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ANNEX 7

Monograph: House of the future

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1 Introduction

The present monograph shall give a picture of how the bulk of buildings in the residential sector could be structured in future. This picture is derived from present research and developments. Buildings serve very fundamental life functions, which will be valid also for future generations. Thus from all energy sectors the building sector is the one which has the biggest resistance against fast change. Building constructions usually are made for a life time of 100 years and more. Thus we can assume, that houses which are built today, will be here also in the year 2100. And we can assume that today's research on buildings will be effective for the bulk of houses in hundred years.
In contrast to the outer shell of the house, however, the inner life can change quite rapidly. Especially in the area of electrical appliances, it can be expected that in hundred years technologies will be needed, from which today not the slightest idea exists. This is specifically true for all which has to do with entertainment and information exchange. Nevertheless, also in this field current developments are shown, which at least give some idea on the future possibilities of technologies in the residential sector.

Currently main energy consumption in the household sector is caused by space heating, warm water preparation and cooking. In countries with hot climate air conditioning gains importance. In the building sector which includes also the public and private services sector, lighting is of primary importance.

The applied techniques and the technologies under development somewhat differ between developing and industrialized countries. While in developing countries the focus lies with the improvement of biomass and solar heat utilization (including for example dung heating, wood cooking and solar stoves) /1/, in developed countries the center of interest lies with electricity driven technologies.

The following chapters show technologies which are currently developed for the so called "low energy house" and "house of the future". Not all of these technologies will become economic and thus will get widespread market penetration, many of them, however, will. Most of the material presented is derived from the Austrian governmental initiative "house of the future" /2/.

The technological overview is complemented by a chapter on social aspects and by technological considerations specific for developing countries.

2 Building Envelope and Glazing

Following are construction targets for the house of the future /3/:

- The whole life cycle energy for the construction and dismantling of a building should be low. This so called grey energy ranges from 1100 kWh/m² building ground are with simple buildings of light construction material to 2500 kWh/m² with complex buildings of heavy construction material. Low grey energy consumption can be achieved by the utilization of light recycling material with low energy uptake during processing and by long life spans of the constructed buildings.
- The final and primary energy consumption should be low. **Table 1** shows target values for the low energy house and the passive house. These values can be achieved by
  - the reduction of transmission heat losses (minimzation of outer wall areas, improved insulation..)
  – the reduction of heat losses by air conditioning (draught free building envelopes, heat recovery from off-air)
  - utilization of renewable energy sources
  - utilization of energy efficient appliances.

- The consumption of ecologically precious area should be low. Construction of buildings connected to public transport and to a general living infra structure should be preferred.
- The consumption of drinking water should be limited to 30 l/capita.d. This can be achieved by “grey” water recycling and rain water utilization.
- Emissions into air, water and soil should be low.
- High air quality must be achieved by total air exchange at least every 3 hours. CO_2 concentration must be kept below 1000 ppm.
- High thermal quality is achieved
  - when the air and wall inner surface temperature lie between 18 and 22 °C in winter, and between 22 and 25 °C in summer,
  - when the relative air humidity lies between 35 and 70 % and the absolute air humidity lies below 12 g/kg,
  - and when the air velocity lies blow 0.15 m/s.
- High visual quality is achieved when:
  - there is sufficient day lighting (for minimum values see **table 2**)
  - there is sufficiently long direct lighting from the sun (see **table 3**)
- High acoustic comfort should be achieved by a noise level in living rooms lower than 20 dB.
- High operation comfort and operation efficiency should be achieved by building automation and a construction structure which allows an easy adaptation to changes in utilization necessities.
- High operation safety should be achieved by fire, flooding, earthquake and other catastrophe counter measures as well as security installations.
- All should be achieved by low micro economic and by low macro economic costs.

Table 1: Target values for energy consumption of low energy house and passive house as compared to existing buildings in kWh/m²$_{living\ area}$.a referred to a climate with 3500 heating degree days per year /3/

	Existing houses constructed before 1980	Low Energy House	Passive House
Room heating consumption	150 - 250	<40	<15
Final energy consumption		<70	<42
Primary energy consumption		<160	<120

Table 2: Daylighting coefficients D for different room types /3/ (D is defined as ratio between horizontal lighting intensity in the building divided by the horizontal day light intensity in %)

Room type	Minimum	Good	Optimum
Sleeping rooms	>0.5 %	>1 %	2 – 3 %
Living rooms, kitchen, working rooms, class rooms	1 %	2 %	3 – 4 %
Rooms with high visual requirements (drawing rooms)	>2 %	3-5 %	5-8 %

Table 3: Duration of sun lighting in hours per day in December /3/ (valid for 45 ° north)

Room type	Minimum	Good	Optimum
Sleeping rooms	>0.5	>1	>2
Living rooms, kitchen, working rooms, class rooms	>0.45	>1.5	>3
Recuperation rooms	>1	>2	>3

Table 4 shows the heat losses of a low energy house featuring advanced insulation technologies and heat recovery from off-air. It can be seen that windows strongly affect the energy use in buildings as they account for 25 to 30 % of the heating energy consumption. But they also can influence the living comfort.

Table 4: Heat losses in a low energy house /5/	
Ground floor	5 %
Outer walls	18 %
Loft	4 %
Air exchange	32 %
Windows and doors	41 %

In order to minimize the heating consumption the passive house concept is built on 3 columns /4/:
- A consequent application of building insulation covering the whole opaque building envelop
- Special insulating windows
- And heat recovery from off-air and possibly from off-water.

The main structure of the building can be either massive (e.g. brick) or wood. Different conventional building insulation systems, like gypsum or polystyrene plates, hollow bricks, rock wool or cavity wall insulation foam, are commercially available and will be applied where economic.

More exotic systems are described in the following:
- Transparent insulation, like low iron glass, thin wall polycarbonate or clear gel, has a high optical transmissivity (70 % of the sunshine is transmitted) but a low thermal radiation transmissivity. With a U-value of 1 W/m²*°C it is a very effective insulation material. A special transparent technology is KAPILUX, which features a honeycomb of small helium filled plexi-glass capillaries (diameter 3.5 mm, length 30 to 120 mm) contained between two 4 and 5 mm security glass panes (see **figure 1**) /5/.
- Passive solar components provide heat collection, storage, distribution and control capacity for the building. A process which uses solar energy stored in massive concrete walls for room heating is the massive-absorber-heat pump /6/.
- Dynamic insulation is the combination, within a wall, of a conventional insulation and some kind of dynamic exchange between outside and inside temperature. In parieto dynamic insulation a fluid (mostly air) circulates in a cavity which serves as heat exchanger (see **figure 2**). This dynamic insulation can be combined with photovoltaic power generation panels (see **figure 3**).

  In permeo dynamic insulation the fluid circulates through a porous material. Dynamic insulation is frequently coupled with ventilation offering an efficient way of fresh air pre-heating.
- Advanced building construction systems feature wood framing, steel framing, masonry construction or structural insulated panels.
- Advanced architecture features closed facades to the north and large glass areas to the south, which can capture more heat than they lose /7/.

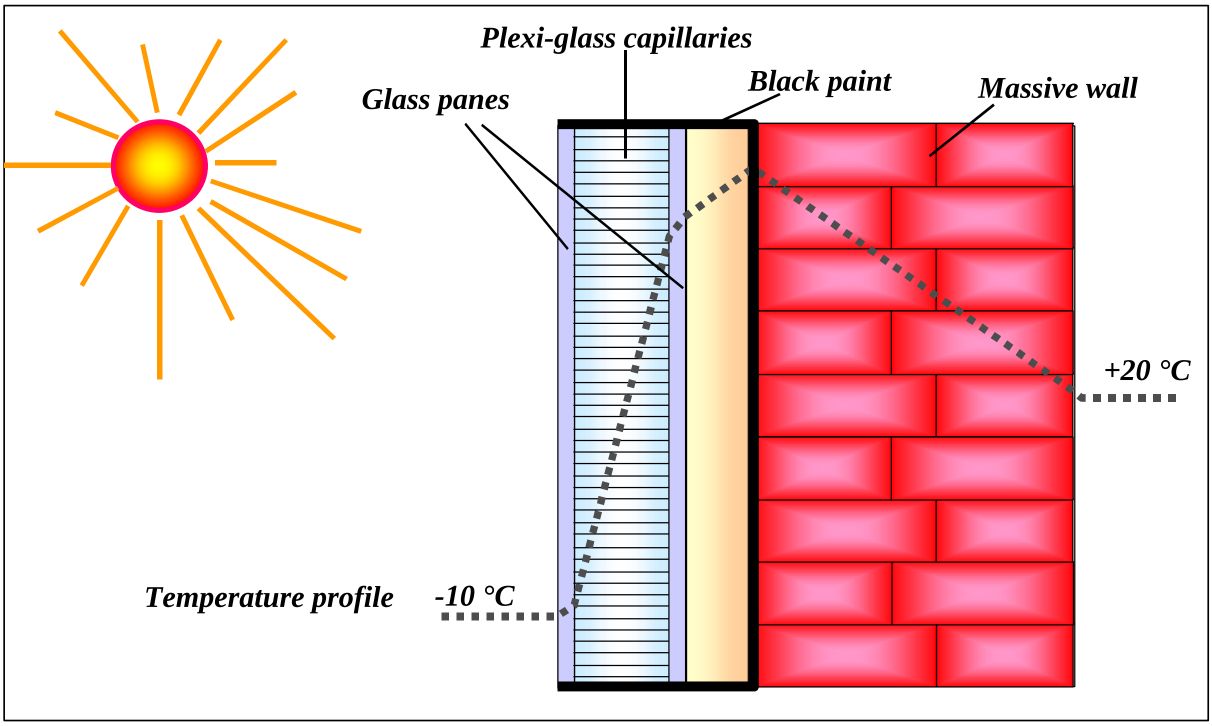

Figure 1: Scheme of transparent insulation with plexi-glass capillaries

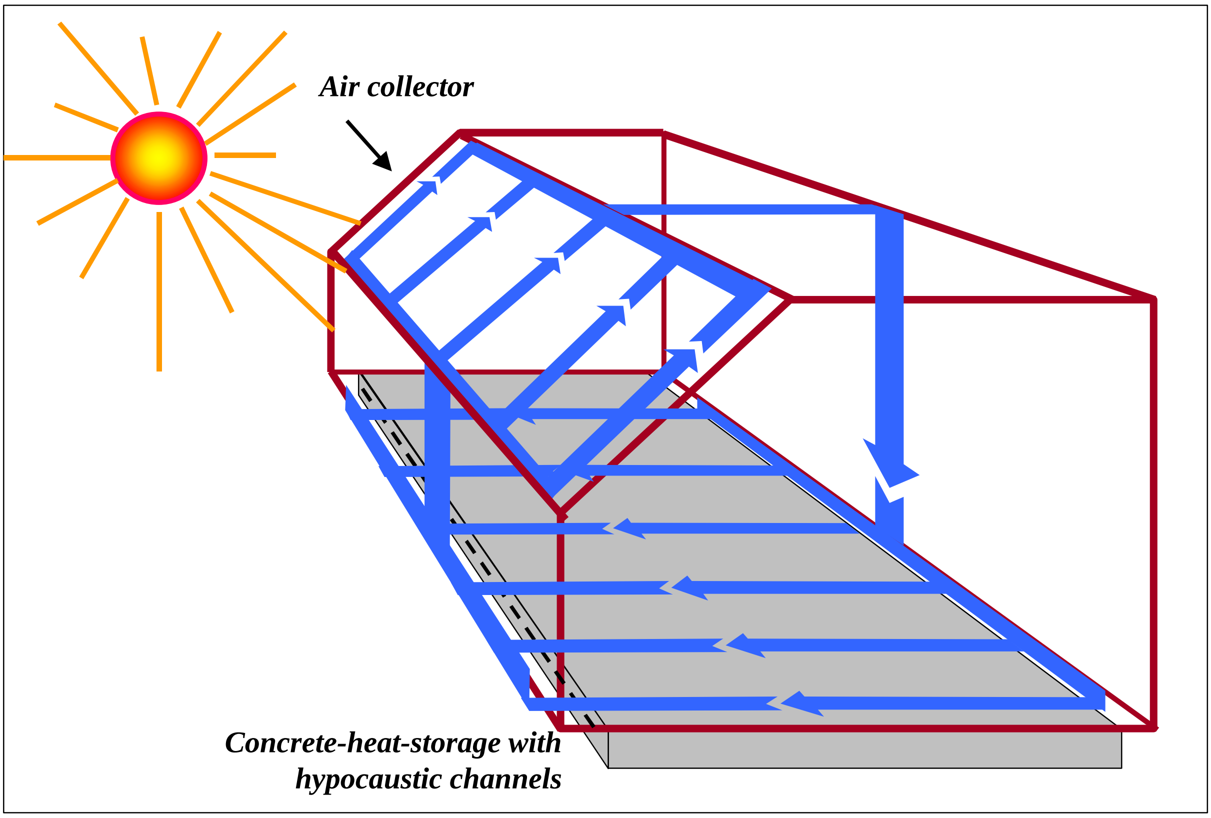

Figure 2: Scheme of a solar air-circulation heating

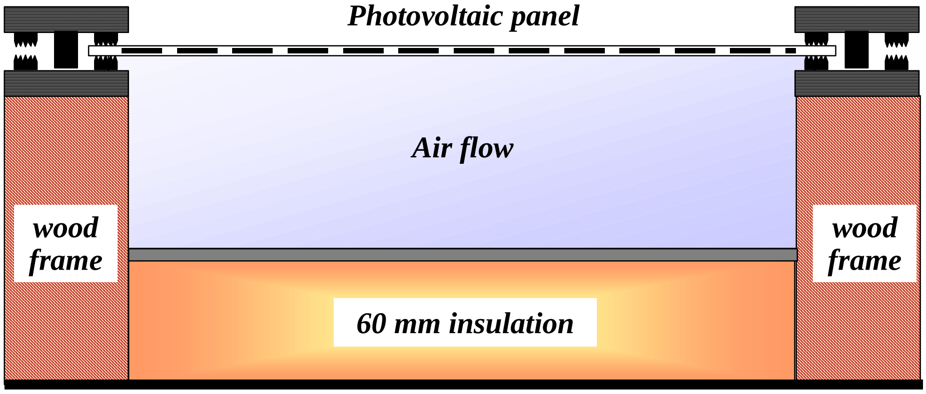

Figure 3: Scheme of a hybrid-air-PV collector

Following advanced window technologies are available or about to be developed:

- Windows with low emissivity coatings bear light-transparent layers of metals or oxides, with low heat conductivity. (For cooling purposes there are spectral-selective low emission coatings which transmit only the visible part of the sun-light but not the heat bearing infrared part of the sun-light).
- Switchable glazing technologies ("smart" windows) have variable solar-optical properties, which can be passively or actively altered.
  - Photochromic coatings change the solar transmittance as a function of light intensity (like sunglasses).
  – Thermochromic materials change their optical properties as a function of their temperature, from transparent when cool, to white/reflecting when hot.
  - Electrochromic materials are multi layer films whose optical properties can be controlled by applying voltage regulation.
- Gas fills feature low conductivity gases like argon or krypton to fill the gap between glass panes.
- Transparent insulation materials are transparent insulation solids which fill the gap between glass panes.
  - Silica aerogel is a microporos material that traps air in tiny holes.
  - Honeycomb or capillary structures are made of plastics or glass.
- Evacuated windows
- Electrically heated windows
- "Super-windows" are three two four pane windows with low emissivity coatings, gas fills and special frame construction leading to a heat conductivity (U-value) as low as 0.6 to 0.8 W/(m²*K). These windows are especially developed for Nordic countries and are also proposed for the passive house. In the annual balance of these windows the energy up-take from sun light is higher than the heat losses.

Technical parameters for the comparison of some of these window technologies are shown in **table 5**.

