How CO_2 Emissions from 3,000 Apartments in Hannover Kronsberg in Germany Were Reduced by 74 Percent

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ABSTRACT

The City of Hannover developed the World EXPO pilot settlement of Kronsberg (2,890 apartments with a combined size of 213,000 m^2) with the goal to reduce the energy consumption from heating by around 45% compared to conventional building methods regarding total domestic energy use (heating, hot water, electricity); thus avoiding at least 60% of the emissions carbon dioxide (CO_2) that is affecting the climate. A target of 80% reduction was attempted by the installation of wind turbines.

This paper describes the audit of the measures consisting of a detailed evaluation of data of the monthly consumption in all apartments over three years. The average thermal energy demand of the buildings in 2001 was determined to be 56 kWh/(m^2*yr), which is about 42% below what is expected for conventional buildings complying to the 1995 building insulation regulation. All buildings on Kronsberg draw their heat and hot water from gas-powered decentral Combined Heat and Power (CHP) plants via two district heating systems. The parallel generation of electricity and heat reduces the primary energy demand and associated CO_2 emissions. An information and motivation campaign conducted in 2001 resulted in further reductions of electricity use of the households.

All measures combined resulted in a 56% reduction in CO_2 emissions. In addition, three wind turbine generators with a total capacity of 3.6 MW were in operation on a nearby hill which account for a further reduction in CO_2 emissions by 28%. In summary, the measures achieved a reduction of CO_2 emissions per Kronsberg by 74%, from 1.7 to 0.4 tonnes per resident and year which is close to the target value of 80%.

Introduction

The City of Hannover contracted with the ifeu-Institut Heidelberg GmbH (IFEU) to conduct CO_2 audits for the years 1999, 2000 and 2001 at the Hannover Kronsberg EXPO settlement. The focus of the audits was on the energy consumption (especially space heating) and the associated CO_2 emissions from the settlement as compared to the planning scenarios.

One of the City of Hannover's objectives for the Hannover Kronsberg EXPO settlement was to reduce the heating energy consumption by 45% and CO_2 emissions by 60% compared to the current conventional building praxis[1]. This was to be achieved by setting appropriate conditions in the planning process, by applying comprehensive quality control monitoring throughout the construction phase and by informing and motivating the residents.

The IFEU assessments for the years 1999 to 2001 show that these extra efforts have born fruit. The findings of the current assessment, for 2001, are summarized and interpreted below.

[1] German insulation regulations 1995 (Thomas Ackermann 1995), with each building provided with heating and hot water from a gas-powered condensing boiler.

