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STATE OF THE ART OF ADVANCED BUILDING TECHNOLOGIES IN IEA COUNTRIES

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1. Introduction

In discussing the state of the art, I should like to include techniques which are feasible today as well as those which can now be recommended to developers since the test results have proved satisfactory. It must be pointed out, however, that the state of the art is not only a matter of technology and costs but also includes planning, construction and maintenance. This applies especially to systems, such as those used in building technologies. The electric heat pump as we know it today is a long-established state of the art device, although its incorporation in a complex structure is not yet a must. Shortcomings on the planning and construction sides are frequently encountered in this respect.

The state of the art, however, also gives rise to the question of technological objectives. The basic aims in the energy technology fields are obviously:

- Economical production and operation, especially with regard to the use of non-renewable materials and fuels,
- Environmental compatibility in the production, operational and also demolition phases.

The following overview does not give the complete picture but a personal assessment of the most important energy utilisation techniques. To a large extent it is based on the situation in Switzerland, which is, however, quite representative of the IEA countries in central and northern Europe.

2. Low-energy buildings

The target values for the energy consumption of buildings which were defined in Swtizerland in 1988 represented the minimum requirements for new buildings. They can be very easily improved by using proven techniques and are therefore already currently achieved in the construction industry. As a rule, the values given in the following table under state of the art are technically feasible and economically justifiable (additional costs < 10 per cent).

	ø 1988	Target value	SoA
Single-family dwelling[1]	210	126	70
Multiple dwelling[1]	210	120	65
Administrative buildings without ventilation system	175	90	55
Administrative buildings with ventilation system	230	115	70
Schools	160	90	50

Table 1: Energy indicators in kWh/m^2yr (heating, hot water and electricity) for different types of building: average for existing buildings (ø1988), target value for new buildings, realistic target for low-energy buildings (SoA).

1. Electric water-heating system.

The state of the art values listed in Table 1 can now be attained with proven technologies. Figures 1 and 2 show what is already feasible, although the buildings listed are still affected by minor shortcomings. A consistent energy plan and an appropriate type of construction are much more important than the most recent technique. This is still the major problem area. In practice, the integrated planning which is so urgently needed can seldom be satisfactorily implemented, especially in the case of complex buildings. Computer simulation models can be used to solve individual problems but hardly any really comprehensive instruments exist. Overall concepts, which for example take into account the environment, land use and the traffic situation, are practically inexistent in the construction industry. Environmental compatibility studies can give some improvement in this respect.

