	Living rooms	area = 93.36m^2	Whole building	area = 121.2m^2
		Hours > 25C	Hours >25	Load	Load	
				kW*h	kW*h	kW*h/m^2
12	+ large sliding glass doors in the first floor and added insulation +	343	7	2164	2652	21.88

Opening the heated living quarters (kitchen, living room) into the unheated first floor hall would cause an increase in the annual energy heating demand. In order to keep the load at minimal level, they are separated by sliding glass doors which join the living rooms and the hall together visually. The result is an increase of solar gain in the hall. This solar gain, together with added insulation of the second floor external envelope[1] cause annual overheating for 7 hours, and bring the energy demand closer to a desirable passive-energy building standard.



		Conservatory	Living rooms	area = 93.36m^2	Whole building	area = 121.2m^2
		Hours > 25C	Hours >25	Load	Load	
				kW*h	kW*h	kW*h/m^2
13	+ insulating internal ceiling.	422	2	1882	2278	18.8
	location changed from Prague to London (Kew)	378	7	1889	2285	18.85
	to Brest (Brittany, France)	431	3	1887	2285	18.85

Until now, the internal ceiling between the first and second floor was basic. It was made out of timber decking on 19mm plywood board. Further savings

---

[1] Added insulation consists of reed, cut into 600mm long pieces and then tied in bundles onto a timber construction attached to an exterior of a second floor external wall. See Appendix 5

in heating energy consumption and better sound performance were achieved by insulating the ceiling with straw.

Figure 5.8: North and south perspectives of a family home.

5.3.2 Conclusion - Simulation II.

Returning to the initial questions from section 2.1.

> *Is it possible to achieve the passive-energy building standard by design while using natural, ordinary and inexpensive materials without heat recovery and without particular care about air tightness?*
>
> Yes. It is possible indeed; only the importance of air tightness shouldn't be underestimated. The infiltration of 0.5 air changes per hour means that the house was built with concern for air tightness. The increase of infiltration from 0.5 to 1 ac/h (still a low level of infiltration) almost doubles the overall annual heating demand. Increasing air tightness can result in moisture problems and consequent health effects. (Tsongas, 2004). Therefore the interior earth plaster, acting as a humidity buffer, in combination with kitchen and bathroom ventilation, is essential for keeping the indoor environment healthy.
>
> *Can heat distribution in the house be effectively achieved solely by natural ventilation, by opening the windows?*
>
> Yes. It needs properly disciplined inhabitants, who would open the windows when they feel too hot, and wouldn't mind the temperature falling to 16 degrees Celsius during winter nights. Otherwise 19 degrees is maintained through the whole winter in the most convenient hours every day in the living room, kitchen, upper bathroom and upper studies.

The charts showing the thermal performance in all of the important spaces of the family house during a one year period are attached in Appendix 9 — 11.

According to those charts, during the spring, summer and autumn, the inhabitants will enjoy a large open space filled with sun, around a flourishing herbal garden in the conservatory courtyard. The hall on the first floor can't be used for comfortable living from November till April. For these five months during the winter, the space becomes more modest, but the expanding views, lit by sun and full of visual pleasure remain, due to the extensive inner glazing.

Chapter 6

Conclusion

The most surprising finding of this investigation was the realization of how insignificant an effect thermal mass has on overheating buffering of the rooms with direct solar radiation.

One very significant factor in thermal performance is insulation. Without a 450mm thick super insulating straw bale wall, it wouldn't be possible to achieve the passive building standard. Earth plastered straw bale not only creates a warm environment, it also improves humidity levels within the whole structure. Clayish earth is a great humidity buffer (Minke, 2005). The embodied energy of those two materials can be absolutely minimal. Ideally, earth would be from the building site and straw from a neighboring farmer.

Although the house is modeled for Prague's climate, table showing 13th step of simulation shows that setting a house in the London (Kew) area or in Brittany, France doesn't make much difference.

Another significant parameter influencing the thermal performance and overheating is the window area and its orientation. The proposed design deals with a solar gain without curtains and shading elements that require care and maintenance. It contains an interior full of direct sunlight. (See Appendix 7 and 8)

With an independent electrical energy source and a hot water supply placed on its flat green roof one could say that this house doesn't squint at the sun, it offers its heart to it.

Clearly, further investigation to improve the design is necessary. This paper is result of author's first experience with computer modeling. However, after several years in the straw bale construction business, one year of UEL, Environment and Energy Studies in the Msc program that included one week of the Computer Modeling unit at CAT in May 2005, I feel confident enough to develop the design and try it on a real build.