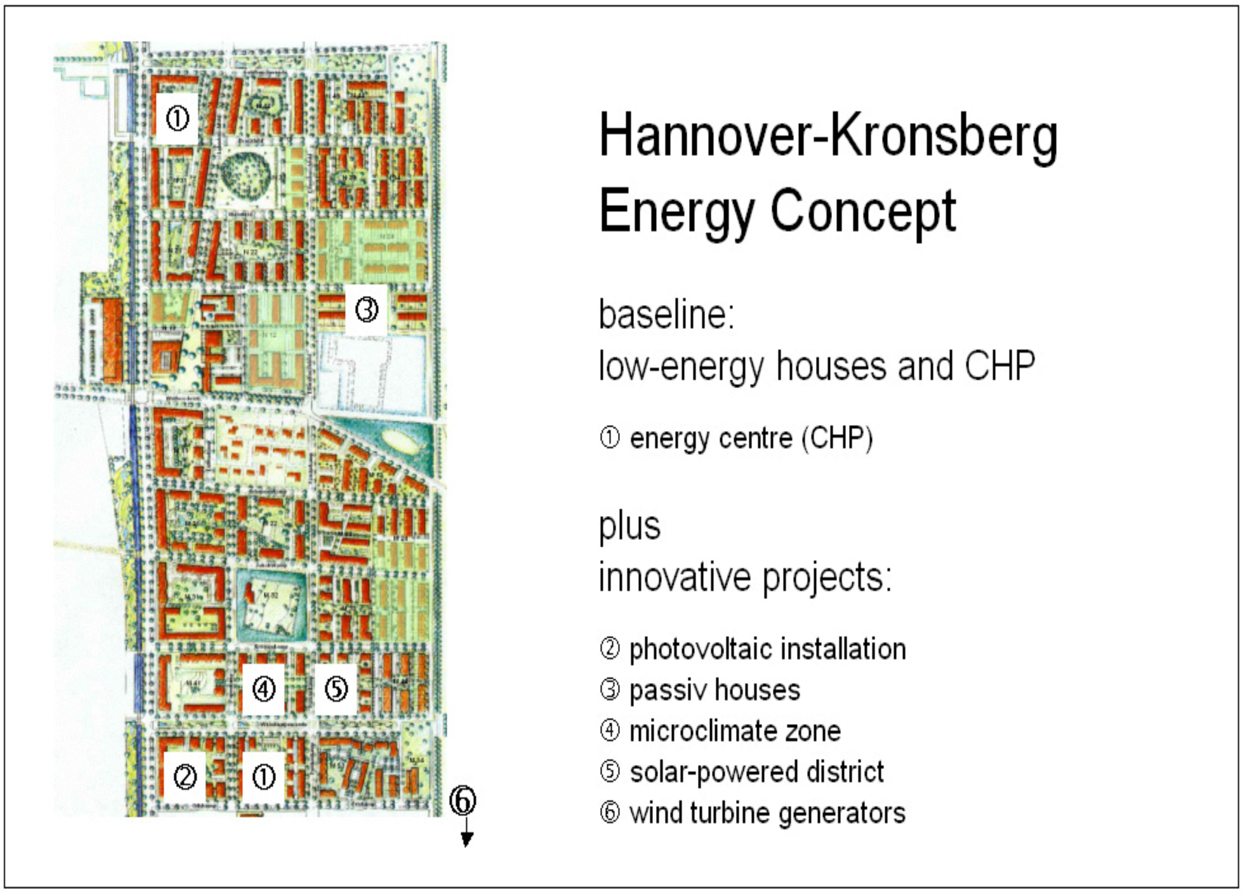
The Kronsberg Energy Concept

Ecological optimization was a crucial design parameter for the new district of Hannover Kronsberg. Aside from soil, waste, and water management, a *Kronsberg Energy Concept* was developed with the goal to reduce energy consumption and CO_2 emissions of about 6,500 inhabitants that live in 2,890 apartments (213.000 m^2 living area) in Hannover Kronsberg (see Figure 1).

The energy concept for the Kronsberg development consists of three components:

1) Low Energy House construction methods with quality assurance, monitoring and measures to improve the skills and qualifications of contractors
2) District heating provided by decentralized cogeneration plants amended by an electricity saving programme
3) Regenerative energy sources (solar and wind power) and innovative technology (passive houses, microclimate zones)

Figure 1. Hannover Kronsberg – Countryside and Elements of Kronsberg Energy Concept



Source: Landeshauptstadt Hannover 2004

LEH Standard and Quality Assurance (QA)

Residential buildings on Kronsberg were erected according to the City of Hannover's specifications as *Low Energy Houses (LEH)*, that means a maximum heating energy demand of 50 to 55 kWh/(m^2*yr) as target value, calculated according to the 'Kronsberg-Berechnungs-verfahren'. Non-residential buildings – schools, kindergartens etc. - had to achieve a maximum energy index of 30% below the 1995 statutory insulation regulations.

The entire construction process, from initial planning to handover, was supervised with the aim of guaranteeing both optimal energy efficiency and the high standards of workmanship demanded by low energy construction, through to advisory services and monitoring. At the beginning standard publications (insulation and airtightness, ventilation and heating technologies) were commissioned by the City and distributed free to developers and planners. Additionally, workshops were held on current or upcoming issues like low-price Low Energy Houses (LEH). Extra costs for quality assurance monitoring to achieve the LEH standard had been subsidized up to a maximum of half the actual expence, but not exceeding 5 Euro/m^2 of living space.

Decentralized CHP and Electricity Saving Programme

Decentralized CHP and district heating provision. Energy for heating and hot water in all Kronsberg buildings is delivered from a district heating network driven by gas-powered decentral Combined Heat and Power (CHP) plants. The housing units and infrastructure are supplied by two district heating networks: the smaller plant operated by GETEC mbH Hannover is located in the north of the area and supplies around 700 homes, the primary school and children's day centre, while a CHP operated by Stadtwerke Hannover AG (SWH) in the south supplies the rest of the settlement.

Electricity saving programme. Issuing five low-energy light bulbs and two water-saving tap fittings to each household, plus an energy saving advice service by the KUKA organisation, were components of the wide-ranging electricity saving programme to reduce electricity consumption. Purchase of energy-efficient household appliances as washing machines, dishwashers, refrigerators and fridge-freezers (see below) was also subsidised by 50 Euro per appliance.

Regenerative Energy Sources and Innovative Technologies

To achieve further reductions in CO_2 emissions and emphasize the sustainable character of the Kronsberg district, various visionary measures were implemented that went beyond the above mentioned energy efficiency optimization framework. Among them were use of regenerative energy sources such as solar and wind power and of innovative technologies such as passive houses, microclimate zones, photovoltaic installations and solar-powered district heating.