Table 5: Technical parameters of different glazing technologies /8/

	Structure in mm	Visible light transmittance in %	Total energy transmittance in %	Color reproduction in %	U-value in W/(m²*K)
Single glass	4	87	>80	99	5.0
Double glass	4-12-4	84	77	99	3.0
Triple glass	4-9-4-9-4	72	74	98	2.2
Double glass, coating on third level	4-16-4	75	62	98	1.7
Double glass, coating on	4-16-4	75	62	98	1.3

third level + Argon					
Double glass, coatings on two levels + Xenon	4-8-4	76	58	98	0.9
Triple glass, coatings on three levels + Xenon	4-8-4-8-4	64	42	96	0.4

The technical components of a passive house which was specifically developed for a rural area is summarized in **table 6**. Aside of some of the above shown components it features clay and wood insulation, as well as a biomass heating. In this configuration the passive house can be seen as highly sustainable technology.

Table 6: Technical features of a rural passive house /9/		
Material: - outer walls of clay stone and limestone - walls and upper ceiling with cellulose insulation - inner walls of clay and gypsum insulation - outer wall coverage wood - solvent free paintings		
Energy concept: - heat consumption approx. 13 kWh/m².a - fit for summer and winter housing - walls are utilized for storing energy - technical air conditioning - 50 m² solar panels for warm water preparation - central pellets heating		
Heat insulation		
Description	Transmission value in W/m²K	Heat storage effective mass in kg/m² (24 h)
KS cellulose insulation	0.127	157
Clay cellulose insulation	0.127	149
Flat roof	0.115	271
3 plate glazing with extra frame insulation	0.79	n.a.
2 plate winter garden	1.6	n.a.
Apartment separation ceiling	0.55	155/253
Cellar ceiling	0.119	157
Apartment separation wall (double wall) KS	0.573	151
Light wall GK	0.547	22
Light wall clay plates	0.592	30

Though the energy uptake for the construction material and for the rehabilitation of a passive house is higher than with a standard house the overall energy balance is much in favor of the passive house. **Figure 4** shows that the total primary energy consumption of a passive house including the energy consumption for construction and rehabilitation is 77 % lower than with a standard house. Due to enforced insulation, low transmission windows and off-air-heat-recovery especially the primary energy consumption for room heating is reduced to about 5 % of the present room heating consumption. Thus passive houses need only much smaller heating systems as standard houses.

The energy consumption for electricity and warm water preparation as shown for the passive house in **figure 4** is based on the assumption that also very efficient electrical appliances and warm water preparation technologies are applied. These technologies are described further down.

Today the construction costs for the passive house are generally higher than for a standard house. In social projects specifically aimed at achieving low costs, the passive house buildings were erected for 1000 Euro per m² living area. Including the costs for the building area and all side costs the total construction costs were with 2000 Euro per m² living area, making the passive house nearly competitive already today /10/. In general today the construction of a passive house with massive walls is about 300 Euro per m² living area more expensive than a standard house. A passive house with wood walls another 150 Euro per m² living area /11/.

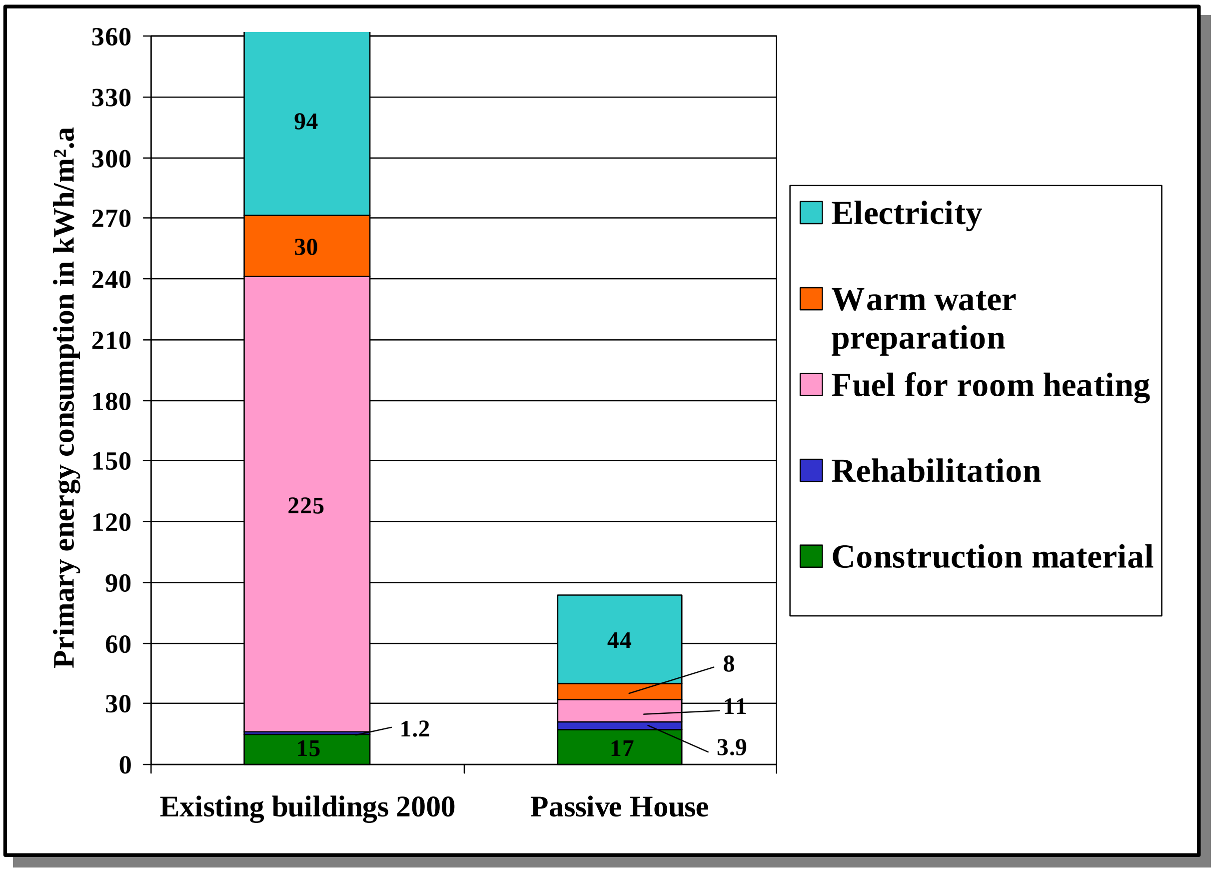

Figure 4: Primary energy consumption for a passive house as compared to an existing average house in Germany (construction and rehabilitation energy consumption are distributed over an 80 year life span) /4/.

3 Warm Water Preparation

Today energy consumption for heating water is, after space heating, the second largest energy user in the residential sector. The average European citizen uses 36 liters of 60 °C hot water daily with tendency for increase in future (see **table 7**). Following warm water heating technologies are frequently used:

- gas water heaters,
- electric water heaters (in many cases connected to a hot water storage tank),
- solar water heaters,
- and systems where hot water preparation is connected to the room heating system.

In recent years low flow solar heating plants have been developed. These, however, show the risk of bacteria growth in their low temperature water systems.
Other advanced energy saving technologies are:

- high efficiency condensing gas water heaters and super insulation,

- heat recovery systems from off-water,
- combined hot water/refrigeration systems,
- and hot water saving devices like special mixers, ergonomic bath tubes and low flow shower heads.

As can be seen from **table 7**, also with conventional technologies efficiency improvements are expected.

Table 7: Technical data for conventional domestic hot water technologies /8/

		1985	1995	2010
60 °C hot water demand	l/(d*person)	26	36	45
Fuel efficiency gas heaters	%	70	80	90
Fuel efficiency electric storage heaters	%	85	90	95
Technical lifetime	a	12-15	10-12	10
Capital cost 100 l heater	€/kW		130-300	
Capital cost 200 l heater	€/kW		200-400	
Capital cost 250 l heater	€/kW		350-500	

4 Heating, Cooling, Air-Conditioning

Many different heat and cool generation technologies are available or under development. Most of them belong to one of the following categories:

- Boilers,
- Heat pumps,
- District heating substations,
- Electric heatings
- Solar panels.

4.1 Fuel Boilers

In **boilers** a fuel is burned, to transfer the released heat to a heat distribution systems. Commonly used fuels are natural gas, fuel oil and solid fuels including wood.

In **condensing boilers** (see **figure 5**) the exhaust gas is cooled below the dew point of water in the exhaust gas setting free the condensation energy. The dew point for natural gas exhaust gas at an air/fuel ratio (λ number) of 1 lies at 58 °C (when the fuel is oil). The condensation energy is 0.63 kWh per kg water. This leads to a utilization factor (which is referred to the lower heating value of the fuel) ranging from nearly 109 % at part load to approximately 102 % at full load (see **figure 6**, right). Condensing boilers thus are an excellent technology for modulating operation. The heat generation can follow the heat demand over a wide load range very efficiently. The efficiency can be further increased, when the return water temperature is reduced to 30 °C (see **figure 6, left**). Thus a condensing boiler can be effectively combined with a floor heating system.

The core piece of the condensing boiler is the heat exchanger which is made of cast aluminum-silicon. This material allows the production of complex heat exchanger forms /12/.

For a comparison of oil, gas and wood fired boilers and expected of the heatings' features till 2010, see **table 8**.

New boiler developments aim at a reduction of NO_x emissions (≤ 25 mg/kWh) and CO emissions (≤ 33 mg/kWh), as well as at efficiency improvements, especially with wood boilers. For the year 2000 it is expected that the market share of condensing boilers in Germany will be 25 % /13/.

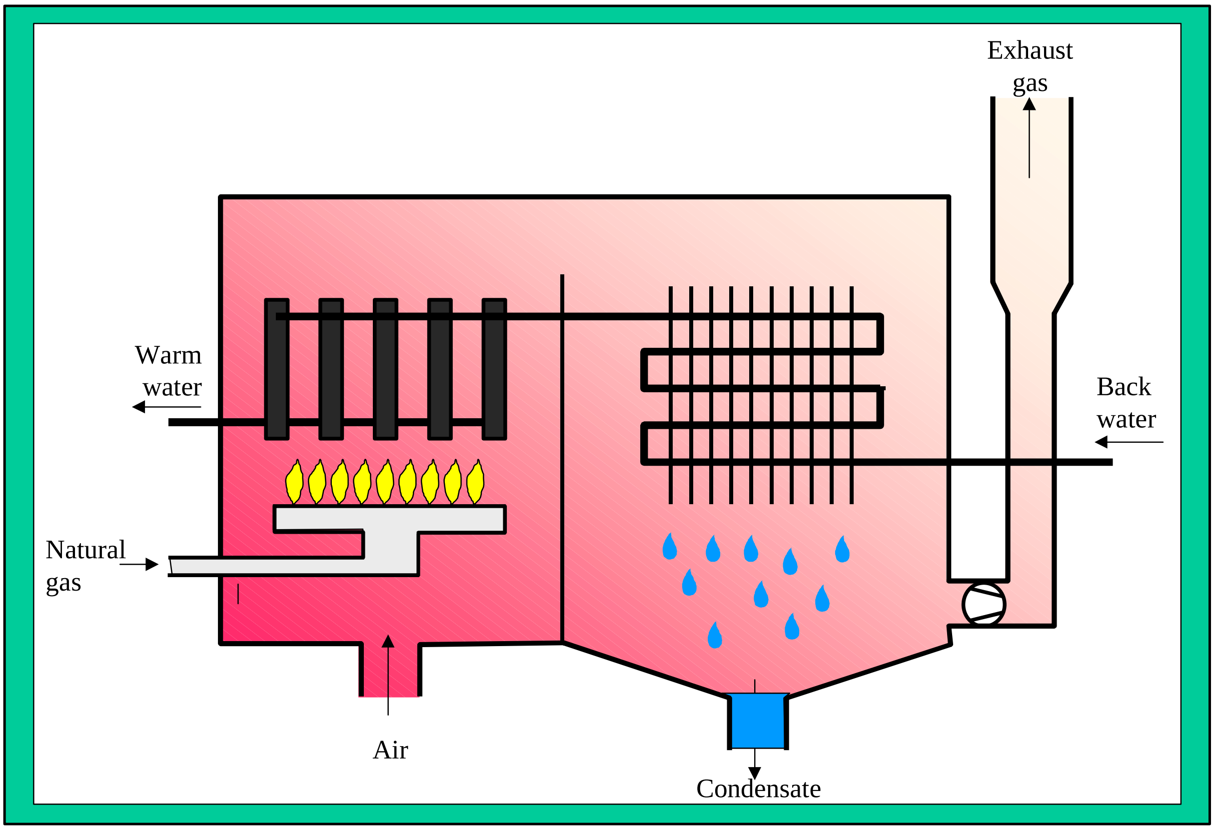

Figure 5: Scheme of a condensing boiler

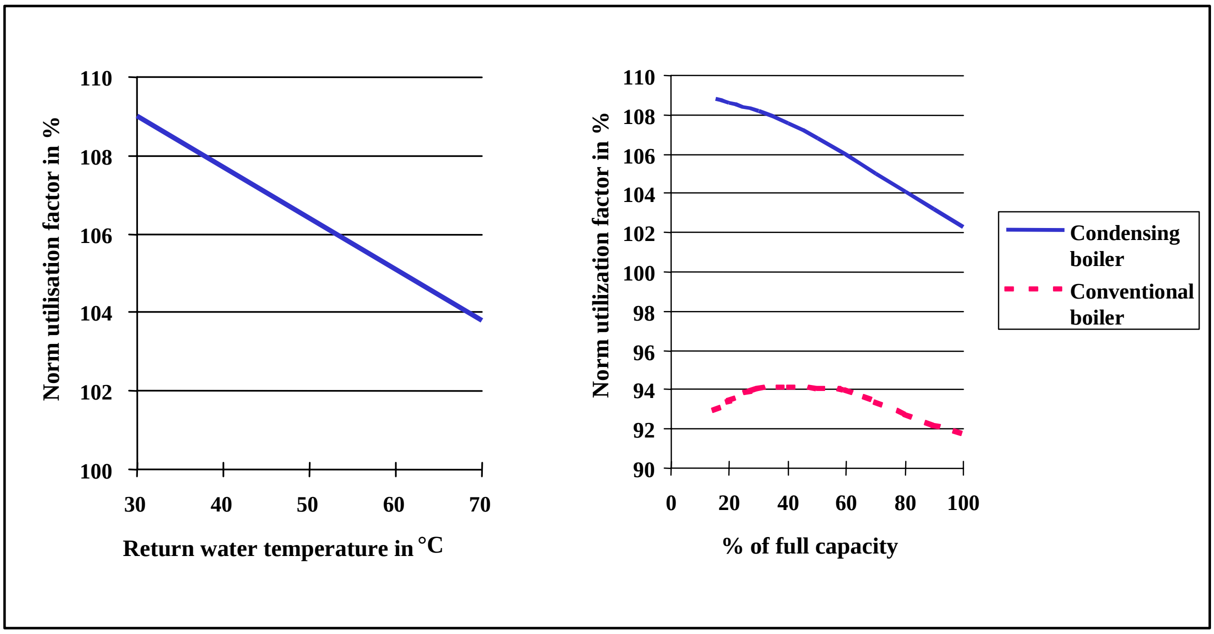

Figure 6: Utilization factor of natural gas fired condensing boiler as function of return-water temperature /14/ and part load efficiency of condensing and conventional boiler /15/

Table 8: Technical and economic data of boilers in the residential sector /8/

		Oil fired boiler		Natural gas fired boiler		Wood fired boiler	
	Unit	1995	2010	1995	2010	1995	2010
Typical unit size	KW	20 (-70)	20 (-70)	20 (-70)	20 (-70)	40	40
Availability factor	%	99.5	99.5			95-98	95-98
Fuel efficiency at nominal heat output	%	90 conventional 103 condensing	93 conventional 104 condensing	95 conventional 108 condensing	95 conventional 108 condensing	85 conventional	90 conventional
Gross capacity	KW	18	18-19	19	19	34	36
Self consumption	KW	0.2 (heat losses) 0.2 (electricity for burner)	0.2 (heat losses) 0.2 (electricity for burner)	0.2 (heat losses) 0.2 (electricity for burner)	0.2 (heat losses) 0.2 (electricity for burner)	0.8 (heat losses) 0.1 (electricity for exhaust fan)	0.8 (heat losses) 0.1 (electricity for exhaust fan)
Technical lifetime	A	20-25 (boiler) 10 (burner)	20-25 (boiler) 10 (burner)	20-25 (boiler) 10 (burner)	20-25 (boiler) 10 (burner)	20-25 (boiler)	20-25 (boiler)
Capital cost	€/kW	170	<170	420	360	105-130	<105-130
Fixed O&M cost	€/a	65-130	65-130				
Variable O&M cost	€/kWh	fuel price	fuel price	fuel price	fuel price	fuel price	fuel price
CO_2 emission factor	G/MJ	73	73	73	73	100	100
SO_2 emission factor	Mg/MJ	23-50	0-20	0.1	0.1	20	20
NO_x emission factor	Mg/MJ	40-50	15-25	80-90	50-70	200-300	<200-300
Particulates emission factor	Mg/MJ	5	<5	0-1	0-1	200-300	<200-300
Non methane volatile organic compounds emission factor	µg/MJ	10	<10	5	<5	10	<10

4.2 Biomass heating systems

Though heating with biomass is the oldest of all energy technologies in human use, there had been important technological and efficiency improvement in recent years, making a modern biomass heating system very comfortable in operation and use. **Figure 7** shows as example the graphic of an automated wood chip stove.