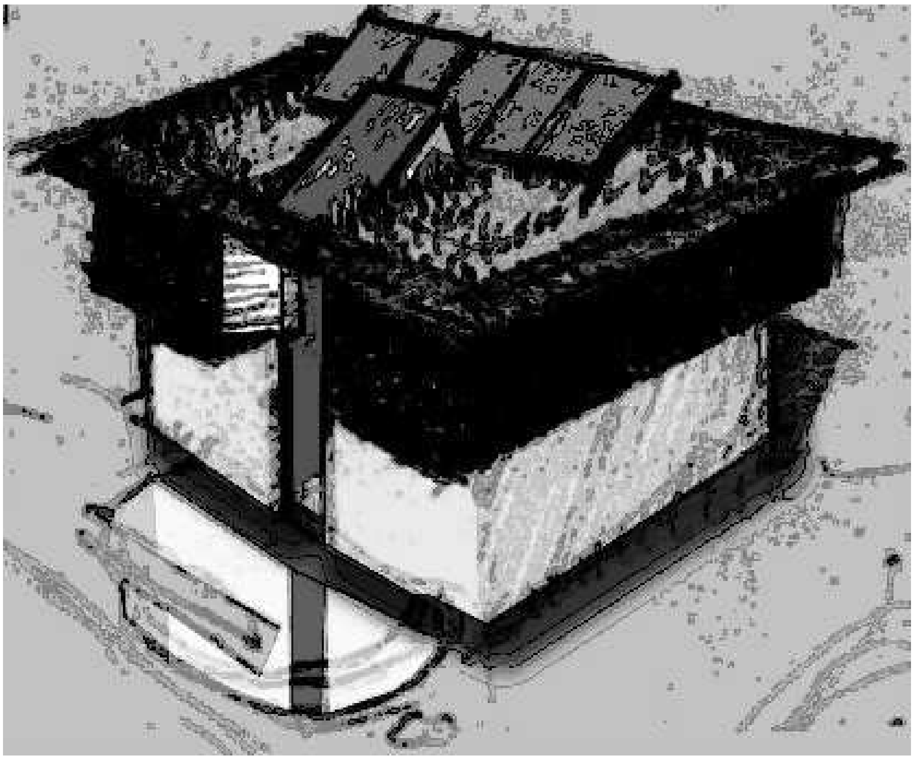


Figure 6.1: Perspective of the family home from above with photovoltaic array and solar water heating panels on the roof.

References:

Amazon Nails (2001) Information Guide to Straw Bale Building, for Self-Builders and the Construction Industry, [Internet], Available from ¡http://www.strawbalefutures.org.uk/¿ [Accessed: July 19th, 2005]

Bares, J. (2005), Fiche technique, [Internet], Available from

Eicker, U. (2002) Solar Technologies for Building, John Wiley & sons, Ltd., Chichester, West Sussex

Hansen, S. (2005) Unfired clay bricks - moisture properties and compressive strength [Internet], Available from

Minke, G. Mahlke F., (2005) Building with Straw, Design and Technology of a Sustainable Architecture, Basel, Birkhauser - Publishers for Architecture, *research by Wimmer (2001)

Oliva, J., P. (2001) L'isolation ecologique, conception materiaux, mise en oeuvre, Mens, terre vivante

Padfield, T. (1998) The role of absorbent materials in moderating changes iof relative humidity,[Internet], Available from

Show, T., Y. (1987) Mechanical Ventilation , Systems for Houses, Air Infiltration, May 1987, Vol. 8, No. 3, [Internet], Available from

THF, (2002) Construction Animation, [Internet], Available from ¡http://www.tibetheritagefund.org/¿ [Accessed: July 19th, 2005]

Tsongas, G. (2004) Case Studies of Moisture Problems in Residences, [Internet], Available from

Tugby, C. (2002) Picture Gallery , [Internet], Available from

Voss, K., Hoffmann, C. (2005)Energy Efficiency of Buildings Norms and Standards in Europe. DETAIL, June, pp 670-671, Issue 6: Solar Arrchitecture, serie 2005, Munchen

Wimmer, R.,(2003) Haus der Zukunft, Wirtschaftsbezogene Grundlagenforschung, Studie im Auftrag des Bundesministeriums fr Verkehr Innovation und Technologie, Wien, GrAT / asbn

Bibliography:

Gilbert, B. (2004) Simulating Straw and Earth Buildings, An investigation of lightweight and heavyweight building materials, In: Thompson, M. Ed. Unit B3 May 05. Msc Architecture: Advanced Environmental and Energy Studies, Centre for Alternative Technology, University of East London