Passive houses. 32 Passive House Standard dwellings in four terraces were erected and occupied. The mean target space heating index was around 15 kWh/(m^2*yr). Electricity consumption should be reduced by about 30% due to energy-saving appliances. Thermal solar water heating further contribute to the reduction of CO_2 emissions.

Solar district heating provision. 104 housing units in the 'Solar City' project draw about 40% of their heating from 1,350 m^2 of thermal solar collector panels. Superfluous solar energy is piped to an extremely well insulated long-term thermal storage tank (2,750 m^3). Thus solar heating is possible from spring through to December.

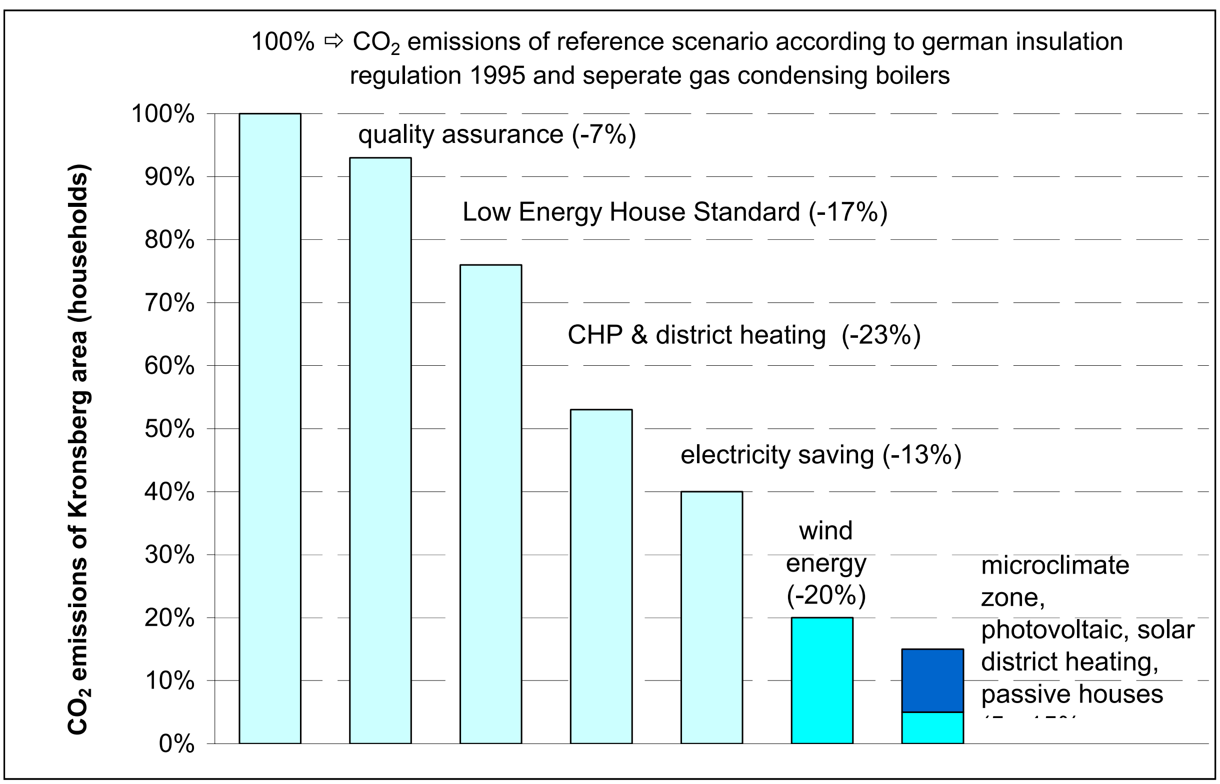
Photovoltaic. Photovoltaic installations producing a total output of 17 kW_p electricity were mounted on various public buildings and the SWH energy facility.

Wind power. In 2001 three wind turbine generators were in operation: one run by the Herrmannsdorfer Landwerkstätten farm (1.8 MW), one by Stadtwerke Hannover AG (0.3 MW) and one by the Windwärts association (1.5 MW).

Target Reductions of CO_2 Emissions in the Kronsberg *Kronsberg Energy Concept*

The City of Hannover developed the *Kronsberg Energy Concept* with the goal of reducing emissions of climate-altering carbon dioxide (CO_2) gas. All measures should lead to reductions in CO_2 emissions of 80% (which is the goal of the German parliament's enquete commission for the year 2050 – (Enquete 1995). In detail quality assurance and LEH standard should lead to 24% (see Figure 2), CHP and electricity saving to 36% and wind energy to 20%. Solar energy and innovative technologies should reduce CO_2 emissions of individual projects by a further 5% to 15%.