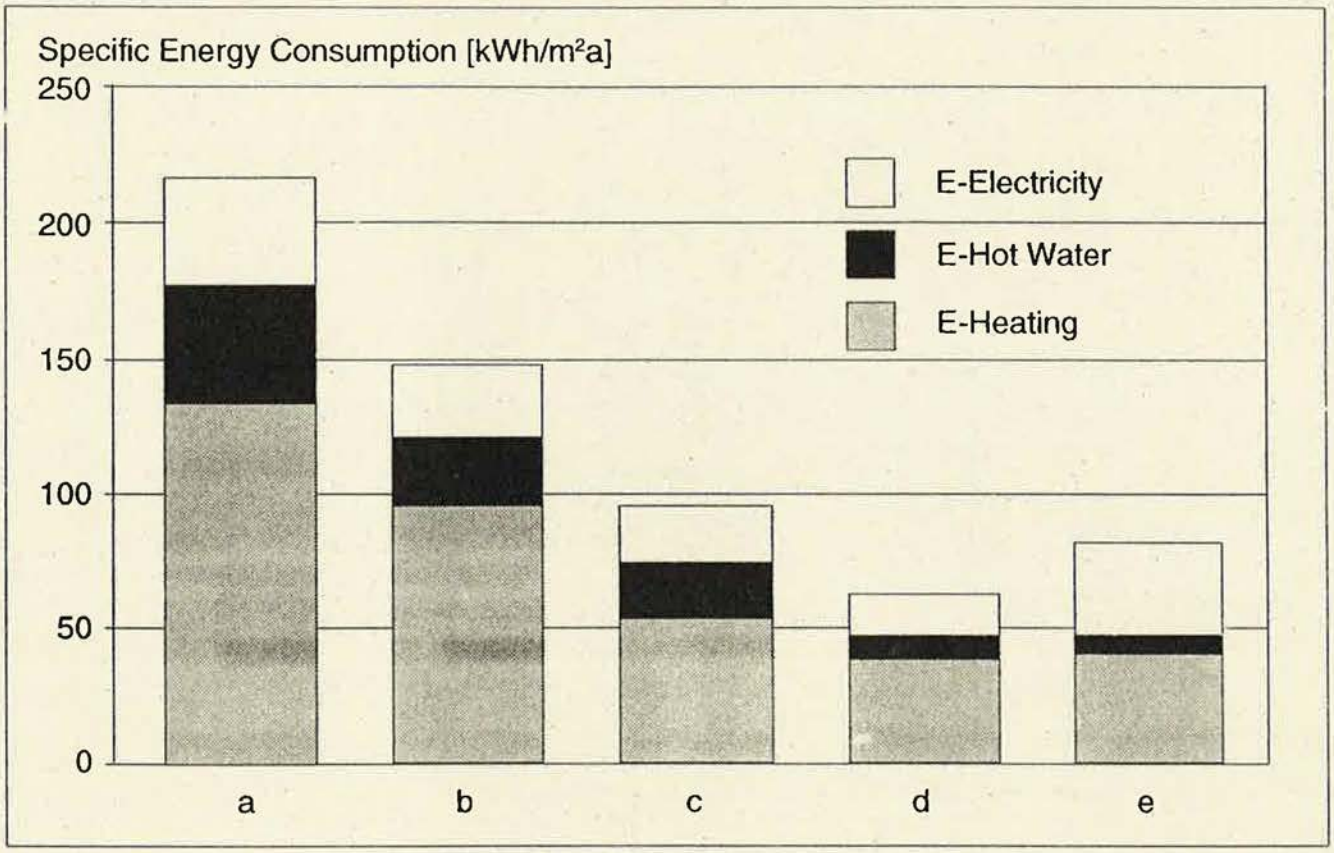

Figure 1: Energy Consumption for Various Buildings

a. Average for Swiss dwellings.
b. Swiss target value for single-family dwellings with combined heating and hot water system.
c. Highly insulated low-energy single-family dwelling in Cham.
d. Low-energy dwelling with passive solar energy use in Urnäsch.
e. Low-energy office block in Winterthur.

The other problem is when the contractor cannot keep up with the technical demands. As long as the contractor does not have the same grasp of interrelationships as the planner, an optimum will never be achieved on the construction side. In future, more attention will therefore have to be given to the training of contractors.

Lastly, the occupants must also be taken into account, since their behaviour has a greater impact on energy consumption than energy utilisation techniques. Figure 3 illustrates this impact in the case of the occupants of a low-energy multiple dwelling.