APPENDIX

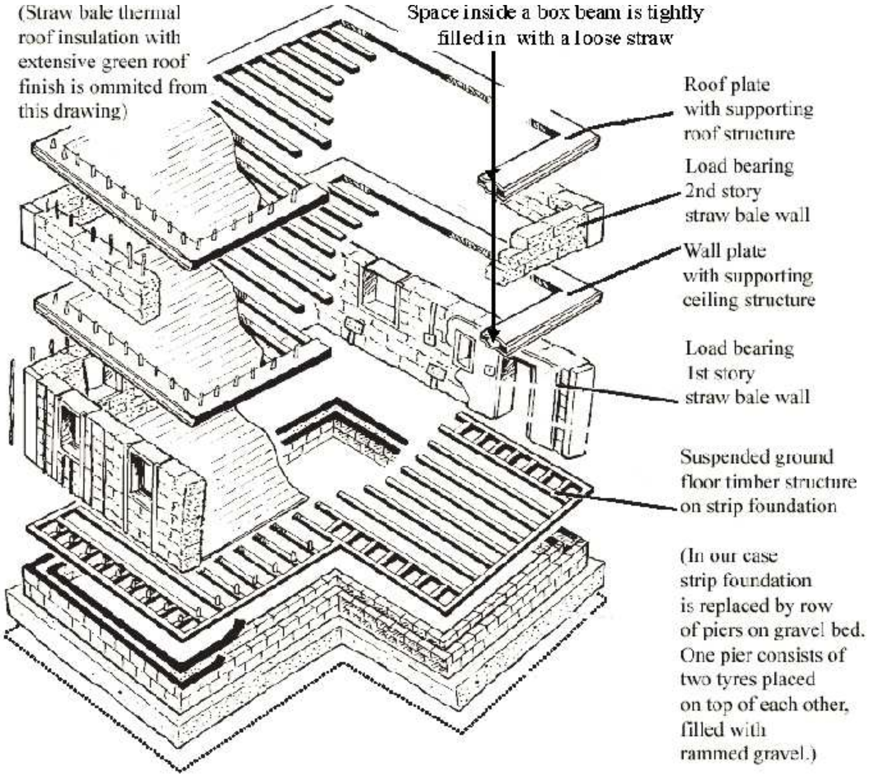


Figure 2: Sketch of double story load bearing straw bale construction, which has been adapted for this essay from Amazon Nails (2001).

Figure 3: The elevated ground floor insulated with straw bales rests on foundations from recycled tires. Those are filled with rammed gravel. Picture of Straw Bale Dormitory in Clow Back (Yorkshire) build by Amazon Nails in 2002. Photography by Konrad (Tugby, 2002)

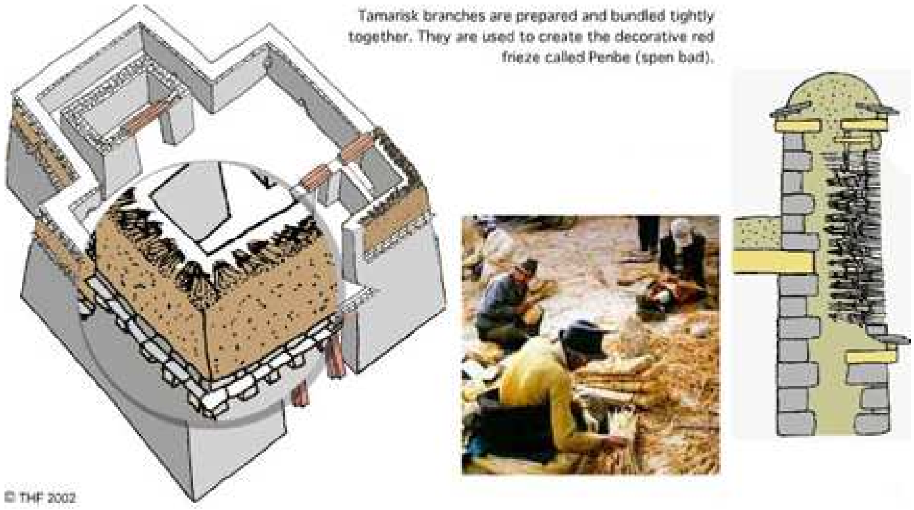


Figure 4: Traditional Tibetan religious building as an inspiration. (THF, 2002)