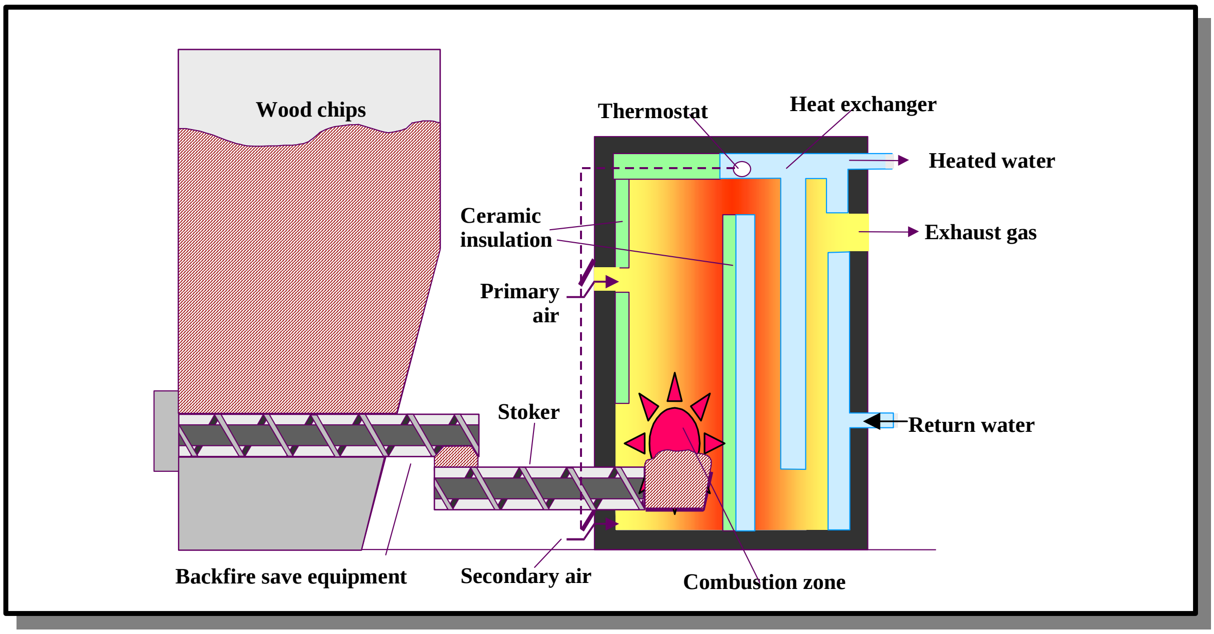

Figure 7: Automated wood chip heating stove

Figure 8 shows the specific investment costs of decentral biomass heating systems. It can be seen that conventional wood heating systems, pellets heating systems and wood chip heating systems, in the capacity range from 15 to 40 kW thermal capacity become cheaper with increased unit capacity. When looking only at the investment costs conventional wood heating systems are the cheapest and wood chip heating systems are most expensive. Also the resulting heat supply costs are lowest with conventional wood heating systems (see **table 9**). Thus at a unit size of 45 kW a pellets heating system is 30 % more expensive than a conventional heating. However, in this calculation it is neglected that pellets heating systems can be much better automated and controlled. The supply can exactly follow the demand. Pellets also allow the development of a standardized market and of a standardized delivery system. The need considerably less storage volume and the total handling is made exclusively by machines. Thus the pellets heating system has seen growth rates of 50 % and more in recent years in Austria.

All wood heating systems have seen considerable efficiency improvements in the last decade. There is also some, however, small space for further improvements (see **table 9**).

Table 9: Room heat generation costs of de-central biomass heating systems

	Spec. Investment costs in Euro/kW		Annual operation costs in % of investment costs	Wood fuel costs in €cents/kWh	load-factor in %	Efficiency in %		Heat generation costs in €cents/kWh			
	at 15 kW	at 45 kW				In the year 2000	In the year 2100	in 2000		In 2100	
	Boiler capacity							with 15 kW capacity	with 45 kW capacity	with 15 kW capacity	with 45 kW capacity
Conventional wood heating	436	247	1.7	2.5	20,5	86	88	5.89	4.58	5.81	4.51
Pellets heating	690	338	1.7	3.3	20,5	87	90	8.36	6.03	8.21	5.89
Wood chip heating	1054	392	1.7	2.5	20,5	88	90	9.96	5.52	9.88	5.45

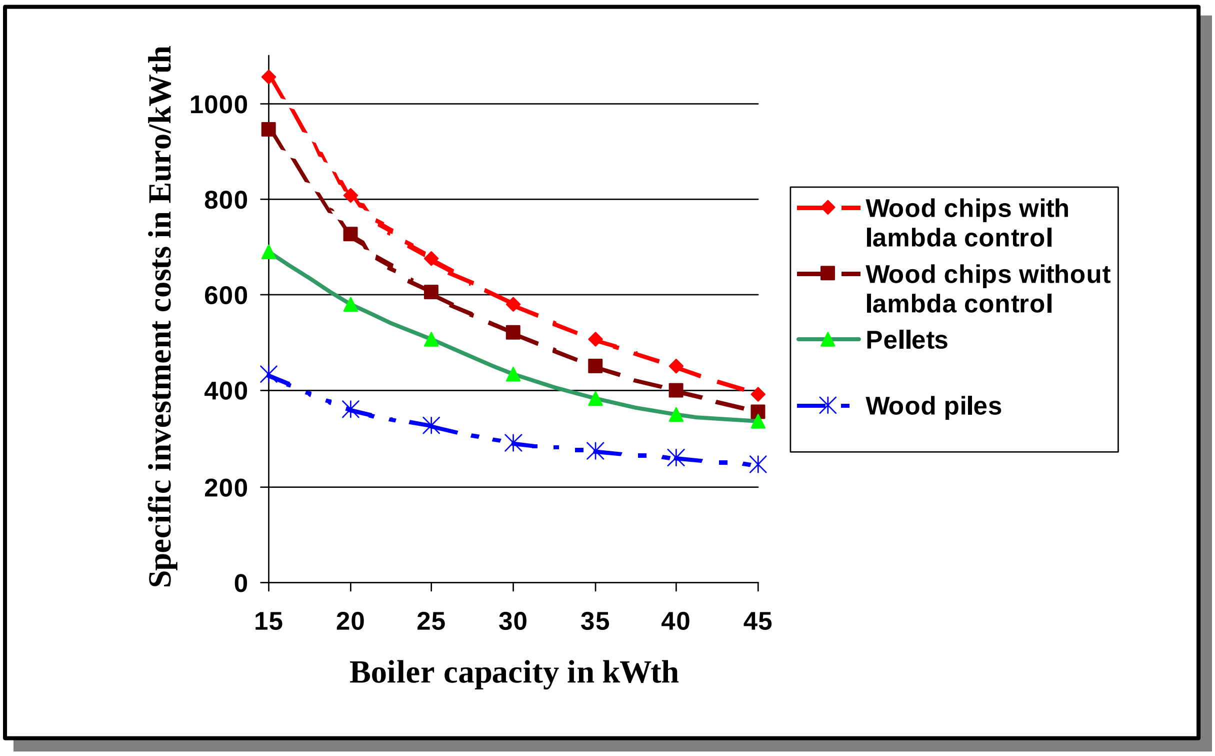

Figure 8: Investment costs of de-central biomass heating systems /16/

4.3 Heat Pumps

With **heat pumps** the energy stored in ambient air, the ground or exhaust air is “pumped” to a higher temperature level, which then can be used for room heating. In the building sector vapor compression and absorption heat pumps are available, the latter is not frequently used, as off-energy with a temperature > 100 °C is needed as energy source. The technical/economic data of compression and absorption heat pumps is shown in **table 10.**

Table 10: Technical/economic data of residential heat pump technologies /8/

		Vapor compression		Absorption	
	Unit	Electric	Gas engine	Single effect	Double effect
Capital cost	€/kW	250	480	190	230
Installation cost	€/unit	570	570	570	570
Maintenance cost	€/(kW*a)	22	34	17	20
Heat output/ energy input	GJ/GJ	2.4	1.4	1.15	1.35
Annual heat output	GJ/(kW*a)	8	8	12	12
Gas input per heat output	GJ/GJ		0.71	0.87	0.70
Electricity input per heat output	GJ/GJ	0.42		0.055	0.055

4.4 Solar Panels

Solar radiation can be converted to heat by absorbers like a house wall, or a solar collector. The scheme of a solar collector is shown in **figure 9**. Light energy is taken up by an absorber of dark color which in turn heats the heat carrier. As heat carrier water or air is in use. The collector cover is light transparent and limits convective heat losses.

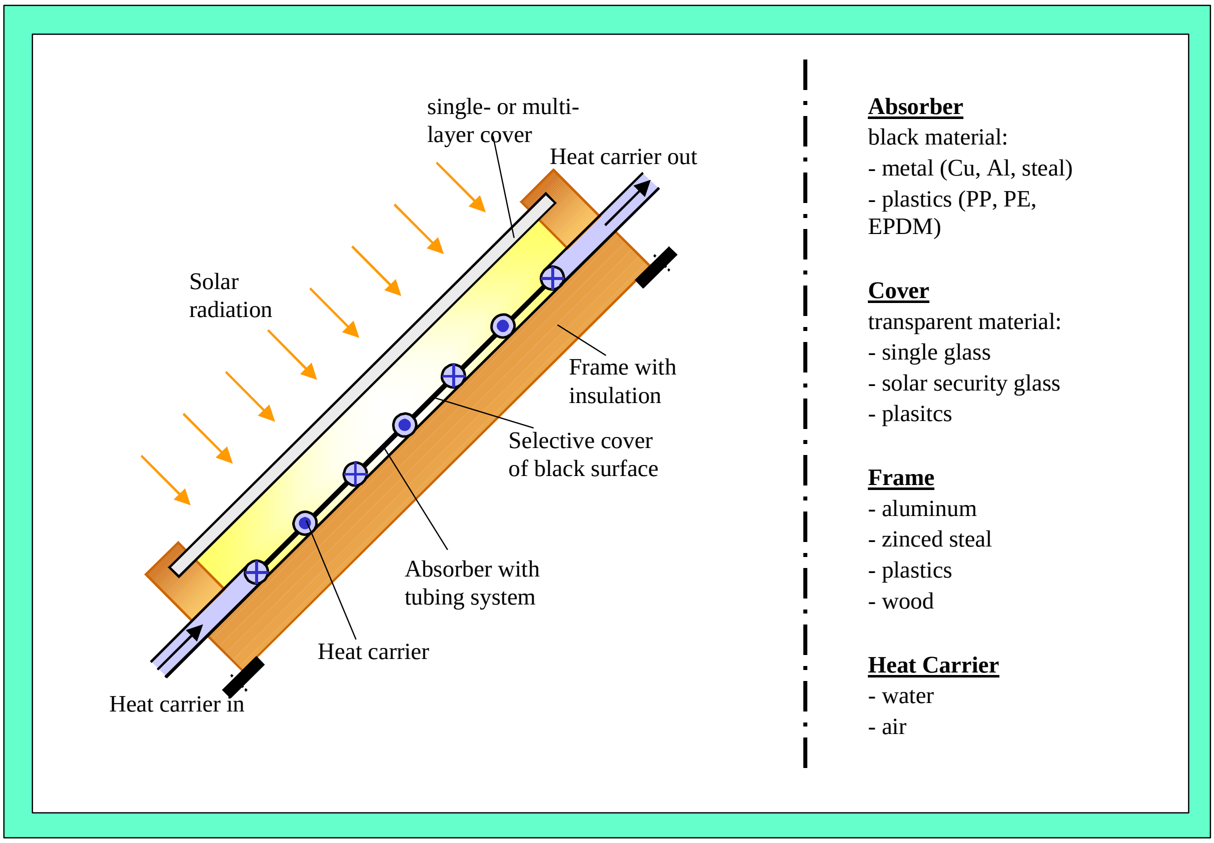

Figure 9: Scheme of a solar collector

There are non-concentrating and concentrating solar collectors. Concentrating collectors are only applied in countries with cloudless skies. In more cloudy countries non-concentrating collectors are used as they can utilize also the diffusive part of the light. Two technologies of non-concentrating solar collectors with water as heat carriers are available:

- the less expensive panel collectors (as depicted in **figure 9**)
- and the more stable tubular collectors.

For a comparison of the costs of these collector types see **table 11.**

Table 11: Costs of solar collectors /17/ (including heat storage facilities)

	Invest costs	O&M costs	Specific heat yield		Heat generation costs		Deprecia-tion period
	€/m²	€/(m²*a)	kWh/(m²*a)		€cents/kWh		a
			Min	Max	Min	Max	
Panel collector	725	12	350	500	15.5	22.0	20
Tubular collector	1788	12	350	500	16.7	28.6	20

In addition to the collectors a total solar heating systems comprises tubing, energy storage equipment and a pump. The losses referred to the incoming solar energy are as follows:

- 14 % reflection at the collector
- 7 % incomplete absorption in collector
- 30 % heat losses to environment
- 6 % heat losses in tubing
- 6 % heat losses in storage system
- 1 % auxiliary energy for pump.

In total only 36 % of the incoming solar energy are actually utilized for heating.

Solar collectors are applied for:

- heating of swimming pools,
- warm water preparation in households,
- support of room heating. In countries like Germany the solar energy supply is anti-correlated to the room-heat demand. That is why, in Middle-European countries solar heating can only be an addition to an other room heating technology, like heat pump or conventional heating systems.

Solar heating is a mature technology which provides only limited space for further development and cost reduction /18/.

4.5 Air Conditioning and Cooling

“Active” air conditioning by power consuming cooling technologies is state of the art. But even among these technologies the efficiency (the output of cooling capacity per electric power input) varies between 1.45 and 5.42 /19/. The impact of usage of “active” air conditioners on the electricity demand is a serious problem for many countries with tropical and subtropical climate. Also in many European countries, as well as in the USA, where the total electric peak load induced by air conditioning is estimated equal to 38% of the coincident peak load, a major consumption of economic resources is connected to cooling.
As air conditioning is expected to become a much bigger role in the future, efficient “passive” cooling technologies gain importance.

In this paper the design of air conditioning installations in the Mediterranean area is discussed, especially the penetration of air conditioning equipment in the Mediterranean area and the impact of urbanization on the cooling demand of buildings. Strategies to decrease or eliminate the cooling load of buildings are presented. Possible improvements in the technology of room air conditioners as well the expected improvements in their efficiency are discussed.

4.5.1 Penetration of Air Conditioning

Increased energy consumption in Southern Europe mainly results from the use of conventional air conditioning systems. **Figure 10** shows that during the last years the penetration of air conditioning in southern Europe is extremely high.