Figure 2. Expected Reductions in CO_2 Emissions on Kronsberg



Source: KUKA et al. 1998

Findings of the Energy Audit

In presenting the findings we follow the structure in the step diagram (see Figure 2) in which the 100% benchmark of the diagram are the CO_2 emissions associated with conventional standards. The ambitious aim of a 60% to 80% reduction in CO_2 emissions in this model project applied to the entire settlement. The reference scenario assumed that:

1. All buildings would have been erected according to the 1995 insulation regulations (Thomas Ackermann 1995);
2. An average of 30 litres of hot water (45°C at the tap) per person per day would have been used;
3. Each building would have been fitted with its own heating system powered by a gas condensation boiler;
4. Lack of quality monitoring would cause an excess in end consumption in the order of 15 % (SWH 1997).

To determine to what extent the target margins were achieved, both in qualitative and quantitative terms, the findings are presented separately according to the following topics:

- Energy consumption and resultant CO_2 emissions for space heating and hot water
- Use of district heating with gas-powered decentral CHP plants
- Electricity saving programme

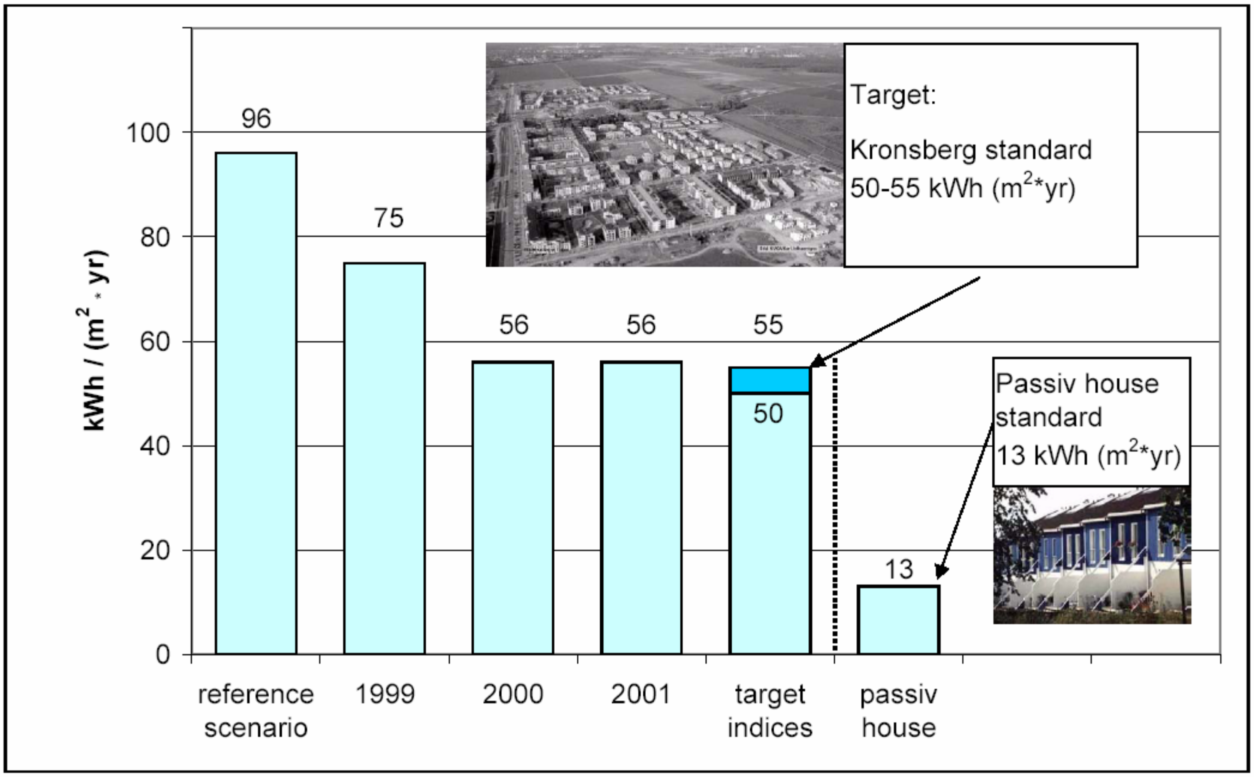
Audit Findings for Space Heating

To the end of 2001 the number of housing units covered by the audit increased from around 1,700 to around 2,900 when the apartments previously used for accommodation of EXPO 2000 personnel were occupied. The total audited living space thus rose from 133,425 m^2 to 212,823 m^2. The passive houses, with a living space of 3,516 m^2, are not included. Figure 3 presents the space heating indices for audited buildings 1999 - 2001. The reference scenario set a mean index of 96 kWh/(m^2*yr) (including 15% due to lack of quality monitoring).