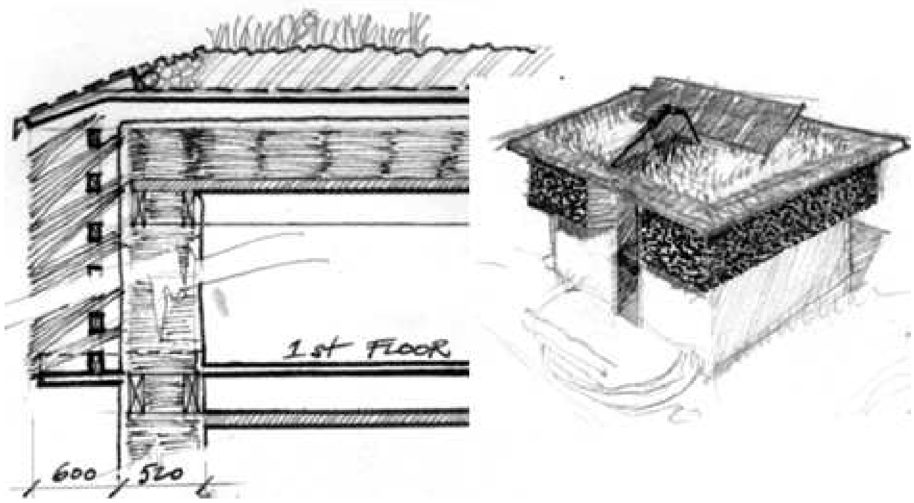
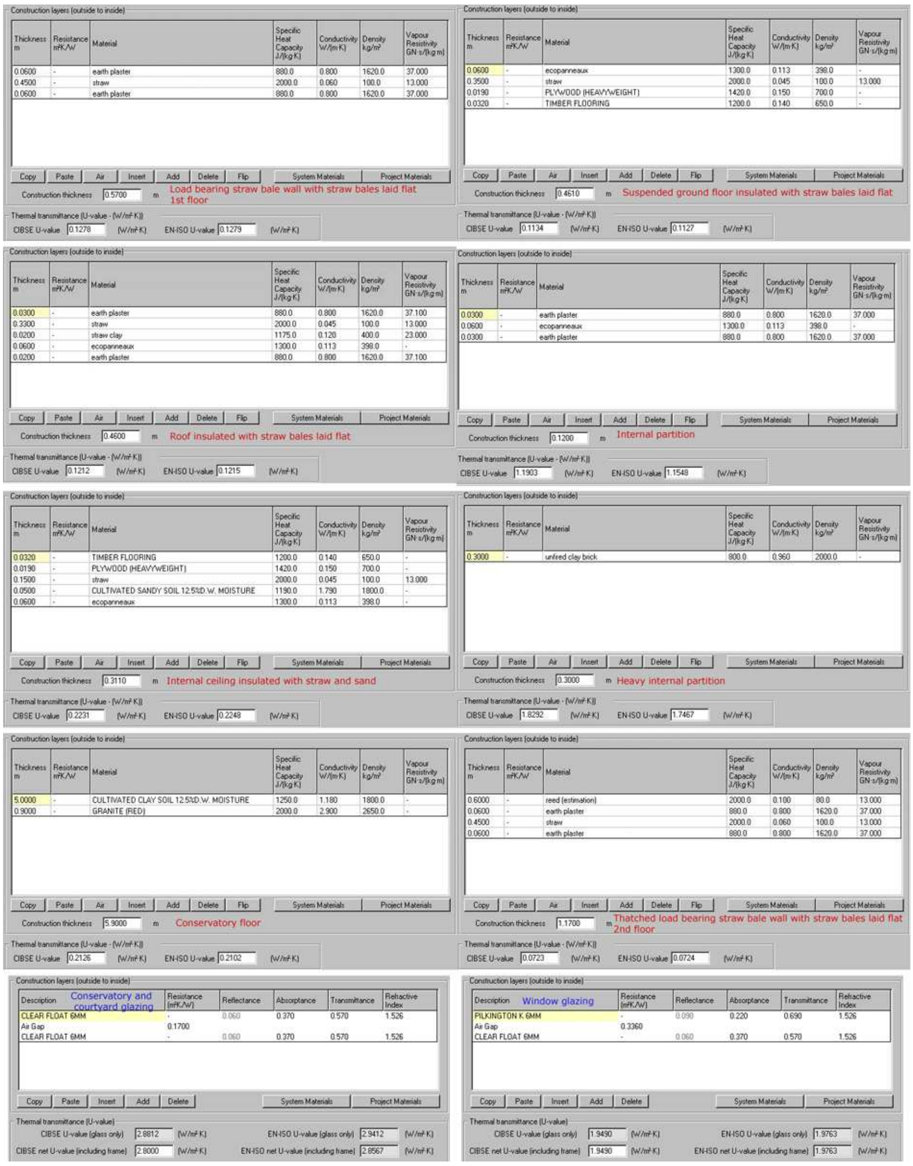


Figure 5: Section through the roof, ceiling and secondary story wall construction with a reed frieze. The reed is cut into 600mm long pieces and then tied in bundles onto a timber construction attached to an exterior of a second story external wall. Frieze adds a thermal insulation and is a protection against driving rain. It creates a necessary overhang and protects the wall below.