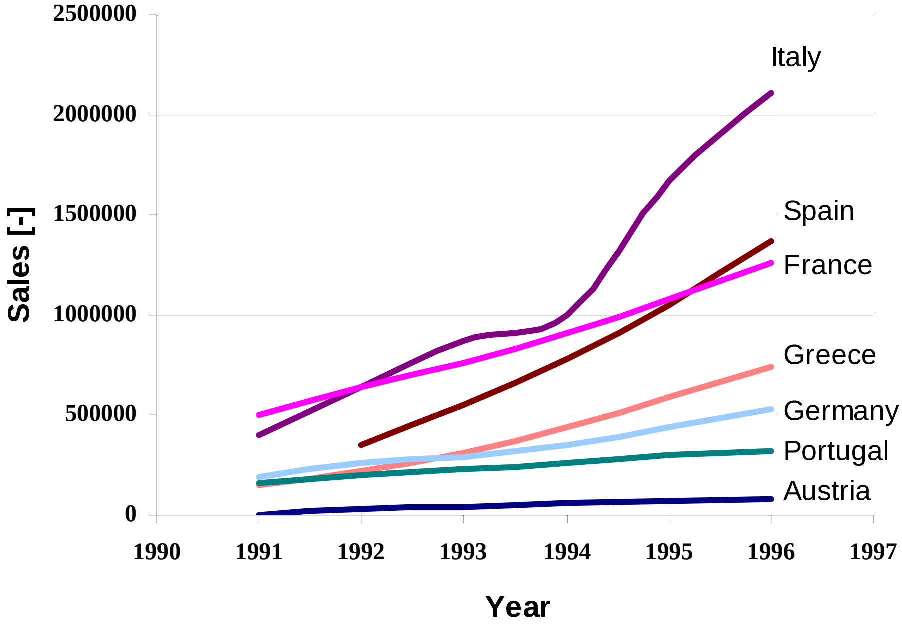

Figure 10: Sales of air conditioning equipment./49/

4.5.2 Urbanisation and Cooling Demands of Buildings

Heat increasing effects in warm to hot climates exacerbates cooling energy use in summer. In US cities with populations larger than 100.000 the peak electricity load will increase 2.5 to 3.5 % for every °C increase in temperature. /49/

Extended urban climate measurements have been carried out in Southern Europe during the last 5 years. When the set point temperature is 28°C, the maximum cooling load for a building (500m²,25 people) is close to 23.5 kW to 27.8 kW.

4.5.3 Techniques to Reduce the Cooling Demand

Cooling technologies investigated in this module are either passive or hybrid. They use only little mechanical energy to move cold air or water and distribute and emit "coolth" or they can do without any mechanical energy. Some of these technologies include the main "source" of cooling while others only deal with efficient distribution and emission of cooling energy. None of the technologies

investigated here use a refrigerant, and all technologies, whether they can be used as lone cooling system or combined with other active conventional cooling systems, lead to substantial decrease in cooling energy consumption, and peak or total cooling capacity: they are low energy cooling technologies.
These technologies cover, with some limitations, a wide range of applications for various climates: residential buildings, commercial buildings, new and retrofit applications.

Development of construction and design of buildings is a necessary condition for the future. A possible solution is passive cooling. Passive cooling maximizes the efficiency of the building envelope by minimizing heat gain from the external environment and facilitating heat loss to the following natural sources of cooling:/48/

- Air movement.
- Cooling breezes.
- Evaporation.
- Earth coupling.

Passive cooling also maximizes the ability of the occupants to lose heat to natural sources of cooling.

Cooling requirements in houses are generated predominantly by climate. Household activities have lesser impact but are still important – especially during periods of “extreme ”weather conditions.

Heat enters and leaves a home through the roof, walls, windows and floor. Internal walls, doors and room arrangements affect heat distribution within a home. These elements are collectively referred to as the building envelope. Envelope design is the integrated design of building form and materials as a total system to achieve optimum comfort and energy savings.

Good envelope design responds to climate and site conditions to optimize the thermal performance. It can lower operating costs, improve comfort and lifestyle and minimize environmental impact.

Passive design should include passive heating provision for winter in all climates except hot humid (tropical). The degree of winter heating can be adjusted for the climate with appropriate passive solar shading.

4.5.4 General Design Principles

The air inside a building should be fully exchanged at least every two hours /5/. This can be done either by natural ventilation (through stacks, windows and doors) or through mechanical ventilation. Mechanical ventilation can be:

- regulated,
- combined with dynamic insulation,
- or combined with a heat exchanger, which transfers heat from the off-air to the in-air.

A number of “passive” cooling technologies are available or about to be introduced which allow the proper air conditioning of buildings at low energy consumption:

Night ventilation:

uses natural means or mechanical power to blow outside air at night in a building and cool its thermal mass allowing it then to absorb internal or external heat during the following day.

Evaporative cooling:

uses wetted pad or water spray on which air is blown to decrease its dry bulb temperature. Evaporate cooling can be " direct " if inlet air is blown directly on the wet media. In this case evaporative cooling provides sensible cooling while increasing latent heat content of air. Evaporative

cooling can also be indirect, when outside air cooled directly through the evaporative cooler transfers its " coolth " to the indoor air to be conditioned through an air to air heat exchanger. In that case, evaporating cooling provides sensible cooling while keeping constant the latent capacity of air.
A new approach is the dehumidification “wheel”, utilizing solar heat and evaporative cooling: Silica gel, packed into a dehumidification wheel, adsorbs moisture from the inlet air. A solar collector heats the outlet air to around 65 °C. As the wheel turns it passes through the stream of the heated exhaust air, making the water desorb from the gel. The gel is then dry enough to adsorb water in the next cycle. A second wheel – a rotary heat exchanger – pre-cools the inlet air while simultaneously pre-heating the outlet air /21/.
One example for an environmentally-friendly Evaporative Cooling System is the Japanese Roof Spraying System (see **figure 11**). Rooftop sprinklers are used to spray water, which absorbs heat when it vaporizes to cool the building interior. No additional air conditioners or other such cooling equipment is used.

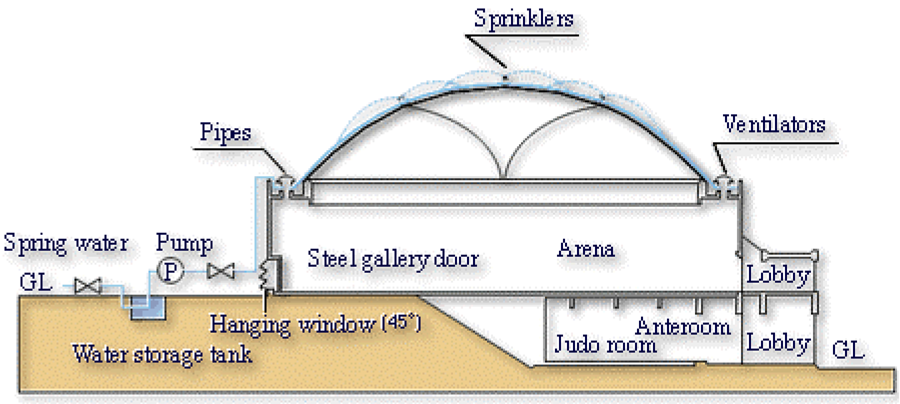

Figure 11: Structural diagram of the passive cooling system

Night sky radiative cooling:

uses radiative heat transfer towards night sky to cool a thermal mass (usually water) component of a building (usually roof mounted). Night sky temperature can be typically 15°C cooler than dry ambient temperature. Cooled mass will be used as heat sink for building internal and external gains during the following day. Such systems can be entirely passive (water bags called roof ponds) or require some mechanical power to pump water up and down and use water to air heat exchanger to distribute cold air inside the building.

Ground cooling with air:

uses long term thermal inertia of ground (a few meters below ground level yearly temperature only a few degrees around mean yearly temperature) to extract "coolth " in the summer (and possibly heat in the winter as well) through air to ground heat exchangers. These heat exchangers are usually made of buried pipes networks in which outside or building air is blown to be cooled.

Like water, earth or subsurface, rock reduces extremes of heat and cold. Although the surface temperature of soil rises during hot summer days, soil at a depth of several feet is much cooler and generally remains at a constant temperature year-round.

The temperature of the surface of the earth varies according to the seasons. Unless a large volume of subsurface soil is available for very little effort and cost, only modest amounts of cooling can be expected from this technique. There are other potential problems as well, including moisture, which can encourage fungi and insect or animal life, causing adverse health conditions. The Earth Temperatures (approximate) at different depths

Ground Surface	1 – 24°C	
1.5m below surface	6 – 17°C	
3m below surface	8 – 16°C	
9m below surface	11 – 13°C	/Source: American Institute of Architects/

Ground cooling with water:

uses fairly low temperatures aquifer water (typically 10°C), when it is available, as cooling source. Such systems require two (or more) wells to pump water up from and return it down to the aquifer. This primary loop transfers cooling energy to the secondary building cooling distribution loop through a water to water heat exchanger. This system can be supplemented if needed by additional cooling systems.

Slab cooling with water:

uses building slabs (usually concrete) as cooling energy distributors and emitters. Water is pumped through closed loop piping network in the slab at typical temperature range of 15°C to 18°C. These fairly high temperatures are possible because of the large cooling emission area. They increase the overall efficiency of the cooling process whatever is the cooling source of the system, active or hybrid/low energy.

Chilled ceiling and displacement ventilation:

use mixture of radiative and convective cooling distribution-emission technologies to keep commercial building cool with significantly lower energy consumption than with conventional convective systems. The main cooling needs is provided by a radiant chilled ceiling that operates through the same process as radiant cooling slab but with increased emission efficiency due to the fact that cold air drops from ceiling. Additional latent cooling needs are provided through cooled fresh ventilation air that can thus be kept to minimum required flow rate for indoor air quality purposes. In these displacement ventilation systems air is supplied at inlets near the floor at 18°C with very low speed (typically 0,2 m/s). It can then spread evenly on the floor surface and makes its way up at the vicinity of internal heat sources. It is then exhausted through the ceiling.

Slab cooling with air:

uses the thermal inertia of building mass for cooling energy storage by circulating cooled air through channels in the building horizontal (floor, ceiling) and possibly vertical (interior and exterior walls) slabs. The building structure will then be a heat sink for internal or external sensible cooling loads. The cooling source is usually night time air but other hybrid or low energy cooling sources could also be used.

Desiccant cooling:

uses desiccant material to absorb moisture (latent load) from air in a dehumidifier. Solid base or liquid based desiccants can be used. During this dehumidification heat is released and the dry bulb air temperature increases. This temperature is then reduced (sensible load) by an auxiliary cooling system (active or low energy). In such systems latent load and sensible loads are dealt with separately allowing to good indoor air humidity control.

4.5.5 Current Market Position for Passive Cooling

The EU market for cooling is dominated by active compression cooling systems. The other cooling technologies existing on the market are night ventilation, evaporative cooling and ventilated cooling beam (chilled ceiling where cooling source is compressor or outside air - specific for Nordic countries). Night ventilation is usual in all mechanical ventilation systems in the commercial sector /9/.

The main market for cooling and air conditioning systems is in the commercial sector. About 6 % or about 20 Mm^3 of existing offices, commercial buildings and industry buildings are cooled in Europe. It is expected that by the year 2010 the cooled building stock volume will be even four times larger.

In the residential sector of the EU cooling systems are unusual up to now. In southern European countries there is a much wider need and use for air conditioning than what can be observed in France, UK or Germany.

4.5.6 The Future of Passive Cooling and Conclusions

Rudimentary forms of passive cooling have been used successfully for centuries and a much-improved technology is available today. However, continued research and development suggest that even greater improvements will be possible in the future. As population increases in hot regions and as energy becomes scarcer and more costly, the demand for passive cooling increases. Although it is presently only a minor contributor to human comfort when compared with conventional cooling methods, the growing demand will create a large potential market. This will stimulate better design and more effective systems and equipment. Better materials and equipment for use in passive cooling seem assured because of advances in allied fields, and the increasing focus on passive cooling technologies. Among these advances are:

- Improved heat rejecting metals and other materials
- Automatic movable insulation and shading devices
- Reversible chemical reactions for heat exchange
- Selective window glazing for heat rejection
- Improved desiccant materials

For the category of buildings, free standing core oriented with mostly open plan and heavy structure, improvements of the building envelope may decrease the cooling load of the reference buildings by 6.6 kW/m²/a or 15 ´% of the cooling load. In parallel, the application of passive cooling technologies may decrease the cooling load by 4.4 kW/m²/a or 10 ´%, while retrofitting of the artificial lightening may reduce the load by 6.6 kW/m²/a or 15 ´% and finally improvements in the HVAC system may decrease the load by 13.2 kW/m²/a or 30 ´% of the cooling load.

Theoretical studies have shown that the application of special design, lighting, passive cooling and insulation may decrease their cooling load by up to 70%.

5 Lighting

Light can be provided by daylighting or by artificial lighting.

Daylighting is the efficient use of sunlight through adapted components and control strategies. Real world examples have shown that sales increase in departments placed under daylight and school performance increased in daylighted classes /22/. A number of technologies and design elements are available or about to be introduced to improve daylighting of buildings, including:

- skylights, rooflights, atria;
- advanced glazing, with spectrally selective glazing, prismatic glazing, holographic films, chromogenic glasses or electrochromic glazings;
- tracking light collectors;
- light pipes, light shelves and reflectors;
- high reflectance painting;
- optical fibers;
- optical control systems.

Artificial lighting is a major power consumer (see **table 12**). The efficiency of a lamp is given as its efficacy in Lumens per Watt (lm/W) with a theoretical maximum of 680 lm/W for monochromatic light and 225 lm/W for white light.

Table 12: Electricity consumption for lighting by sector /8/

Sector	**% of electricity used for lighting in sector**
Offices	50
Hospitals	20-30
Factories	15
Schools	10-15
Private building	10

Different lighting technologies which show different efficacy and lifetime are available, including following types of lamps:

- Incandescent lamps consist of a wire filament which is heated and emits light. Halogen gases and special tungsten filaments can increase brightness. The life of the lamp is not affected by the number of starts. These lamps create comfortable color light, are easy to dim and cheap.
- A linear fluorescent tube is a low pressure discharge lamp in which an electric arc excites mercury vapor and produces UV radiation, which in turn excites phosphors to emit visible light.

Fluorescent lamps produce 3 to 5 times as much light as incandescent at 6 to 8 times longer life time (which is affected by the number of start-ups).

- Compact fluorescent lamps (CFLs) consist of 2 to 4 small fluorescent tubes with a plug-in base. CFLs of 7 to 26 W and 60 to 70 lm/W offer energy savings of up to 80 % at 6 times longer life spans than incandescents. During the 1990ies the price of CFLs fell from 20-23 € to 7-18 €. In the same time CFLs got nearly as small as incandescent lamps and the life time extended from 8,000 to 15,000 hours. In future CFLs are expected to become fully applicable for all uses of incandescent light bulbs. For a comparison of CFLs and incandescent lamps see **table 13**.
- Induction lamps have a similar efficacy as fluorescent tubes at a 50,000 hours life time, but are very expensive. These lamps consist of an arc tube in which the discharge occurs, surrounded by an outer envelope. They require a control gear for start up and for maintaining stable operating conditions. Three kinds of induction lamps are currently available:
  - High pressure sodium (HPS) lamps are the most efficient lamps, producing a golden light of warm appearance but poor color rendering. They now have a life time of 16,000 h leading to a replacement cycle of 3 to 4 years with street lighting;
  - High pressure mercury (HPM) lamps are significantly less efficient but also less expensive;
  - Metal halide (MH) lamps are HPM lamps which, by the addition of metal halides, achieve an efficacy similar to that of HPS lamps and a good color rendering.
- In recent years 24 V, halogen lamps, which allow special design features got more and more popular. They need, however, a voltage transformer.