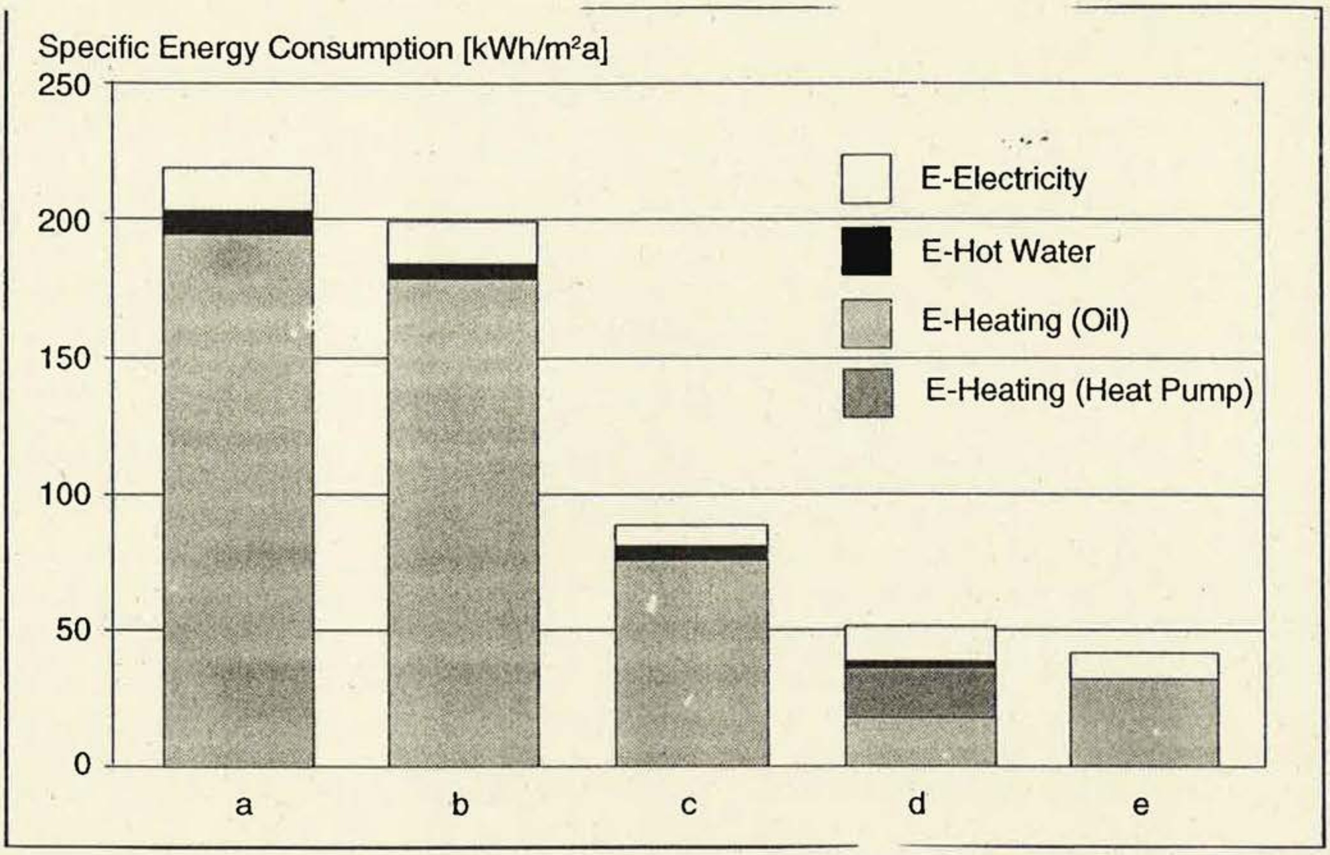

Figure 2: Comparison of energy indicators for Swiss school buildings

a. Ø Swiss schools in 1980.
b. Ø Swiss schools in 1990.
c. Target value for schools in 1988.
d. Gumpenwiesen school building.
e. Jona school building.