Construction layers (outside to inside)

Thickness m	Resistance m²K/W	Material	Specific Heat Capacity J/(kg·K)	Conductivity W/(m·K)	Density kg/m³	Vapour Resistivity GN·s/(kg·m)
0.0600	-	earth plaster	880.0	0.800	1620.0	37.000
0.4500	-	straw	2000.0	0.060	100.0	13.000
0.0600	-	earth plaster	880.0	0.800	1620.0	37.000

Construction thickness 0.5700 m Load bearing straw bale wall with straw bales laid flat 1st floor

Thermal transmittance (U-value - (W/m²·K))
CIBSE U-value 0.1278 (W/m²·K) EN-ISO U-value 0.1279 (W/m²·K)

Construction layers (outside to inside)

Thickness m	Resistance m²K/W	Material	Specific Heat Capacity J/(kg·K)	Conductivity W/(m·K)	Density kg/m³	Vapour Resistivity GN·s/(kg·m)
0.0600	-	ecopanneaux	1300.0	0.113	398.0	-
0.3500	-	straw	2000.0	0.045	100.0	13.000
0.0190	-	PLYWOOD (HEAVYWEIGHT)	1420.0	0.150	700.0	-
0.0320	-	TIMBER FLOORING	1200.0	0.140	650.0	-

Construction thickness 0.4610 m Suspended ground floor insulated with straw bales laid flat

Thermal transmittance (U-value - (W/m²·K))
CIBSE U-value 0.1134 (W/m²·K) EN-ISO U-value 0.1127 (W/m²·K)

Construction layers (outside to inside)

Thickness m	Resistance m²K/W	Material	Specific Heat Capacity J/(kg·K)	Conductivity W/(m·K)	Density kg/m³	Vapour Resistivity GN·s/(kg·m)
0.0300	-	earth plaster	880.0	0.800	1620.0	37.100
0.3300	-	straw	2000.0	0.045	100.0	13.000
0.0200	-	straw clay	1175.0	0.120	400.0	23.000
0.0600	-	ecopanneaux	1300.0	0.113	398.0	-
0.0200	-	earth plaster	880.0	0.800	1620.0	37.100

Construction thickness 0.4600 m Roof insulated with straw bales laid flat

Thermal transmittance (U-value - (W/m²·K))
CIBSE U-value 0.1212 (W/m²·K) EN-ISO U-value 0.1215 (W/m²·K)

Construction layers (outside to inside)

Thickness m	Resistance m²K/W	Material	Specific Heat Capacity J/(kg·K)	Conductivity W/(m·K)	Density kg/m³	Vapour Resistivity GN·s/(kg·m)
0.0300	-	earth plaster	880.0	0.800	1620.0	37.000
0.0600	-	ecopanneaux	1300.0	0.113	398.0	-
0.0300	-	earth plaster	880.0	0.800	1620.0	37.000

Construction thickness 0.1200 m Internal partition

Thermal transmittance (U-value - (W/m²·K))
CIBSE U-value 1.1903 (W/m²·K) EN-ISO U-value 1.1548 (W/m²·K)

Construction layers (outside to inside)

Thickness m	Resistance m²K/W	Material	Specific Heat Capacity J/(kg·K)	Conductivity W/(m·K)	Density kg/m³	Vapour Resistivity GN·s/(kg·m)
0.0320	-	TIMBER FLOORING	1200.0	0.140	650.0	-
0.0190	-	PLYWOOD (HEAVYWEIGHT)	1420.0	0.150	700.0	-
0.1500	-	straw	2000.0	0.045	100.0	13.000
0.0500	-	CULTIVATED SANDY SOIL 12.5%D.W. MOISTURE	1190.0	1.790	1800.0	-
0.0600	-	ecopanneaux	1300.0	0.113	398.0	-

Construction thickness 0.3110 m Internal ceiling insulated with straw and sand

Thermal transmittance (U-value - (W/m²·K))
CIBSE U-value 0.2231 (W/m²·K) EN-ISO U-value 0.2248 (W/m²·K)

Construction layers (outside to inside)

Thickness m	Resistance m²K/W	Material	Specific Heat Capacity J/(kg·K)	Conductivity W/(m·K)	Density kg/m³	Vapour Resistivity GN·s/(kg·m)
0.3000	-	unfired clay brick	800.0	0.960	2000.0	-

Construction thickness 0.3000 m Heavy internal partition

Thermal transmittance (U-value - (W/m²·K))
CIBSE U-value 1.8292 (W/m²·K) EN-ISO U-value 1.7467 (W/m²·K)

Construction layers (outside to inside)

Thickness m	Resistance m²K/W	Material	Specific Heat Capacity J/(kg·K)	Conductivity W/(m·K)	Density kg/m³	Vapour Resistivity GN·s/(kg·m)
5.0000	-	CULTIVATED CLAY SOIL 12.5%D.W. MOISTURE	1250.0	1.180	1800.0	-
0.9000	-	GRANITE (RED)	2000.0	2.900	2650.0	-

Construction thickness 5.9000 m Conservatory floor

Thermal transmittance (U-value - (W/m²·K))
CIBSE U-value 0.2126 (W/m²·K) EN-ISO U-value 0.2102 (W/m²·K)

Construction layers (outside to inside)

Thickness m	Resistance m²K/W	Material	Specific Heat Capacity J/(kg·K)	Conductivity W/(m·K)	Density kg/m³	Vapour Resistivity GN·s/(kg·m)
0.6000	-	reed (estimation)	2000.0	0.100	80.0	13.000
0.0600	-	earth plaster	880.0	0.800	1620.0	37.000
0.4500	-	straw	2000.0	0.060	100.0	13.000
0.0600	-	earth plaster	880.0	0.800	1620.0	37.000