Table 13: Comparative technical information of incandescent lamps and CFLs

Type	Incandescent 100 W			Tungsten halogen (incandescent) 100 W			CFL 20 W		
Year	**1980**	**1995**	**2010**	**1980**	**1995**	**2010**	**1980**	**1995**	**2010**
Nominal flow in lm	1000	1350	1400	1300	1600	2000	800	1000	1160
Efficacy in lm/W	10	13.5	14	13	16	20	40	50	58
Lifetime duration in h	900	1000	1000		2000	2500	6500	8000	15000
Color temperature in K	2800	2720	2600	2900	2830	2700	3500	2700	2600
Color rendering in %	100	100	100	100	100	100	80	92	100
Price in €/bulb	0.8	0.6	0.4	17	10	4	31	21	10

Some recent light source developments reported in /23/ are:

- A diode emitting white colored light is now available, extending the field of application for light emitting diodes to illuminating indoor rooms and outdoor areas. The big advantage of diodes is their long life time of 100,000 h and their small warming.
- Most up-to-date linear fluorescent tubes of 14 to 35 W now have only a diameter of 16 mm and an efficacy of 24 to 80 lm/W.
- The shape of latest CFLs is made very similar to incandescent light bulbs, so that CFLs can replace traditional light bulbs now in most application.
- Recent metal halide lamps utilize ceramic burners instead of quartz burners. Ceramic burners show a more stable light color and lead to “natural” colors even under artificial illumination, making metal halide lamps perfect for lighting shops. These lamps are available in the 70 to 150 W range. Following the trend of miniaturization now a 35 W metal halide lamp with 85 mm in length, 17 mm in diameter and an efficacy of 90 lm/W is available.
- Small halogen lamps 50 mm in length and 14 mm in diameter which can be operated directly by 230 V have been developed recently.

6 Electrical Appliances

Table 14 shows the electricity consumption of typical electrical appliances of Austrian households as of 1995, **table 15**, the electricity consumption of market best and market worst appliance per category.

Table 14: Annual electricity consumption by appliance for a typical Austrian 3 person household /24/

Appliance	Size/utilization frequency	Electricity consumption in kWh/a
Stove with baking oven		500-800
Freezer	200 l	300-400
Refrigerator	180 l	250-350
Dish washer	5 times / week	350-400
Washing machine		250-300
Tumble dryer		300-350
Coffee machine	8 cups / day	60
Hair drier	1 hour / week	30
Hand mixer	10 minutes / day	10
TV-set + HiFi (incl. Standby)		200-250
Personal computer		70

Table 15: Austrian 1995 market best and worst appliances from "Forum Haushalt 2001" (OKA-Geraetedatenbank) in /24/

Type	Specification	investigated sample	el. consumption of market best	unit	el. consumption of market worst	unit
Stove	600 hours/a operation	98	292	kWh/a,100 l	693.5	kWh/a,100 l
Refrigerator	Without freezing compartment, below 200 l	111	58.4	kWh/a,100 l	255.5	kWh/a,100 l
Refrigerator	Without freezing compartment, above 200 l	34	32.85	kWh/a,100 l	186.15	kWh/a,100 l
Refrigerator	3 star, below 200 l	98	102.2	kWh/a,100 l	310.25	kWh/a,100 l
Refrigerator	3 star, above 200 l	37	109.5	kWh/a,100 l	237.25	kWh/a,100 l
Refrigerator-freezers	with 0°C zone	15	135.1	kWh/a,100 l	299.3	kWh/a,100 l
Refrigerator-freezers	without 0°C zone	162	73	kWh/a,100 l	332.15	kWh/a,100 l
Freezers (vertical)	below 200 l	119	127.8	kWh/a,100 l	511	kWh/a,100 l
Freezers (vertical)	above 200 l	60	109.5	kWh/a,100 l	255.5	kWh/a,100 l
Freezers (horizontal)	below 200 l	24	113.2	kWh/a,100 l	324.85	kWh/a,100 l
Freezers (horizontal)	above 200 l	64	65.7	kWh/a,100 l	229.95	kWh/a,100 l
Dish washer	50 to 60 cm wide, 2500 set menus/a	153	175	kWh/a	400	kWh/a
Dish washer	45 cm wide, 2500 set menus/a	68	275	kWh/a	625	kWh/a
Washing machine	95 °C washing program, 500 kg laundry/a	214	120	kWh/a	300	kWh/a
Tumble dryer	Condensation, 800 rpm, 500 kg laundry/a	42	210	kWh/a	475	kWh/a
Tumble dryer	off-air, 800 rpm, 500 kg laundry/a	35	210	kWh/a	350	kWh/a

6.1 Electric cooking

Most electric stoves are equipped with heating plates made from cast iron. An increasing market share gain glass ceramics cooking fields (see **figure 12**). From conventional hotplates to glass ceramics the maximum efficiency increased from 50 to 60 %. With the induction cooking stove, a technology, which is still in its development phase 90 % efficiency can be achieved. Here not the cooking field is heated, but the ferric cooking vessel itself by eddy currents. This reduces the heated mass and convective heat losses (see **figure 13**). **Table 16** gives a comparison of induction heating to more conventional stoves.
Another electric cooking appliance, which has achieved 34 % market share in Austria, is the micro wave stove, which is primarily used for fast re-warming of already cooked food.

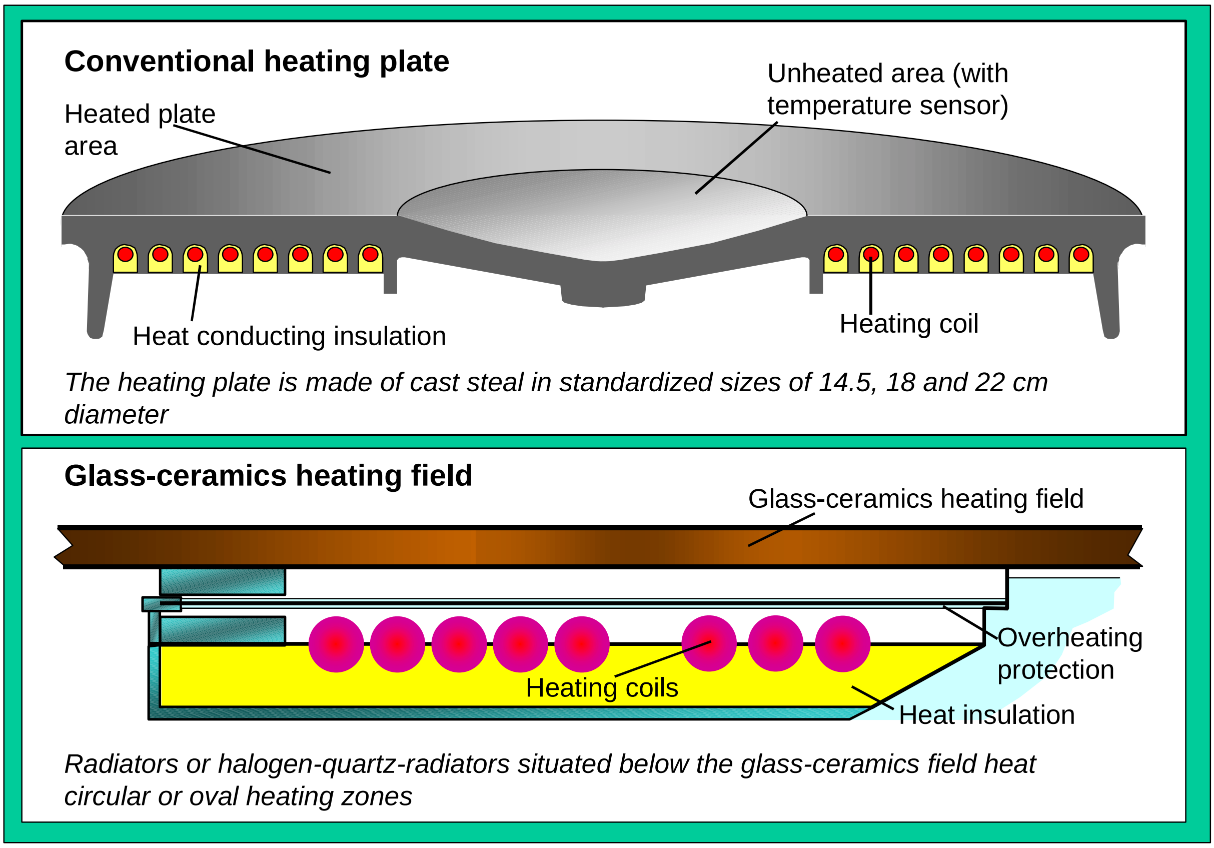

Figure 11: Scheme of conventional heating plates and glass ceramic cooking fields

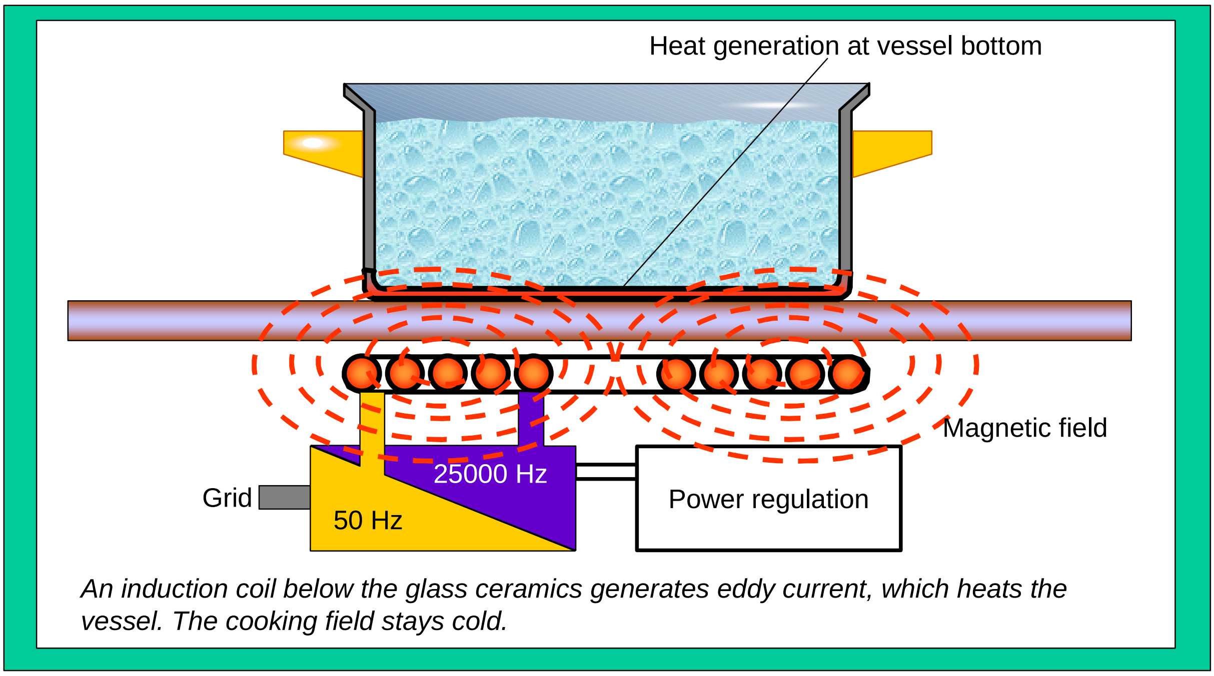

Figure 13: Scheme of induction cooking

Table 16: Comparison of stove technologies /25/				
	Domestic maximum power in kW	Efficiency in %	Time to heat 1 liter of water to 60 °C	Energy uptake for heating 1 liter of water to 60 °C in Wh
Induction	2.8	90	2'	90
Glass ceramics	2.2	60	3'50	140
El. Hot plate	2	55	4'30	150
Gas stove	3.3	50	3'10	160

6.2 Food Cooling and Freezing

By increased heat insulation the electricity consumption of refrigerators and freezers was reduced by 50 % in the years from 1980 to 1995. Energy saving refrigerators and freezers are on the market, which reduce the electricity uptake by another 40 %. **Table 17** gives a comparison of electricity consumption and investment costs of standard and energy efficient refrigerators and freezers currently available on the market. With respect to freezers it can be seen, that horizontal freezers provide 50 % more freezing volume at the same electricity consumption as compared to vertical freezers.
For the future it can be expected, that energy consumption will be further reduced, by further improved insulation techniques.

Table 17: Comparison of standards and energy saving refrigerators and freezers from Liebherr /26, 27/						
	Type	**Total service volume in liter**	**Cooling volume (5°C) in liter**	**Freezing volume (-18°C) in liter**	**El. Consumption in kWh/a**	**Investment costs in €**
Refrigerator, smaller 200 l, 3 star						
Efficient	Kte 1483	134	119	15	160.6	583
Standard	KT 1433	129	114	15	244	474
Refrigerator-freezer combination, larger 200 l						
Efficient	KG 3366	287	199	88	313	1141
Standard	KGK 3255	285	197	88	450	1083
Freezer (vertical)						
Efficient	GS 2266	180		180	255	916
Standard	GS 2385	180		180	332	833
Freezer (horizontal)						
Efficient	GTS 3162	291		291	237	816

6.3 Wet appliances

Also with the wet appliances washing machines, clothes dryers and dishwashers there is space for cost effective efficiency improvements. /28/ estimates that washing machines can be improved by 25 %, dishwashers by 33 % and tumble dryers by 10 % with respect to energy efficiency. With wet appliances not only the energy uptake can be reduced. A further focus of development is the reduction of water consumption and consumption of detergent. **Table 18** gives an overview on energy, water and detergent consumption of standard and efficient washing machines, as well as of washing machines in the development and conceptual phase.

Table 18: Development status of efficient washing machines /28/			
	Electricity consumption in kWh/a	**Water consumption in l/a**	**Detergent in kg/a**
Market standard	225	12500	13.5
Market efficient	105	6000	7.8
Development phase	85	5500	7.8
Conceptual phase	75	4300	5
Assumed: 100 washing cycles per year at 95 °C, 5 kg each			

6.4 Brown Goods

With brown goods, these are the office, information and entertainment appliances outside the kitchen area, the development focus lies with reducing the stand-by losses. **Tables 19 and 20** gives an overview, on the stand by consumption for different appliances according to /29/ and /24/. Though both sources give quite different figures, they agree in the conclusion that stand by losses must be reduced.

Table 19: Stand by electricity consumption as opposed to active consumption according /29/					
	Time of use in h/d	Power load in W		Electricity consumption in kWh/a	
		Active	Stand-By	Active	Stand-By
Fax		20	20	4	171
TV	4	80	20	116	146
Video-recorder	2	40	20	29	16
Radio alarm	1	20		175	
Transcoders[1]	3	20		175	
Telephones	2	10		88	88
[1] such as pay TV, satellite antenna preamplifiers					

Table 20: Stand by electricity consumption for different appliances according to /24/			
Appliance	**Stand-by electricity consumption in kWh/a**	**Appliance**	**Stand-by electricity consumption in kWh/a**
Color TV	73	Fax	96
Video recorder	101	Answering machine	26
Sat-receiver	263	Mobile phone	26
Cable-TV	35	PC	162
HiFi with remote control	73	Black&white ink-jet printer	12
20 W halogen lamp	44	Color ink-jet printer	123

7 Residential Low Energy Technologies for the Developing World

Basically there is no difference between development requirements of modern industrial energy use technologies and low cost household equipment for developing countries, they need to be profitable to producers, merchants and customers /42/.

A specialty in developing countries is that the preparation of food is the primary energy consumer. Thus current technology development focuses on this energy service and here specifically with cost efficient solutions for the poor.

7.1 Biomass stoves

Recent estimates indicate that biomass energy is the fourth most important energy source in the world. Biomass energy is the dominant fuel in many subsaharan African countries with a market share on final energy consumption ranging from 60 % in e.g. Nigeria to over 94 % in Ethiopia /30/.
In spite of the long traditions with biomass stoves there are many problems connected to the current operation of this technology, including:

- Limited availability, poor harvesting, no transport, high humidity, low heating value of the fuel
- Poor efficiency and maintenance of the stoves
- Poor hygienic conditions and safety precautions
- Energy and time consuming cooking
- No experience in improving the technologies by professionals

In order to overcome the problems of efficiency, safety hazard and health impact, a number of simple stove designs were proposed for different developing countries. 6 of such designs are shown in **figure 14**. Their design data are shown in **table 21**.
Common to all is a relatively simple construction, mostly from material which is readily available in the respective countries. Also important is the fact that the fabrication can be either done on site or by simple local factories.