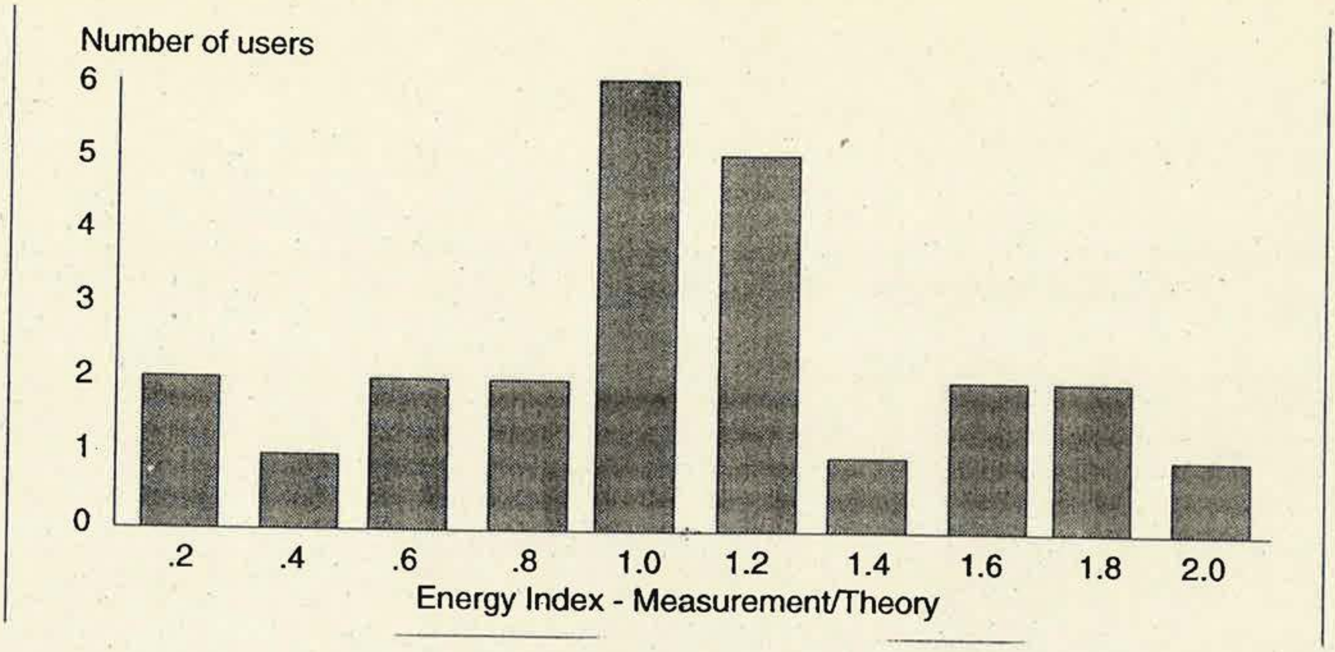

Figure 3: Impact of occupants on energy consumption in a low-energy multiple dwelling. Consumption varies by a factor of 10.

3. Building fabric

Good heat insulation is obviously an important requirement for energy savings in buildings. The low-energy dwellings defined some time ago as state of the art buildings are conceivable only if they are insulated from top to bottom. In new buildings the insulation of walls and roofs is hardly a matter of cost but rather a problem of the use of space and building technology. The energy needed to produce insulating material bears no relation to the energy which can be saved if it is properly used over a normal period of time.

Recently, however, insulating materials in particular have increasingly come under fire for their detrimental effects on the environment and health. Chlorofluorohydrocarbons must be replaced by harmless gases in polyutherane and extruded polystyrene foams, which detracts from their insulation properties. At any rate organic foamed materials should be avoided as far as possible since their production is energy-intensive and is based on non-renewable raw materials. But mineral wools are also being increasingly criticised, since it is suspected that inhaled fibres -- like asbestos in its time -- may cause cancer. Should such fears be confirmed, the question is what insulating materials can actually be used in the future to provide the best possible insulation.

The following table provides heat insulation figures in the light of k values for parts of a building.

	Ø Buildings in the 80s	**Target value**	**SoA**
Walls	0.5	0.3	0.2
Roofs	0.5	0.3	0.2
Windows with frame	2.8	1.6	1.0
Glazing	3.1	1.3	0.7

Table 2: Typical k-values in W/m^2K for parts of a building: values for good buildings in the 1980s, Swiss target values for 1988 and state of the art (SoA).

In the case of windows, the accent today is obviously on insulated glazing. The value of 1.6 W/m^2K applies to a normal window size (including edge losses) with double glazing. For all practical purposes, this value can be referred to as state of the art. If required by a special energy plan, however, much better glazing can be used. With argon glass panes, values of 1 W/m^2K can be obtained with triple glazing, 0.8 W/m^2K with double-double glazing and even 0.5 W/m^2K using crypton. Further improvement of such windows is therefore pointless unless the cost/benefit ratio is also improved or unless a better solution can be found for weak points such as the glass edge joint.

Another characteristic of the building fabric is airtightness. To prevent excessive losses from occurring when outside temperatures are low, but also to prevent dampness, the building fabric should be as impervious as possible. Ventilation rates are expressed by the n_{L50} value, i.e. the hourly air change rate which can be measured with an overpressure in the building of 50 pascals. Typical n_{L50} values are given in Table 3.

	normal n_{L50}	target
Massive structure	1	<1
Light structure	5-10	<3
Massive structure with wooden ceilings	5-10	<1

Table 3: n_{L50} values for average (normal) dwellings and low energy buildings (target).

These targets are quite feasible with sound detailed planning, but there is often a lack of conscientiousness in the construction phase. New blow-out techniques with cellulose flakes made from wastepaper can substantially improve insulation as well as airtightness, especially in old buildings.

4. Ventilation

Progress in energy-efficient ventilation can be mainly achieved by reducing excessive ventilation rates with a simultaneous improvement in comfort. Ventilation rates in offices can be reduced from about 5 to 8 air changes per hour to about 2 to 3.

The ventilation aspect is, however, so complex that in reality many problems remain unsolved. In particular, the ventilation industry has not been able to keep up with progress in research and to market energy-efficient products. Similarly, too much is expected of the planner, who is hardly in a position to transform progress in air flow simulation into suitable equipment.

In many areas it is therefore still doubtful whether mechanical ventilation is preferable to natural ventilation without heat recovery. Particularly in housing, solutions still have to be found that are satisfactory in terms of investment, energy savings and maintenance.

5. Energy-saving heating systems

Domestic heating systems are a much more complex matter than the building fabric. Firstly, technical development in this area is much more rapid as a result of microelectronics and the shorter service life of equipment, and secondly, it is almost invariably the case with such equipment that, despite the technical maturity of the component parts, the system as a whole does not work satisfactorily. As previously mentioned, planning and construction problems must be taken into account when judging the technique. The following brief comments are intended to give simplified, succinct information on the state of the art as regards heating systems.