Construction thickness 1.1700 m Thatched load bearing straw bale wall with straw bales laid flat 2nd floor

Thermal transmittance (U-value - (W/m²·K))
CIBSE U-value 0.0723 (W/m²·K) EN-ISO U-value 0.0724 (W/m²·K)

Construction layers (outside to inside)

Description Conservatory and courtyard glazing	Resistance (m²K/W)	Reflectance	Absorptance	Transmittance	Refractive Index
CLEAR FLOAT 6MM	-	0.060	0.370	0.570	1.526
Air Gap	0.1700				
CLEAR FLOAT 6MM	-	0.060	0.370	0.570	1.526

Thermal transmittance (U-value)
CIBSE U-value (glass only) 2.8812 (W/m²·K) EN-ISO U-value (glass only) 2.9412 (W/m²·K)
CIBSE net U-value (including frame) 2.8000 (W/m²·K) EN-ISO net U-value (including frame) 2.8567 (W/m²·K)

Construction layers (outside to inside)

Description Window glazing	Resistance (m²K/W)	Reflectance	Absorptance	Transmittance	Refractive Index
PILKINGTON K 6MM	-	0.090	0.220	0.690	1.526
Air Gap	0.3360				
CLEAR FLOAT 6MM	-	0.060	0.370	0.570	1.526

Thermal transmittance (U-value)
CIBSE U-value (glass only) 1.9490 (W/m²·K) EN-ISO U-value (glass only) 1.9763 (W/m²·K)
CIBSE net U-value (including frame) 1.9490 (W/m²·K) EN-ISO net U-value (including frame) 1.9763 (W/m²·K)

Figure 6: Tables of project constructions. From Apache.

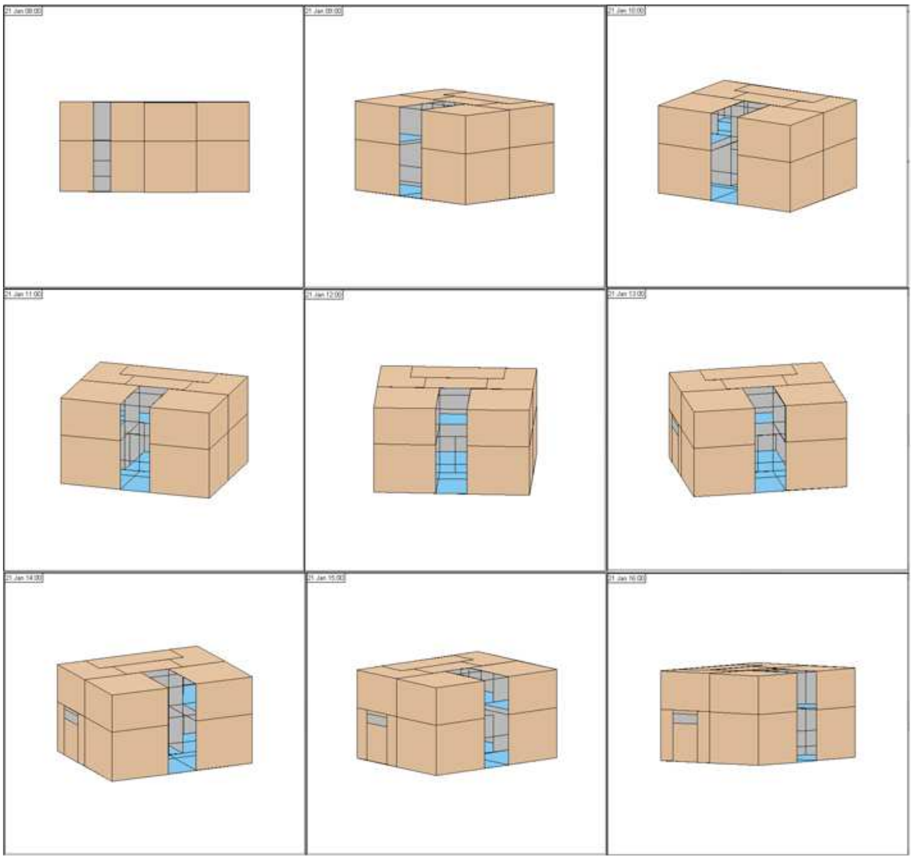


Figure 7: *21st of January. Sequence from Suncast—Solar Shading Analysis.* The IES—Virtual Environment package includes software that enables one to view the model from the direction of the sun.