Because of excessive initial losses, the weather-adjusted energy consumption indices measured in 1999 for space heating were still 75 kWh/(m^2*yr) and thus 22% below the base index. It was encouraging to note that by 2000 and 2001 this value was 56 kWh/(m^2*yr), which is 42% below the reference index and only little above the target range of 50-55 kWh/(m^2*yr).

The major proportion of energy savings was achieved through the good insulation and airtightness of the buildings (for example low-E double glazing windows and external wall insulation of 20 cm mineral wool) combined with quality assurance monitoring during the construction phase.

Figure 3. Energy Consumption Indices for Space Heating at the Hannover Kronsberg Development: **Reference Scenario, 1999, 2000, 2001 and Target Values**



Source: H. Hertle et al. 2003

Hot Water Provision

The base value in the step diagram is 30 litres of water at 45°C per person per day. This produces a specific end user energy demand in the reference scenario (see also Figure 5) of 17 kWh/(m^2*yr). In 1999 the specific end user consumption was around 14 kWh/(m^2*yr), rising in 2000 with higher occupancy levels to 16 kWh/(m^2*yr). The evaluation of hot water consumption for 2001 resulted in a specific end user demand of ca. 15 kWh/(m^2*yr), meeting the target scenario.

Heating Losses

In the reference scenario (see Figure 5) it was assumed that each building was fitted with a separate heating system powered by a gas condensing boiler. The annual level of utilization for space heating and hot water provision was set at an assumed 80%. Included are distribution losses in the pipework that do not heat the accommodation, and the wastage from boilers and hot water provision. The energy index for heat losses in the reference scenario was 28 kWh/(m^2*yr).

In 1999, however, the actual losses from heating provision system were markedly higher, at 53 kWh/(m^2*yr). This was mainly caused by the losses from the distric heating network pipes during the construction phase. It was not until 2000 that losses decreased to around 27 kWh/(m^2*yr). In 2001 total specific losses were recorded at the calorific meters of 24 kWh/(m^2*yr). They comprise losses from the district heating network pipes (8.6 kWh/(m^2*yr)), losses from the hot water tank and pipework (10.8 kWh/(m^2*yr)) and losses from pipework in the space heating system (4.9 kWh/(m^2*yr)).

A target was set for Hannover Kronsberg, along with the space heating target index (useable energy) of 50 kWh/(m^2*yr) for hot water provision of 15 kWh/(m^2*yr), and reductions in heat loss (from the calorific meter at the heating plants) of 19 kWh/(m^2*yr). To achieve this target, the tank and pipework losses inside the buildings would have to be reduced by a further 50%. The specific measurements and optimization of single buildings and the reasons for heat losses should be investigated.

Electricity Consumption

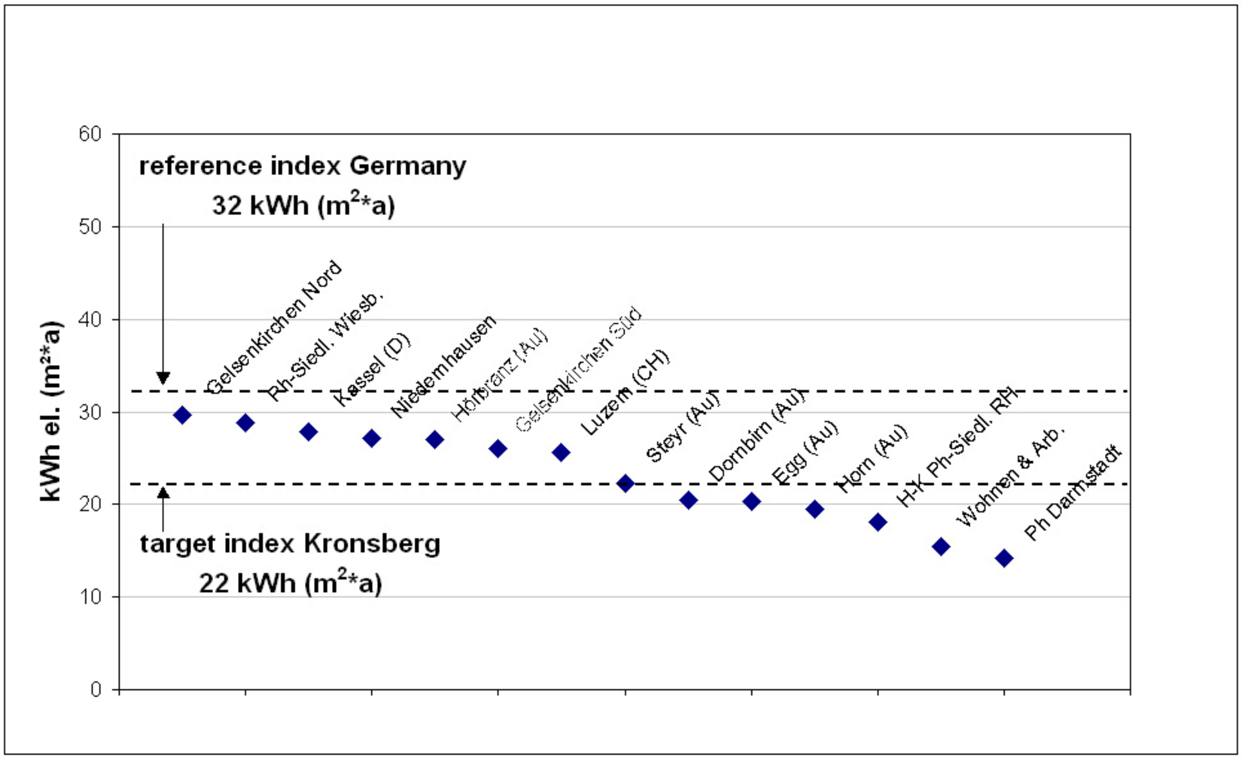
The reference scenario assumed electricity consumption of 2,500 kWh per household per year, which is equivalent to an index relative to the average living space of 32 kWh_{el}/(m^2*yr). Through savings of around 6% by measures seen below, this figure could be reduced in 1999 and 2000 to 30 kWh_{el}/(m^2*yr) (see also figure 5). Across all 2,890 households in the audited area, in 2001 the average saving was 5.3%. The average consumption of a household would thus be around 2,370 kWh/yr, the electrical energy index around 30 kWh_{el}/(m^2*yr).