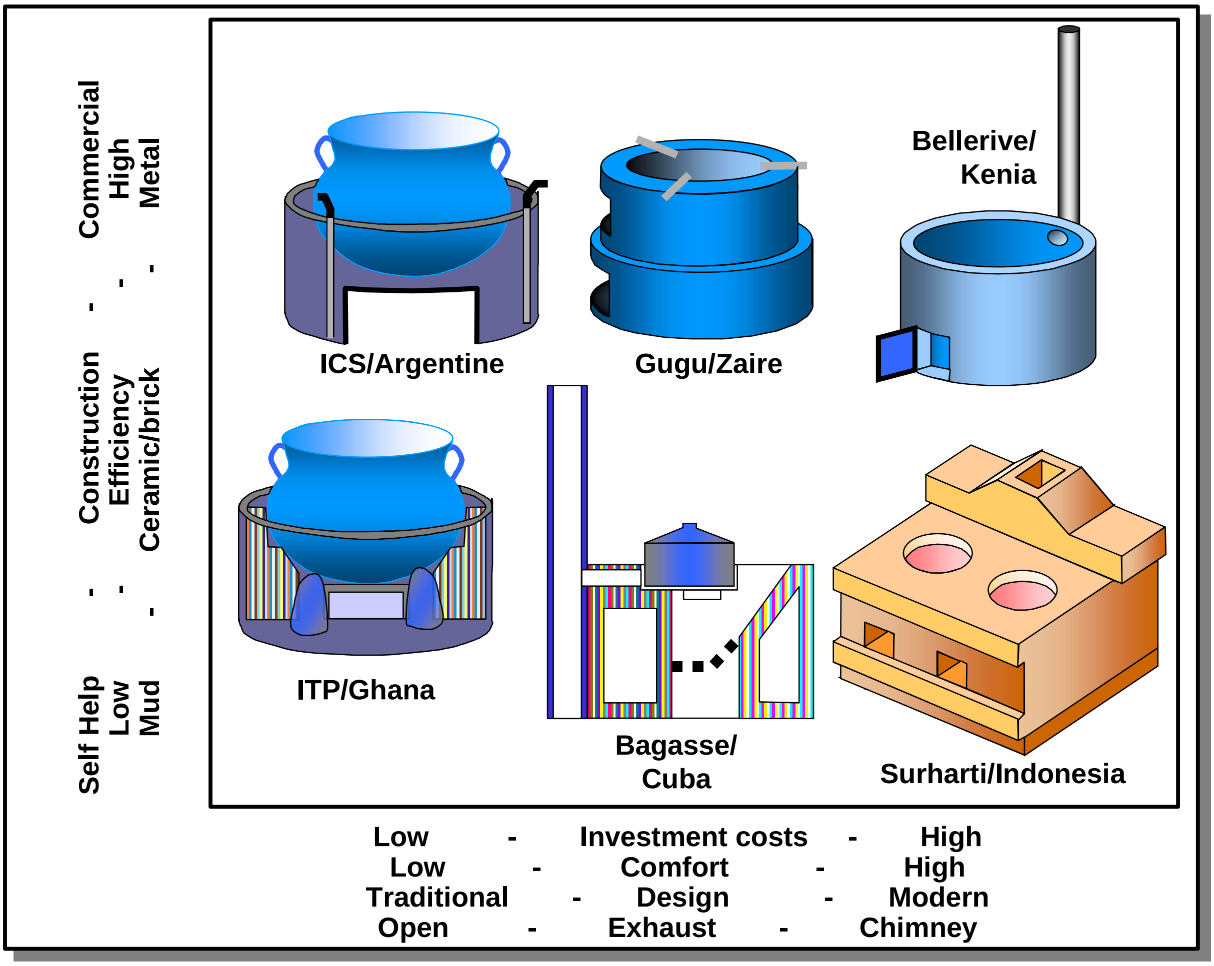

Figure 14: Efficient stove designs for developing countries

Table 21: Design data of 6 selected efficient stoves for developing countries			
Stove name	**Stove description**	**Type of fuel used**	**Thermal Efficiency**
Agentinian community stove	For pots of 44 cm diameter	Firewood	42 %
Zairian Gugu Mobile	Characterized by highly ventilated combustion chamber, also for slightly fresh wood, made from oil drums	Wood, agricultural waste	32 %
Bellerive Institutional Stove / SMP 200 /Kenya	Made of a mild steel frame for pots of 200 l	Dry firewood of 20 cm length	
Ghanian Street Vendor Stove	For street food sellers and 50 to 100 l pots	Wood, agricultural waste	35 %
Cuban Institutional Bagasse Stove	A channel type stove with stepwise grate for 150 l pots	Sugar bagasse pellets, pelleted or powdered waste fuel	25 %
Surharti Institutional Stove / Indonesia	A composite stove made of cast iron and brick for pots of up to 70 cm	Firewood, coconut husks, straw, shaved wood, leaves	28 %

7.2 Solar stoves

In order to reduce the dependence on biomass as primary energy source in developing countries many solar stove designs have been proposed. Most of them follow one of the three design types shown in **figure 15**. The box stove design is the most popular, followed by the concentration stove type. The solar stove capacities range from 500 ml jam-glasses to food for 800 persons. The heating time ranges from 6 minutes to 2 hours, the achieved maximum temperature from 91 to 198 °C. The costs lie in the range of 50 €/stove. The payback period is 18 months, referred to fuel saved.
In areas where the solar stove was carefully marketed it achieved market shares of 38 % and high acceptance by the users. Globally, however, solar stoves did not yet achieve high penetration rates.
A study by GTZ investigated the reasons why solar stoves up to now have not achieved a higher market share /31/. The barriers against solar stoves market introduction were identified as:

- Lack of operation skills of the cook
- Lack of budget control by the cook
- No external incentives
- Lack of durability of the stoves.

Factors who could accelerate the market introduction are:

- Motivated cooks
- External incentives for the reduction of fuel consumption.

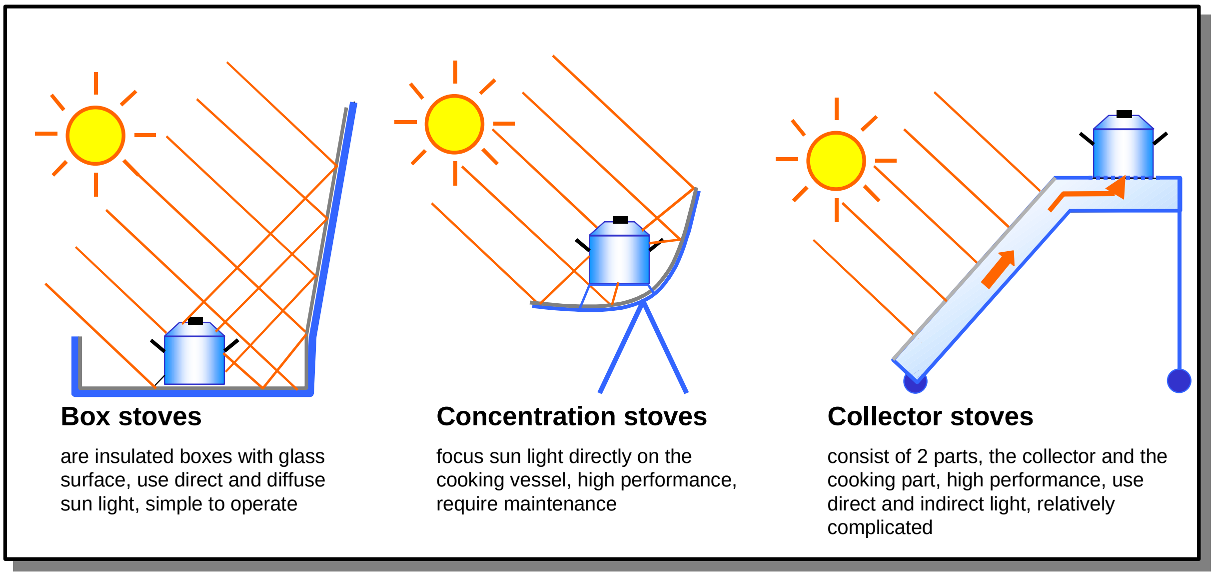

Figure 15: Basic types of solar stoves

8 Household Electricity Demand Pattern

An extrapolation of the electricity demand growth in Austria as derived from the historic data from 1980 to 1998, results in an average growth rate of 1.46 %/a.

Figure 16 shows the electricity consumption of Austrian household electrical appliances by type of appliance (without room heating and warm water preparation) for the years 1960 to 1995) /32/ and extrapolated to 2100. It can be seen that appliances which already have reached market saturation, like washing machines, freezers and TV sets will contribute less to the total household electricity consumption due to efficiency improvements. Electrical cooking and lighting will maintain a high share in energy consumption as efficiency improvements (e.g. by market penetration of energy saving light bulbs) are equalized by additional service demand or new fashions (like halogen lamps). Other appliances like tumble dryers and dish washers have not yet fully penetrated the market, but are expected to do so in the next two decades. Highest growth rates of electricity consumption in households can be referred to small appliances, including information and entertainment technologies. This category is just about to pass lighting as the most power consuming appliance category within households. Not shown in **figure 16** is electric heating (which is expected to lose some market shares), electric warm water preparation and air conditioning. The latter till now play a minor role in Austria, but are of primary importance in the United States and other countries with hot climate.

When assuming a constant demand for electricity on heating and warm water purposes till 2010 the household electricity demand would grow slowly, at 0.54 %/a. After 2020 household electricity demand would even decrease. A further growth of household electricity demand would only occur if a new type of energy services could be provided by electrical technologies which are not yet known. These are marked by a "?" in **figure 16**.

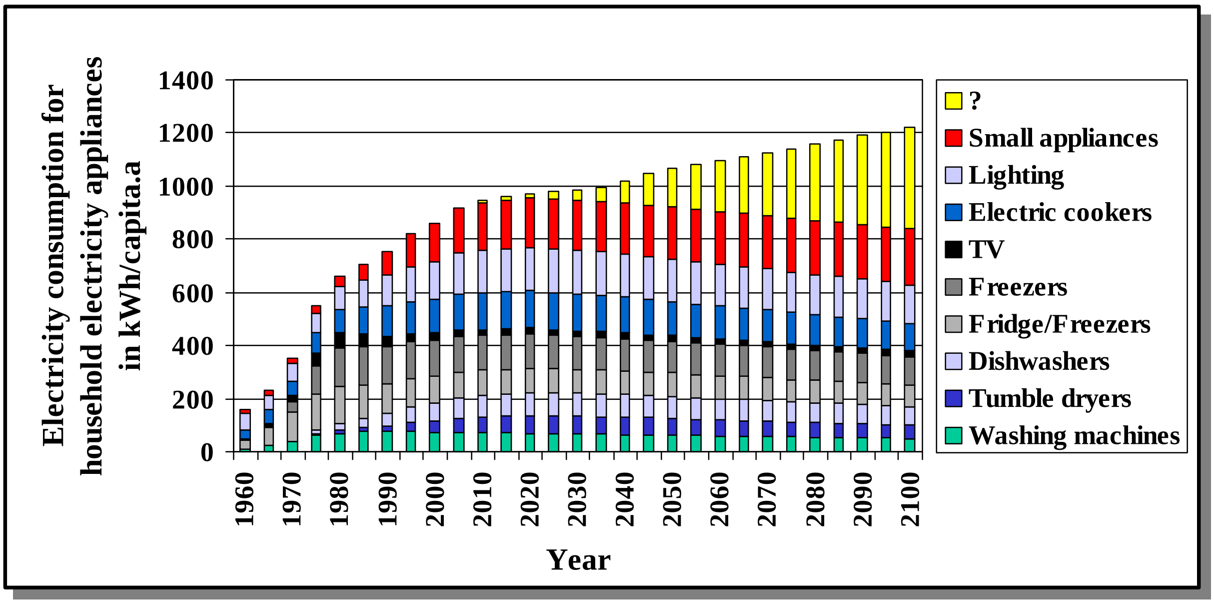

Figure 16: Electricity consumption of electrical appliances in Austrian households (without room heating and warm water preparation) – historic development /32/ and extrapolation till 2100

A possibility for reducing the peak load demand in buildings is load shedding by means of remote control via internet, power lines /33/, mobile phones or satellite connection. Those appliances which have some storage capacity, like refrigerator or warm water boiler, are switched-off during peak load hours by a central control system. This measure, which is already applied in industries, leads to a better, more economic utilization of the power supply capacity.

Modern micro electronics can even do more. The European Installation Bus for example controls:
- lighting in and outside the building,
- jalousies in dependence of temperature and user wishes,
- security of windows and doors,
- conference media,
- kitchen electrical appliances,
- heating and ventilation /5/.

9 On-site Electricity Generation and Small Scale CHP

CHP plants for the residential and commercial sector typically are smaller than 30 kW_{el}, and convert about 30 % of the input energy to electricity and 50 % to useful heat. In the residential sector the CHP technology is the most efficient way of generating energy out of natural gas or waste/biofuels. The capital costs range from 900 to 2400 €/kW, the O&M costs lie at 5.2 US¢/kWh /8/. Currently most small scale CHP units are gas diesel engines. In future micro-turbines, Stirling engines and fuel cells will be available. 3 kW_{el} to 1 MW_{el} low temperature fuel cells (PAFC and PEFC) are expected to be introduced for power only production. High temperature fuel cells (especially SOFCs) should be available for CHP production after 2010.

Additional research for dispersed CHP aims at:
- the construction of even smaller CHP units for single houses,
- efficiency improvements and alternative biomass fuels
- a combined generation of heat, power and cool,
- a reduction of the current 80-300 g/GJ NO_x emissions.

10 Social Aspects

New technologies mean change for the life style of people. The prospect of change causes resistance. It is not known how new technologies will effect the way of living. It is not known if they really bring comfort or if they rather bring new responsibilities, new risk and new nuissance. This general resistance against change is the more critical the nearer the new technology shall be applied to everday's living sphere. This resistance is especially critical for technologies which shall be applied in homes and thus for energy efficient equipment of low energy houses.

Anticipating that efforts have to be made to overcome this resistance in an early phase of development, a number of sociological and technological studies have bee performed in the frame of the Austrian impulse program "Nachhaltig Wirtschaften – Haus der Zukunft" (Sustainable economizing – house of the future). These studies featured surveys with designers and early users of innovative energy efficient technologies and analyzed specifically following questions:

- What do residents wish from their homes?
- Can concern on energy spending be a motivation for living in low energy houses?
- Which lessons can be learned from early users and early planners of low energy houses?
- Which social, political and legal environment must be developed in order to get wide spread acceptance for new energy efficient technologies?

10.1 Dreams for the home of the future

This section discusses the factors which are necessary that a resident feels well within the own 4 walls. The most important aspects for the home of dreams are:
- A silent site with high living quality
- Enough rooms
- A well developed infrastructure for the basic living requirements (shops, schools, medical doctors)
- A good infrastructure for the leisure time
- Easy to reach recreational areas
- A good public transport system for reaching the basic infrastructure and leisure time institutions
- The possibility for good recreation and entertainment within the own 4 walls
- High quality of construction material
- Good lighting
- Good storage possibilities
- A good ground plan
- Safety and security.

Of secondary importance are:
- A good price/quality ratio
- Apartment house specific equipment like low energy demand or a special offer on common rooms.

Factors which can easily cause dissatisfaction is the quality of building material, details in planning and too little storage room.

For the future, when the general trend of individualization proceeds special attention has to be put on such areas and facilities where people can come into contact. It is also expected, that future residents will be satisfied with prefabricated solutions. It rather will be necessary, that the future residents are early involved in the planning process /34/.

What has remained the same, now since many decades, and which can be expected to be also valid in future, is the wish of an own single family house in a green environment as home of dreams /35/.

10.2 Energy saving and sustainability as motivation for low energy houses

Heating and energy are only of tertiary importance in the mind of residents. In spite of changing energy prices, there is lack of information with respect to energy use and costs. For example existing warm water meters frequently are not known by the residents. Less than 50 % of residents know, that warm water and room heating are responsible for the majority of energy costs.