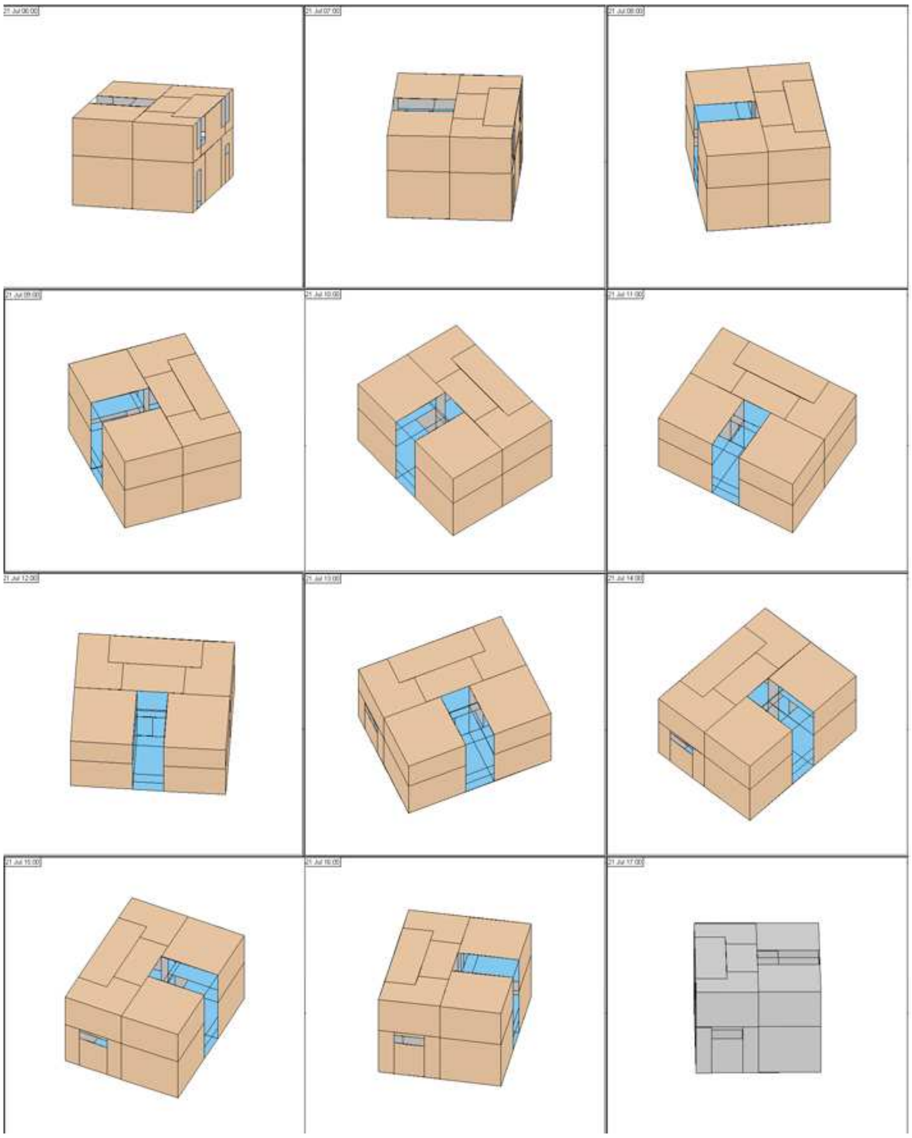


Figure 8: *21st of July. Sequence from Suncast—Solar Shading Analysis.* The difference between interior exposure to sun arrays in winter and summer is obvious.