Only about one-fifth of the intended electricity savings of 750 kWh/yr per household has thus been achieved by the end of 2001. The actual savings are far below the 30% target set for Hannover Kronsberg, which would lead to a target index of 22 kWh_{el}/(m^2*yr). To clarify this large discrepancy between target and achieved index, the electricity consumption was more closely examined along the following questions:

1. Q: Was the assumed average consumption too high?
   A: Compared to nationwide assumptions on average consumption in private households, the assumed reference value was completely realistic.
2. Q: Are the savings targets unrealistic?
   A: Compared with the electricity indices applied to other pilot projects, it can be seen that around half of them lie below the Kronsberg electricity target index of 22 kWh/(m^2*yr) (see figure 4). The households in the passive house development on Kronsberg could also achieve an index of 22 kWh/(m^2*yr). It can thus be seen that the desired savings are entirely possible.
3. Q: Were too few savings measures carried out?
   A: Within the electricity saving programme, by the end of 2001 acquisition of the following energy-saving appliances had been subsidised:

- washing machines	77	about 3% of households
- dishwashers	106	about 4% of households
- refrigerators	56	about 2% of households
- freezers	66	about 3% of households
- low-energy light bulbs	5,600	about 2 per household

Figure 4. Overview of Electricity Indices in Low-Energy Settlements



Source: Wolfgang Feist et al. 2001, H. Hertle et al. 2003

It is evident that of all measures, only the low-energy light bulbs were widely used. Low energy white goods were acquired by only 2-4% of households. Because only a small number of these large appliances were bought new for the move to Kronsberg, and new tenants will be moving in continually, exploiting this potential will remain a long term task.