For most Austrian residents environmental protection means separating waste and electricity saving. Low energy apartments did not make their residents more concerned about the environment. Thermal comfort has the same importance for people living in standard houses and for people living in low energy houses. However, the utilization of thermostats for heat regulation is much more common in low energy houses (more than 33 %) than in standard houses (13 %).
The sources of knowledge on heating and energy for most people are mass media. Few people have contact to professionals or public information systems. The level of knowledge is independent from the educational level /36/.
Less than 20 % of people living in standard houses wished to live in energy saving homes. Most think they know enough about energy, indicating an over confidence, which is not reflected by the reality. Especially in apartment houses with central heating systems, the energy bill is hidden in the general rent and as such not known. In order to stipulate more concern on the actual costs of energy it will be necessary to visualize the actual heating, energy and operation costs in a more transparent way. This should include graphics, a comparison with the preceding years and a comparison with average and minimum consumptions /34/.

10.3 Lessons learned from early users and early planners

This section presents the results of interviews with early users of low energy or passive houses.
In general it can be stated that the low energy buildings constructed during the last ten years always corresponded to the requirements of ecological construction; by the steady increase of living area and the tendency towards extensive building, however, the gains often were equalized.
Most early users of low energy houses are classical innovators and early adopters of high educational and income level. The main motivation for the new building, however, is still very traditional. It is new living space.
With respect to the motivation to live in a low energy house there is a big distinction between residents of single family houses and residents of multi apartment houses. While in the first category, ecology is a big concern, in the second it is not. Also satisfaction is distributed in a similar way. This can be referred to the lack of involvement or apartment residents during the planning process and thus to a lack of identification with the building /37/.

One of the major components of a low energy house is the artificial ventilation system in combination with air heat recovery. As this system requires some change in the general living behavior it is of interest to specifically look at the experience of early users with this technology /38/.
In principle the users were quite satisfied with the ventilation system. However, some objections were raised against the high noise level and against lack in controllability. The situation is more problematic in larger multifamily houses where the tenants frequently had no influence on the selection of the ventilation systems, which are sometimes of lesser quality due to price pressure. In addition the users sometimes were bad informed on the appropriate use of the ventilation systems. There is, however, the positive sign that the level of satisfaction increased with younger ventilation systems which have been introduced in the last years.
The bigger part of the problems with controlled air ventilation is not caused by technical components but is rather connected to the design and implementation of the plant, to the integration with the total building, to the information of the users, to the cost pressure and to the commissioning of the system.

Though the experience with professionals improves the bigger part of architects, engineers and craftsmen is not yet used to the innovative ventilation systems.

10.4 Social, political and legal environment for new energy efficient technologies

Strategies for the dissemination of energy efficient buildings should tackle 5 levels:

1. The legal, economic and organizational environment for the introduction of low energy buildings should be further developed. This includes
   - the specialized training and certification of professionals,
   - the adaptation of supporting schemes /39/ and standards (especially the enforcement of energy efficiency standards)
   - the evolution of an integrated low energy house planning and construction culture and
   - the creation of demand with building cooperation and residents by marketing and information programs
2. The experience gained so far with low energy buildings should by introduced systematically and comprehensively into the further development of low energy building components. This introduction can be implemented on the level of technology development by means of surveys, focus groups and lead user workshops, on the level of planning, construction and commissioning by the participation of experienced users.
3. The concerns which have been raised against low energy buildings and their components by non-users should be tackled by marketing and information programs. These concerns frequently are quite opposed to the actual experience of users. For example the fear of draught with ventilation systems, caused many potential users to decide against the ventilation systems, while such a draught was not felt by the users who actually operated the ventilation systems
4. The future residents should be introduced to the planning process as early as possible in order to stipulate identification.
5. Information on the "difference" which is made by a low energy house as compared to a standard houses must be distributed. This includes on the one hand information on energy consumption in the standard house and on the other hand information of possibilities to reduce the energy consumption and the environmental impact. For example modern information technology provide the opportunity to measure the energy consumption of different appliances separately. This possibility should be utilized /40/.

Though the above shown recommendations were designed specifically for Austria, they mostly are generally valid for the European Union and possibly also for a wider area of the world. In an earlier EU project /41/ it was found that, in spite of big cultural and climatic differences, between Austria and the United Kingdom, the problems and possible solutions for improving the efficiency of energy use in the household sector are very well comparable.

10.5 Inhibitors and Promoters for the Passive House

Investigations on the consumer behavior in terms of inhibitors and promoters of innovative house building were performed in recent years in Austria. The spectrum of the considered buildings reached from small single family houses to large residential buildings.

10.5.1 Inhibitors to innovative building

A basic inhibitor, for singular technologies as well as for innovative projects, is the lack of information for consumers. This is valid for the users of the building as well as for building owners and designers. The knowledge about different technologies varies. As innovative technologies energy efficient lighting, solar thermal water treatment, central heating systems for buildings and heat pump technologies are commonly known.

In case of private house buildings, the fact can be realized, that the information level grows during the construction of the building. Building owners learn about innovative technologies while construction work is going on. However, in the original planning phase innovative technologies are really considered.
There is no dependence of information level on education level. Misinformation has been identified specifically with respect to governmental support.

According to several interviews with planners and designers for the building of a low energy house a special, professional and integral planning is necessary. For the building owner it is not possible to carry out the design of a passive house on its own, nor is it possible for him to put together the single detailed planning of different specialists, without additional professional support.
Building a passive house is different in technology from conventional house building. Due to the lack of information of planners and designers for high quality passive houses several efficient planning techniques, are scarcely applied. Thus the complete supervision of construction work is very demanding to the site manager.

Inhibitors resulting from market economy represent the most important hurdle for overall market penetration of the low energy house. Building owners generally are economically oriented and building organizations are interested in maximization of profits. Landlords rather forward the higher energy costs to the end consumer than invest in new technologies to minimize energy consumption.

Innovative planners are confronted with competition, the increased planning expense is not covered by the restrictively formulated prize rates for planners. For this reason the fee for the specialist is a substantial obstacle for the use of professional and integral planning.
The low earnings for planning services of low energy houses is an inhibitor for the overall implementation of this house type. Small private houses are less lucrative because of the high specific investment costs and the low readiness of the owners. Large residential buildings, which present an economical incentive for the planner, show low potential due to the competition to conventional planners.

The building owners value the initial investment costs much higher than the long or medium term lower operation costs. On the one hand the investment costs for energy saving occur at the same moment as several other investment costs, on the other hand (private) building owners do not generally belief in an immense reduction of the operation costs and therefore judge investments in lowering the energy consumption as being inefficient.

10.5.2 Promoters for the Low Energy House

In general the consumers basically are badly informed about low energy house technology, but in general are attracted by the concept of a house with low energy consumption.
Main reasons for this behavior are the expectations of a gain of living comfort and the importance of health. Additional motives are the aspiration for presentation and prestige, which are covered by technologies like visible solar passive elements or solar thermal collectors. Low operation costs for the passive house seldom represent the main reason for installing innovative technologies, these facts are compared to above mentioned motivations of less attraction.
The degree of identification of the consumer with the building, the construction site and the technical installations is essential for their acceptance. The degree of identification is strongly connected to the degree of decision making during planning and construction work as well as to the financial properties.

According to interviews with planners and designers of passive houses a trend towards following inhibitors and promoters can be recorded.

Table 22: Inhibitors and Promoters for Passive Houses in the view of planners /33/		
Category	Inhibitors	Promoters
Technical	• a lack of simulation and planning software	
Economic	• fees for planners • competition to conventional designs	low energy costs for passive houses
Social/psychological	• faulty cost-benefit analysis • people connect energy standard with architectonical design • low trust in benefits • uncertainties (e.g. no heating system) • communication problems and prejudice between designer and consumer • habits of consumer • lack of information • lack of sensibility	• gain of image • gain of living comfort and importance of health
ecological		installation of ecological materials low energy consumption
legal	• scale of charges for designers	
political	• no connection to sponsorship • official restriction	
institutional	• planning culture • additional education of designers • lack of marketing • generalists are inefficient • barriers in interface management	

The technology of passive houses is state of the art. In order to achieve a considerable market penetration the attractiveness of these houses need to be

11 Summary

Today in a passive house the building envelope and the heating system costs about 12 % more than a standard house. For example the envelope and heating of a semi-double-house in Germany costs about 125.000 € in the standard version and 143.000 € in the passive house version. When taking into account also the planning, financing and site specific area costs the German 125 m² (living area) house comes for 274.000 € in the standard version and for 289.000 € in the passive house version /44/.
Today the extra costs for the passive house range from 50 € to 210 €/m² living area, depending on the surface to volume ratio and the applied technologies of the building /45/. In the future it can be expected that the extra costs for the passive house will range from 30 to 100 €/m² living area. Thus a passive house in the future can be expected to cost 278.000 to 286.500 € or 2 to 5 % more than the standard house.
The relatively small cost difference between the standard house and the passive house leads to the assumption, that within the next 100 years the passive house will penetrate the market, leading to houses with much less heating demand. It, however, must be kept in mind that additional maintenance activities are necessary and that the passive house engages some additional electricity consuming appliances for ventilation and heat recovery.

Figure 17 shows the scheme of an on-site heat and power supply system in a low energy house. This system consists of:

- a pre-warming of the fresh air through earth covered pipes,
- a heat exchanger between fresh air and off air,
- a heat pump which extracts energy from the off air and shifts it to a warm water tank
- a solar heating system
- a fuel cell which supplies electricity and peak heat
- and a water storage tank.

The heat supply from this system for a typical one family house in Germany is shown in **figure 18**. The technical and economic parameters of the system are shown in **table 23**. The energy savings of a low energy house as compared to a standard building are shown in **figure 4** above. In rural areas biomass heating systems could be the main heat source.

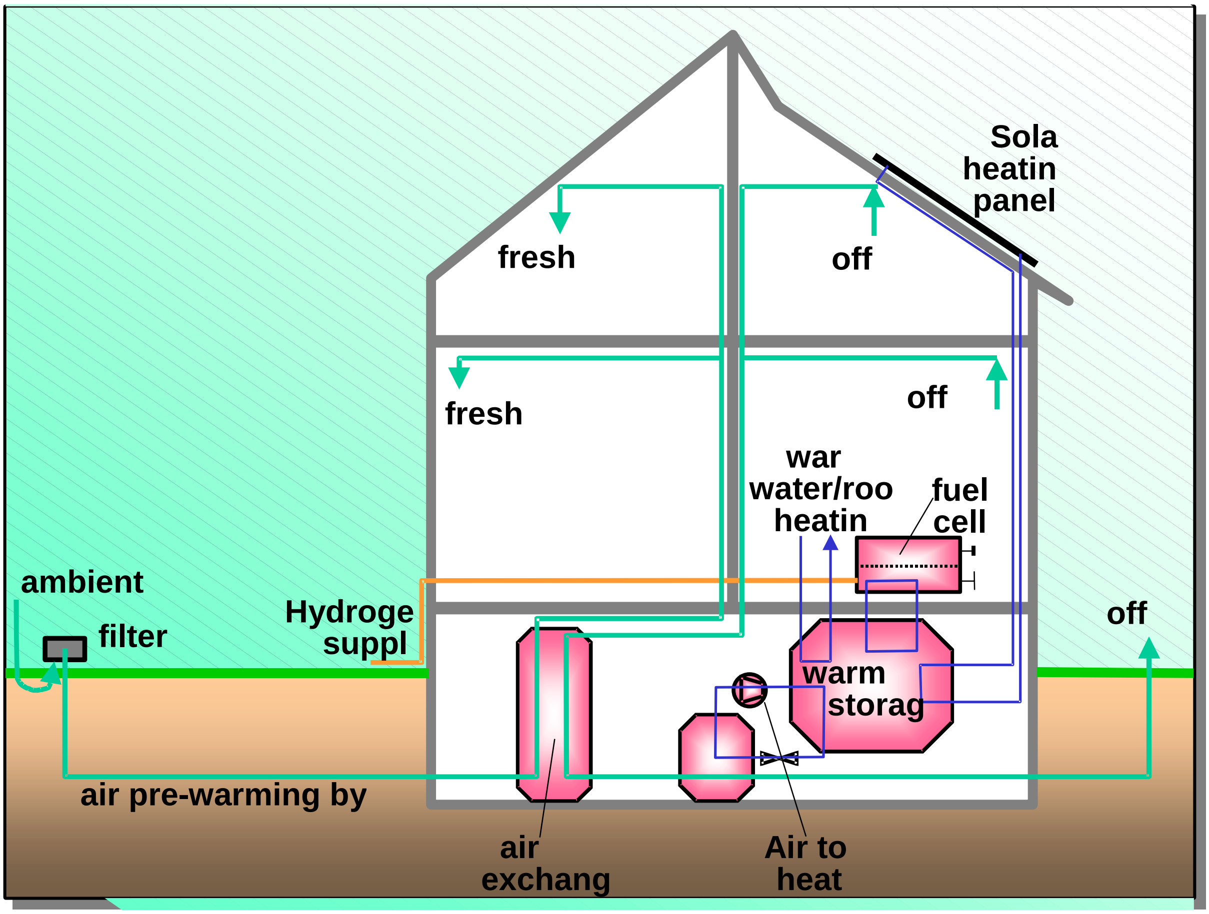

Figure 17: Electricity and heat supply for a passive house in northern countries /46/

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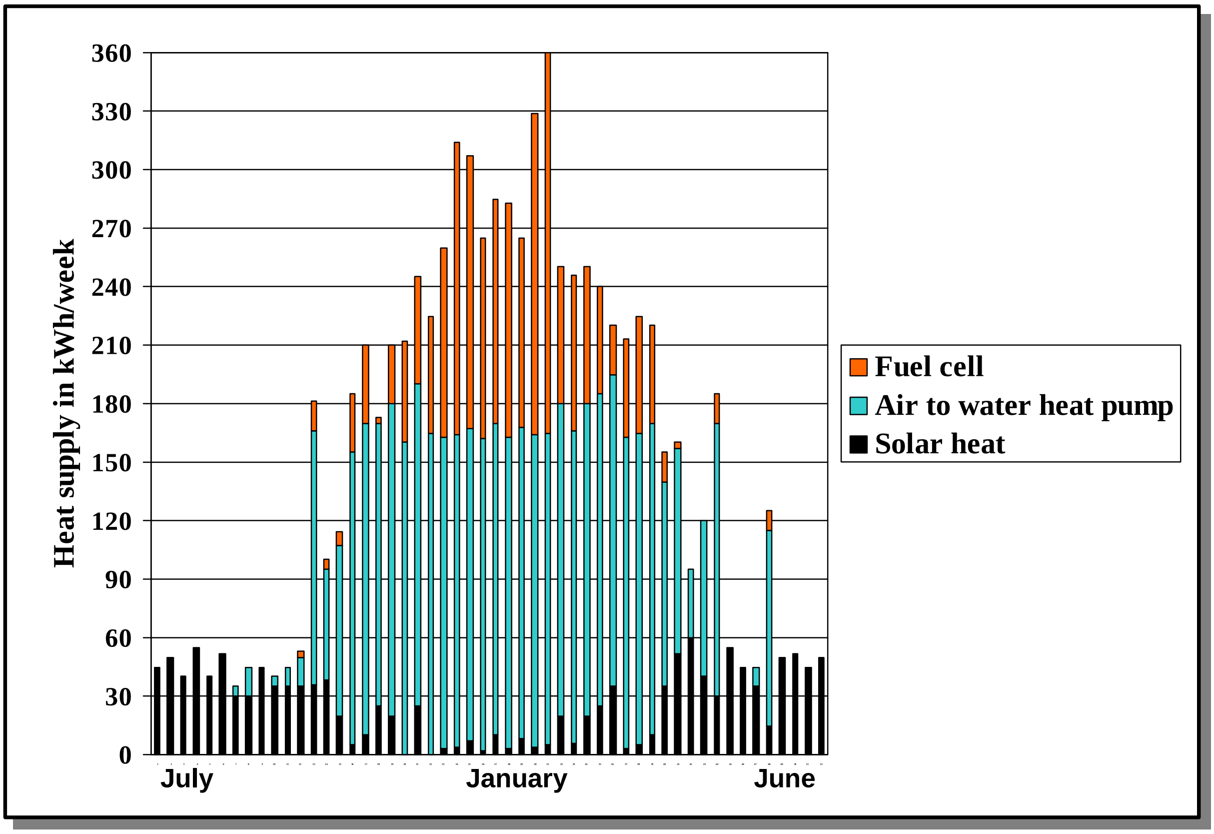

Figure 18: Passive house weakly heat supply by the different sources shown in figure 17 (assumptions: house for a 4 person family with 120 m² living area) /46/

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Table 23: Energy balance and energy supply technologies for the passive house (4 person 1 family house of 121 m² living area, total air exchange every 1.7 hours – also by window opening)

Item	Unit	Value
Energy demand		
Warm water demand	kWh/a	2699
Room heating demand	kWh/a	5473
Total heat demand	kWh/a	8172
Electricity demand for electrical appliances (derived for the year 2100 from figure 16)	kWh/a	4800
Electricity demand for heat pumps	kWh/a	1491
Total electricity demand	kWh/a	6291
Energy supply		
Solar panels		
Area of solar panels	m²	5
Heat supply from solar panels	kWh/a	1531
Costs of solar heating system (including storage facilities)	€	3625
Air to water heat pump		
Heat supply from heat pump	kWh/a	4530
Costs of heat pump	€	2500
Fuel cell		
Electrical efficiency	%	60
Thermal efficiency	%	30
Electric capacity	kW	3
Electricity supply	kWh/a	6300
Heat supply	kWh/a	2115

Hydrogen consumption	kWh/a	10500
Costs of fuel cell (target value)	€	2400
Total investment costs for on site power and heat generation	**€**	**8525**

The energy supply system shown in **figure 17** is optimized for a passive house in latitudes of 45 ° and higher. In lower latitudes the need for heating the buildings and for insulating them is much reduced. However, there is need for cooling in tropical and subtropical countries. There a heat pump could be used for cooling the fresh air (see **figure 19**).