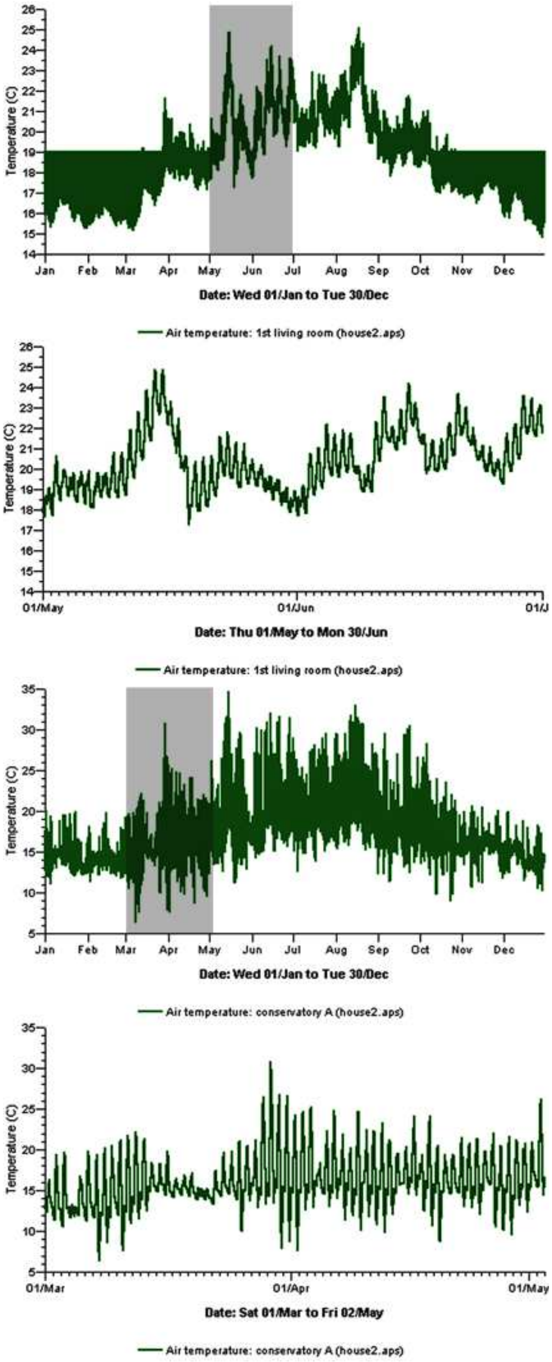


Figure 9: Temperature development in living room and conservatory.

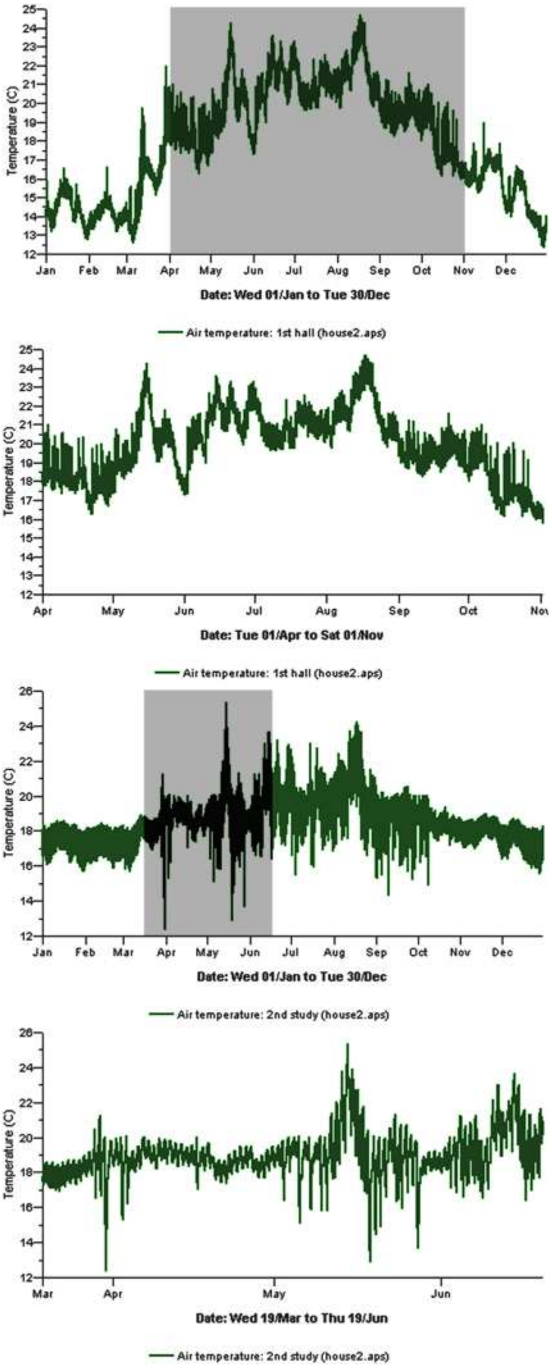


Figure 10: Temperature development in first story hallway and the indirectly heated study on the second floor (connected with directly heated living quarters with permanently open door-like opening).

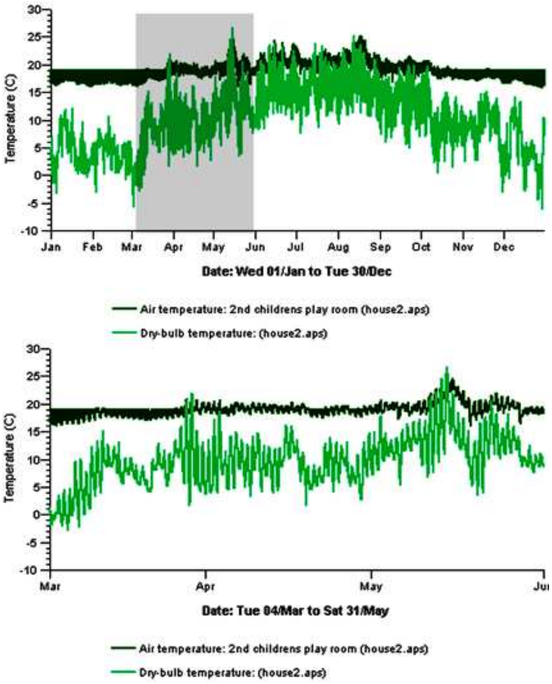


Figure 11: Comparison of temperature developments in directly heated second story living quarter with outside dry-bulb temperature.