Oil heating

Capacities of 15 kW and above are no problem, but burner malfunctions are to be expected more frequently at lower values. A satisfactory technical solution has still not been found for the condensing operating mode in oil heating, especially for small systems. Combustion efficiency in good systems is between 90 and 95 per cent. Low-NO_x combustion has been tested and introduced. Along with gas heating, oil heating has thus become one of the cleanest heat sources.

Gas heating

Capacities starting at 8 kW are feasible. The condensing mode is suitable for gas heating systems. Combustion efficiency levels of up to 105 per cent (NCV) can thus be achieved. Low-NO_x combustion has long since been established as a state of the art technique.

Wood-firing systems

The following are justifiable in terms of pollutants and efficiency:

-- Systems burning large pieces of wood with a hot (uncooled) combustion chamber and a hot secondary combustion chamber (next comes the heat exchanger). Thermal output is around 30 kW and over.

-- Automatic systems for burning small pieces of green and dry wood. Green wood heating systems are usually cheaper to operate and therefore more attractive. The systems also have a hot, uncooled combustion chamber as well as a dust collector for flue gas particles. Thermal output is around 200 kW and over.

An optimum air supply is extremely important for low-pollutant wood combustion. The continuous control system needed for this purpose is, however, not yet available. Systems burning small pieces of wood to heat low-energy dwellings do not exist either. Such equipment would be a very important step forward, since wood-fuelled heating systems could be the cheapest way of providing heating for low-energy dwellings (about 1 000-2 000 kWh/yr) by means of renewable energy sources.

Envirnomental pollution [mg/MJ]	**Soot**	**SO_2**	**NO_x**	**CO**	**Ch**
Extra light fuel oil	5	100	35	22	15
Diesel heat pump	10-30	100	37	200	5-90
Natural gas	0	0	35	70	15
Gas engine heat pump	0	0	25-100	100-200	50-130
Conventional wood firing	50-150	0	150	150-2 500	100-700
State of the art wood firing	5-26	0	40-150	130-650	26-50
Chimneys-stoves	90-4 500	0	50-500	800-14 000	360-7 200

Table 4: Typical emission values for wood-firing equipment compared with other heating systems.

Heat pumps

The power factor of electric heat pumps is still unsatisfactory. The average value is around 2 to 2.5, which does not justify the use of valuable and expensive electricity. A marked improvement in the power factor is not expected until around the end of the century. For the time being, however, a deterioration has to be accepted owing to the switch to refrigerants that are less harmful to the ozone layer.

But the incorporation of a heat pump in a heating system also usually gives rise to control and maintenance problems.

Mainly larger systems exceeding 200 kW can be used in the case of gas-engine heat pumps. Diesel engine heat pumps cannot yet be recommended because of unsolved exhaust gas problems.

Absorption heat pumps provide an alternative, but they are more suitable for small capacities between 20 and 40 kW and have a relatively low average power factor of about 1.4.

Co-generation

In the case of plant with a thermal capacity of over 200 kW, gas-operated co-generation plants may be a useful future solution for the cost-effective production of heat and electricity. Standard modular co-generation plants are especially advantageous and technically sound. A small co-generation plant with a power rating of 15 kW and a thermal rating of 39 kW has, however, been marketed. This technique has been proved and can be used provided the services of good, experienced planners and contractors are obtained.

With regard to diesel generators, the necessary catalyst technology is also lacking as in the case of heat pumps.

Solar systems (active)

Progress in recent years has been mainly due to better planning, systems error avoidance and systems simplification.

The following are state of the art applications:

-- Hot water heating,

-- Hot water preheating,

-- Swimming pool heating systems.

Although the solar heating of buildings is technically feasible, it is demanding both from the economic and planning viewpoints. Simple systems with slighty reduced efficiency standards therefore come closest to the state of the art.

Heat emission and heating control

Heating control systems, which operate exclusively on the basis of the outside temperature, no longer comply with the state of the art, especially if the sensor is located on the north side of the building. The latest control systems also take into account room temperature or available room heat. Thermostatic heater valves are a minimum requirement in this respect. Electronic room thermostats, which work more quickly and accurately, are preferable. In many cases the use of a sun sensor would also be appropriate. Various electronic devices to adjust heating to needs do exist, but like sun sensors they are seldom used.