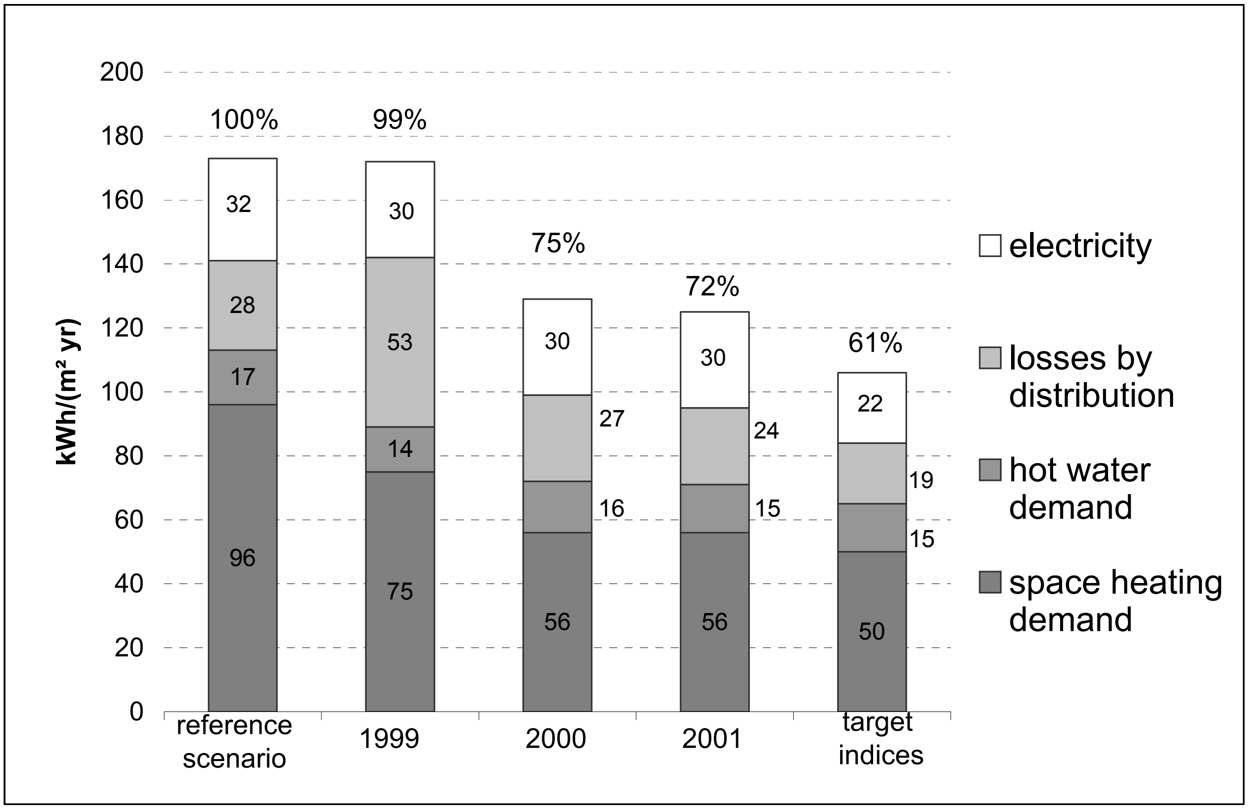
Trends in the Overall Energy Index

Figure 5 shows the overall energy indices for the years 1999 to 2001. Compared to the overall energy index of the Reference scenario (173 kWh/(m^2*yr) the values for 1999 had not changed to any practical extent. Reductions from 96 to 75 kWh/(m^2*yr) for space heating (-22%) and of a few percent in hot water and electricity consumption were offset by higher losses in heating provision. The reasons for this are given in the construction of the district heating network with uncompleted heating plants, and temporary mobile heating without decentral CHP plants.

The year 2000 saw an overall energy index of 129 kWh/(m^2*yr), a reduction of 25% compared to the reference scenario. This can be traced to the positive development in the space heating index to 56 kWh/(m^2*yr) as the initial losses disappeared. Heat losses were also halved in 2000 compared to 1999, as expected to 27 kWh/(m^2*yr), with the construction of the district heating network almost complete. For hot water, the demand increased as expected due to the increased number of residents, creating an index of 16 kWh/(m^2*yr). The electricity index was steady at 30 kWh/(m^2*yr).

In 2001 the overall energy index fell further, to 125 kWh/(m^2*yr), a 27% reduction compared to the reference scenario. The reasons are the slightly lower hot water consumption and further reductions in heat losses (especially in the district heating network) to 24 kWh/(m^2*yr). The electricity index remained at 30 kWh/(m^2*yr). The target index of 106 kWh/(m^2*yr) is 39% below the reference scenario.

Figure 5. Energy Consumption Indices for Heat and Electricity at the Audited Hannover Kronsberg Development: Reference Scenario, 1999, 2000, 2001 and Target Indices