The most commonly used active cooling systems are compressor cooling systems
Cold temperatures created by any cooling system, passive or active, should be stored in the building as long as possible. The best way to do this is to use concrete slabs for cold storage.
A system to generate cool air with low energy on basis of ground cooling combined with a compressor cooling machine, is shown in the figure below.
A glycol or water energy carrier is pumped through a water pump cycle. The energy carrier is cooled in the sub earth heat exchanger. Active cooling happens just by forced convection. As the earth has a constant temperature of about 6-11°C in 3m depth cooling is possible at a very low electricity consumption. If cooling power is too low and additional cooling is necessary, the compressor has to be started.

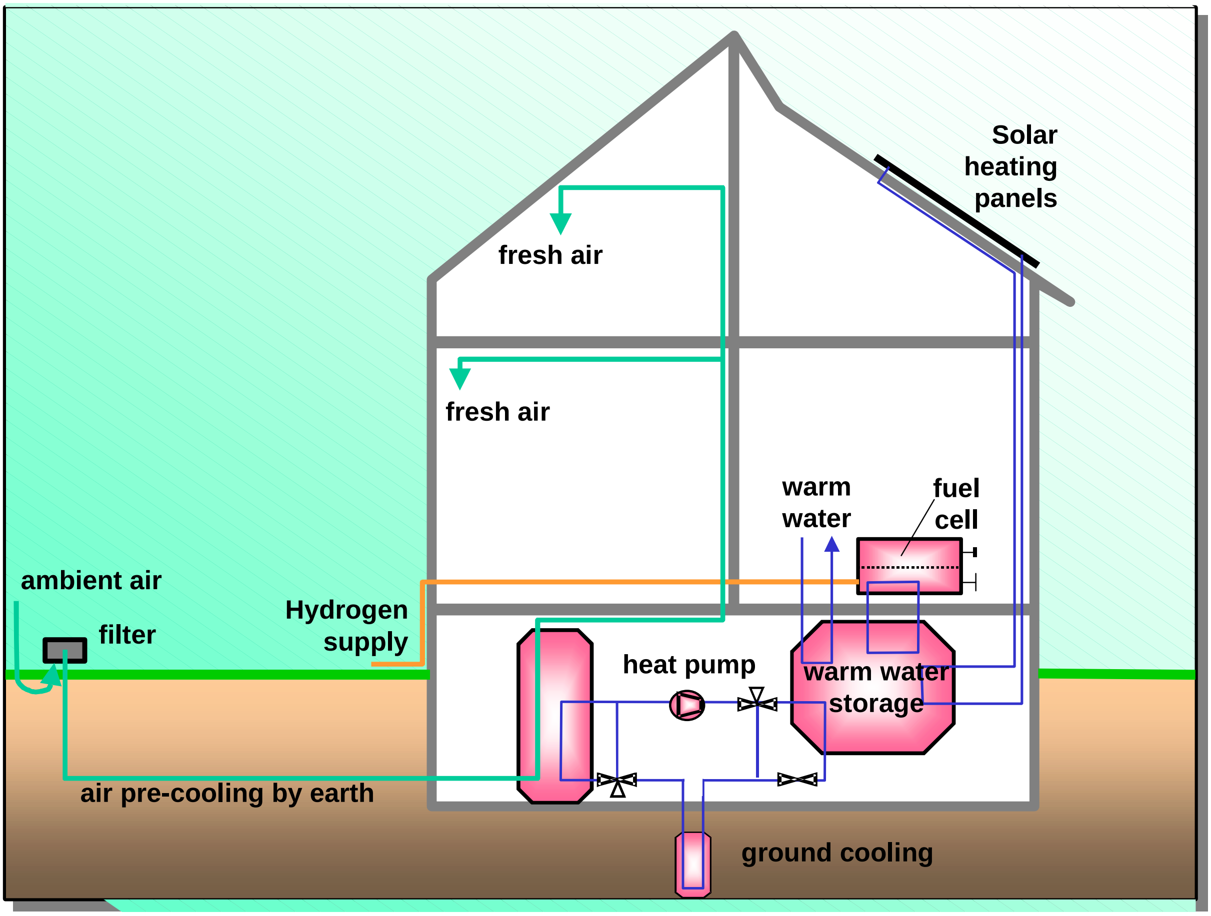

Figure 19: Electricity and heat supply for a passive house in southern countries

15 List of Abbreviations

D	daylighting coefficient
GTZ	Deutsche Gesellschaft fuerTechnische Zusammenarbeit GmbH
HVAC	Heating, Ventilation and Air Conditioning
n.a.	not applicable
U-value	Heat transmission value, heat conductivity

16 References

/1/ World Energy Council, Food and Agriculture Organization of the United Nations; The Challenge of Rural Energy Poverty in Developing Countries; WEC, October 1999

/2/ bmvit; Haus der Zukunft – 1. Ausschreibung im Rahmen des Impulsprogrammes Nachhaltig Wirtschaften; Bundesministerium fuer Verkehr, Innovation und Technologie; www.hausderzukunft.at (2001)

/3/ Bruck, M.; Total Quality ist das Ziel; Proc. Symposium Das oekologische Passivhaus, St. Poelten, Austria, 16.-17. Oct. (2000) pp. 5-16

/4/ Feist, W.; Das Passivhaus – ein Konzept fuer nachhaltiges Bauen; Proc. Symposium Das oekologische Passivhaus, St. Poelten, Austria, 16.-17. Oct. (2000) pp. 17-24

/5/ Wilk, H.; Haus der Zukunft; VEOe-Journal 6 (1997) 56-61

/6/ Primus, I.-F., Jastrow, R.; Solar-Thermie und Nahwaerme mit Massivabsorber-Waermepumpen; Elektrizitaetswirtschaft, 97 (1998) No. 11, pp. 31-35

/7/ Tschaetsch, H.-U.; Umwelt und Energie: Schwerpunkte setzen; in: Beste, D.; Fazit – Megatrends in Wissenschaft und Technik; VDI Nachrichten, 42 (1999)

/8/ European Commission; Atlas Data Base; http://europa.eu.int/en/comm/dg17/ atlas/htmlu/, 23.07.1999

/9/ Ritsch, W, Torghele, K.; Passiv im urbanen Haus; Proc. Symposium Das oekologische Passivhaus, St. Poelten, Austria, 16.-17. Oct. (2000) pp. 65-70

/10/ Rudolf, R.; Erfahrungsbericht ueber Planung und Ausfuehrung von 70 Passivhaeusern; Proc. Symposium Das oekologische Passivhaus, St. Poelten, Austria, 16.-17. Oct. (2000) pp. 25-34

/11/ Horn, G.; Gesamtsystem Passivhaus: Massiv in Stein oder leicht aus Holz; Proc. Symposium Das oekologische Passivhaus, St. Poelten, Austria, 16.-17. Oct. (2000) pp. 35-42

/12/ Lotze, H.-J.; Auf die Konstruktion kommt es an; IKZ-Haustechnik, 17 (1997) pp.62-69

/13/ Kring, H.-G.; Das System entscheidet über den Erfolg; IKZ-Haustechnik, 17 (1997) pp.52-59

/14/ Kring, H.-G.; Brennwertkessel bis 50 kW; IKZ-Haustechnik, 18 (1996) pp.65-73

/15/ Egger, R.; Waermeerzeugung fuer fluessige und gasfoermige Brennstoffe; IKZ-Haustechnik, 11 (1996) pp.23-32

/16/ Berger, M., et al.; Strategien zur weiteren Forcierung erneuerbarer Energieträger in Österreich unter besonderer Berücksichtigung des EU-Weissbuches für erneuerbare Energien und der Campaign for Take Off; Institut für Energiewirtschaft, Technische Universität Wien, im Auftrag von BMWA und BMLFUW, Wien 22. November 2000

/17/ BINE; Erneuerbare Energien in Deutschland; ISSN 0937-8367, Nr. 5, September (1998)

/18/ Kaltschmitt, M., Wiese, A. (eds); Erneuerbare Energien; Springer, Berlin, 1995

/19/ Ritter, H.; Raumklimageraete – Kuehle Luft fuer heisse Tage – und auch fuer's Energiesparen?; Energy 2 (1999) 37

/20/ Henning, H.-M.; Sunshine cooler; Innovation and Technology Transfer, 4 (1999) pp. 25-26

/21/ Henning, H.-M.; Sunshine cooler; Innovation and Technology Transfer, 4 (1999) pp. 25-26

/22/ EPRI; Here Comes the Sun; News briefs, fall 1998, http://www.epri.com/corporate/discover_epri/news/briefs/fall98.html

/23/ Zieseniss, C.-H.; Lichtquellen: Neuheiten auf der Weltlichtschau '99 waehrend der Hannover Messe '99; Elektrizitaetswirtschaft, 98 (1999) No. 16, pp. 23-27

/24/ Zeinhofer, H.; Strom im Haushalt – Energiesparratgeber; VEOe Verband der Elektrizitaetswerke Oesterreichs, Vienna, 1996

/25/ Leclerc, O., et al.; DSM in the kitchens; DA/DSM Europe 96, Vienna, October 8-10, 1996

/26/ Liebherr; Merchandizing leave letter "Supersparsam und superkomfortabel; Liebherr-Werk Lienz GmbH, Postfach 184, A-9900 Lienz

/27/ Oberoesterreichischer Energiesparverband; Besonders sparsame Haushaltsgeraete 1995; Oberoesterreichischer Energiesparverband, Landstrasse 45, A-4020 Linz

/28/ Bilde, O.; Wet appliances; Workshop on Efficient Appliances, Vienna, 12-13 October, 1995

/29/ Roturier, J.; Office technology – Energy efficient technologies: survey of present situation and discussion of future trends; Workshop on Efficient Appliances, Vienna, 12-13 October, 1995

/30/ Usinger, J., Karekezi, St.; Project and Stove Design for Large Scale Cooking in Developing Countries; GTZ, Eschborn (1999)
/31/ Schichtel, C., et al.; Solarkocher in Entwicklungslaendern; GTZ, Eschborn (1999)
/32/ Haas, R., et al.; Impacts on electricity consumption of household appliances in Austria: a comparison of time series and cross-section analyses; Energy Policy 26 (1998) 13, p. 1031-1040
/33/ Kudlicza, P.; Der Kampf um die Last Mile; Industrie, 12.05.1999, p. 36-37
/34/ Keul, A.; Subjektiver Wohnwert als soziales Akzeptanzkriterium von Nachhaltigkeit; BMVIT, Impulsporgramm Nachhaltig Wirtschaften – Haus der Zukunft; www.hausderzukunft.at (2001)
/35/ Tappeiner, G.; wohntraeume – nutzerspezifische qualitaetskriterien fuer den innovatiosorientierten wohnbau; BMVIT, Impulsporgramm Nachhaltig Wirtschaften – Haus der Zukunft; www.hausderzukunft.at (2001)
/36/ Biermayr, P.; Analyse foerdernder und hemmender Faktoren bei der Markteinfuehrung von innovativen Wohnbauten; BMVIT, Impulsporgramm Nachhaltig Wirtschaften – Haus der Zukunft; www.hausderzukunft.at (2001)
/37/ Stieldorf, K.; Analysis of user behavior and post-occupancy experiences of inhabitants of pilot and demonstration housing projects and office buildings; BMVIT, Impulsporgramm Nachhaltig Wirtschaften – Haus der Zukunft; www.hausderzukunft.at (2001)
/38/ Rohracher, H. et al.; Akzeptanzverbesserung von Niedrigenergiehaus-Komponenten als wechselseitiger Lernprozess von Herstellern und AnwenderInnen; BMVIT, Impulsporgramm Nachhaltig Wirtschaften – Haus der Zukunft; www.hausderzukunft.at (2001)
/39/ Wimmer, R.; Nachwachsende Rohstoffe im Bauwesen; BMVIT, Impulsporgramm Nachhaltig Wirtschaften – Haus der Zukunft; www.hausderzukunft.at (2001)
/40/ Rohracher, H. et al.; Intelligent and green?; BMVIT, Impulsporgramm Nachhaltig Wirtschaften – Haus der Zukunft; www.hausderzukunft.at (2001)
/41/ ESD, Verbundplan, et al.; Non-Technical Aspects of Demand Side Management in Liberalized Electricity Markets; Joule-III- project of the European Commission (1998)
/42/ Usinger, J., Karekezi, St.; Project and Stove Design for Large Scale Cooking in Developing Countries; GTZ, Eschborn (1999)
/43/ Schichtel, C., et al.; Solarkocher in Entwicklungslaendern; GTZ, Eschborn (1999)
/44/ Schulze Darup, B.; Oekologische Bewertung von Passivhaeusern; Proc. Symposium Das oekologische Passivhaus, St. Poelten, Austria, 16.-17. Oct. (2000) pp. 71-79
/45/ Horn, G.; Gesamtsystem Passivhaus: Massiv in Stein oder leicht aus Holz; Proc. Symposium Das oekologische Passivhaus, St. Poelten, Austria, 16.-17. Oct. (2000) pp. 43-55
/46/ Paul, E.; Waermerueckgewinnung im Passivhaus mit integrierter Luftheizung und Brauchwasserbereitung; Proc. Symposium Das oekologische Passivhaus, St. Poelten, Austria, 16.-17. Oct. (2000) pp. 43-55
/44/ Tetzlaf, K.H., The Better Way to an Energy Economy without Emissions, Theoretical and Engineering Solutions, Int. Symposium, Sept. 9th-14th (2001), Vol1, pp.-118-122
/45/ Anda, M., Climate Sensible Building Design in the Tropics and Subtropics, Womens Leaders on the Uptake of Renewable Energy Seminar, June 2001, pp. 69-75
/46/ Mossberg, C.., Passive Cooling Part I, Home Power #82 (2001), pp84-92
/47/ Stulz, R. LEO: Low Energy Office Building, Energy Efficiency and Renewable Energy Sources, (1999), 18, pp.20-21
/48/ Rosenbaum, P.E., Passive and Low Energy Cooling Survey (2001)
/49/ Santamouris, M., Cooling heats up: Specific problems of southern Europe, Energy Efficiency in Buildings, 1/2 (2001)
/50/ Mossberg, C.., Passive Cooling Part II, Home Power #83 (2001), pp. 63-74