Heat is usually emitted from central heating systems via:

-- rapid heating elements (usually with heat emission blades) which are especially suitable for premises with greatly varying heating needs,

-- floor heating for premises requiring the most constant form of heating possible.

The problem today is no longer one of heat emission but rather of heat distribution which often accidentally and unavoidably wastes most of whatever small amount of heat is needed.

Air heating systems with good comfort standards are technically feasible today, but practical experience is still too limited for them to be classified as state of the art.

6. Water heating

Modern water heating systems now work with oil or gas, and in summer possibly also with electricity. Should the central heating boiler also be used for water heating, it may be advantageous to switch the boiler off in summer and heat water electrically.

As hot water costs also have to be calculated on the basis of consumption, the use of individual boilers in flats is again a topical question. Systems incorporating central solar preheating and local reheating devices are extremely advantageous but are not extensively used.

The heat pump boiler also complies with the state of the art. It is, however, not widely used for cost reasons, although it does provide an extra electricity savings potential. Indeed the significance of warm water supply is underestimated by both energy researchers and the market.

7. Concluding remarks

In the last ten years energy utilsiation techniques have been substantially improved in the construction field, so that today it would be basically possible to build, at a justifiable additional cost, low-energy dwellings for which renewable energies could be extensively used. Greater emphasis should, however, be given in the future to three aspects:

. New developments should not be exclusively directed at new buildings. Only the rehabilitation of buildings will lead to a lasting reduction in energy consumption in buildings.

. Unless the co-operation of building occupants is obtained, energy utilisation techniques will not result in the expected savings.

. Comprehensive studies taking into account ecological relationships are becoming increasingly important and will mean that many existing solutions have to be reconsidered.

But many techniques are also not yet mature enough to be used extensively. The following summary shows the areas in which further developments are necessary:

. **Building fabric**

-- Insulating materials and techniques must be reviewed and further developed with regard to environmental pollution and health factors.

-- Further improvements in glazing are doubtful as long as a satisfactory solution has not been found for the glass edge joint.

- **Ventilation**

Greater ventilation efficiency is possible and necessary (heat exchangers, ventilators, control systems, etc.). But here too it must be realised that ventilation is much more of a human than a technical problem.

- **Heat production**

-- Low-energy buildings with a heating energy requirement of 10 to 30 kWh/m^{2}yr can be built. This remaining need should be covered in the long term with renewable energies. Solar systems exist for this purpose, but because of the necessary seasonal storage, they are expensive and comparatively unreliable. By comparison, the use of any form of biomass could be considerably more advantageous andensure security of supply. However, scarcely any small systems are available.

-- Electric heat pumps should have an average power factor of about 4 if they are to be extensively used. But at the same time refrigerant and maintenance problems also have to be solved.

-- Systems for controlling heating according to needs, as well as other types of control systems, have to be further developed and simplified for practical use. Special attention should be given to socio-technical aspects which enlist user support more effectively.

- **Hot water**

-- There are good prospects for the use of waste heat (e.g. by means of heat pumps) as well as the active use of solar energy. In both cases technical solutions have been found, but progress is not sufficient for wider applications. Further simple and cost-effective developments are therefore necessary in this area.

- **Electricity**

-- The rational use of electricity in buildings is still a major challenge. The steady increase in consumption is only partly due to the buildings themselves and mostly to the continually increasing amount of electrical equipment in use. Considerable improvements are still possible and necessary with regard to daylight use/artificial light concepts, and ventilation and heating drive systems. In addition, alternatives without the use of electricity must be provided for heating, cooling and hot water production.

To sum up, it can be said that good progress has been made towards "energy-independent" buildings thanks to ntensive research and development work. It is also clear, however, that the path towards this objective is becoming ncreasingly difficult. Low energy prices are not the only major obstacle, for many of the "new" techniques will robably not survive and will have to be replaced.

With a view to taking into account more effectively these long-term interconnections and needs in the research ield, the **Future Buildings Forum** has been started up under the direction of IEA. The objective is:

. to compare the state of the art with the long-term requirements for future buildings,

. to identify long-term tasks relating to energy use and the environment, taking into account basic economic and technical conditions, and

. to define and initiate appropriate research and development work.

Accordingly, the Future Buildings Forum is not only seen as a means of identifying and tackling long-term esearch projects, but is also to play a role in information exchange and co-ordination between IEA's research activities n the buildings field.