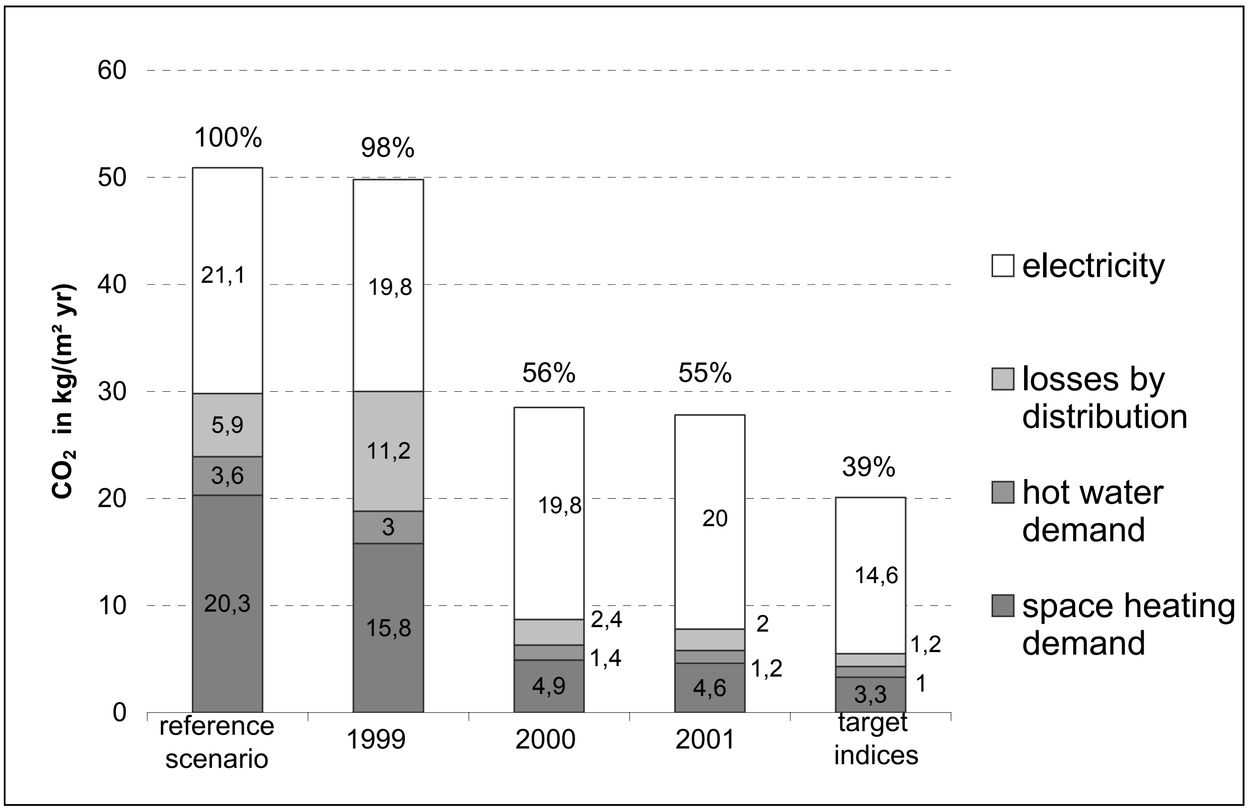
Future developments. Further efforts are needed to achieve the target index. The potential for savings in space heating is virtually exhausted at the present index of 56 kWh/(m^2*yr). After the optimization of a few development blocks with very high indices, the desired overall maximum index of 55 kWh/(m^2*yr) can be achieved. The end user energy consumption for hot water provision meets the target value at 15 kWh/(m^2*yr). A heat loss index of 24 kWh/(m^2*yr) is just halfway towards the target of 19 kWh/(m^2*yr), even though losses from the district heating network were reduced to around 9% in 2001. The question of whether losses from tanks and pipework inside the buildings (installations) can be halved by retrofitting can be answered only after more precise measurements.

Overall, in 2001 a heating energy index (without electricity) of 95 kWh/(m^2*yr) could be achieved, 13% above the target. The electricity index is the least satisfactory, 37% above the target. The high savings potential in purchasing patterns and consumer behaviour should be exploited here in the next few years. The overall energy index for 2001 was, at 125 kWh/(m^2*yr) still 18% above the target of 106 kWh/(m^2*yr).

Trends in CO_2 Emissions

At Hannover Kronsberg electricity and heat are generated at two local power stations with gas-powered CHP plants. This reduces the primary energy consumption and the emissions dramatically compared to conventional power stations, where around two-thirds of the energy is released into the atmosphere as waste heat. Figure 6 presents the overall CO_2 emission indices, divided into applications, for the various end uses. The emission factors are derived from a 1994 study by Stadtwerke Hannover (SWH 1997). The CO_2 emission factor for natural gas is 211 g/kWh. For electricity, in this report a value of 660 g CO_2/kWh was used. With respect to electricity the bars in Figure 6 (end-use energy) compared to Figure 5 are markedly higher. This is because CO_2 emissions from electricity consumption are higher by about a factor of 3 relative to natural gas due to generation and transmission losses. The trends in CO_2 emission indices from the reference scenario to the actual values for 1999 reflect trends in the energy indices. The overall CO_2 index hardly alters; reductions from 20.3 to 15.8 kg/(m^2∗a) in space heating (-22%) and of a few percent in hot water and electricity are negated by higher losses from the heating provision system.

Figure 6. Trends in CO_2 Indices at the Audited Hannover Kronsberg Development: Reference Scenario, 1999, 2000, 2001 and Target Indices



With 28.5 kg/(m^2*yr), the year 2000 saw significant CO_2 reductions of 44% against the reference scenario. These dramatic savings came roughly equally from the end-use savings and the commissioning of the decentral CHPs. In 2001 the emission indices decreased to 27.8 kg/(m^2*yr), 45% below the reference scenario. Compared to the reference scenario, for space

heating and hot water demand there is 74% less CO_2 emissions, there was a slight increase of 6% for electricity.

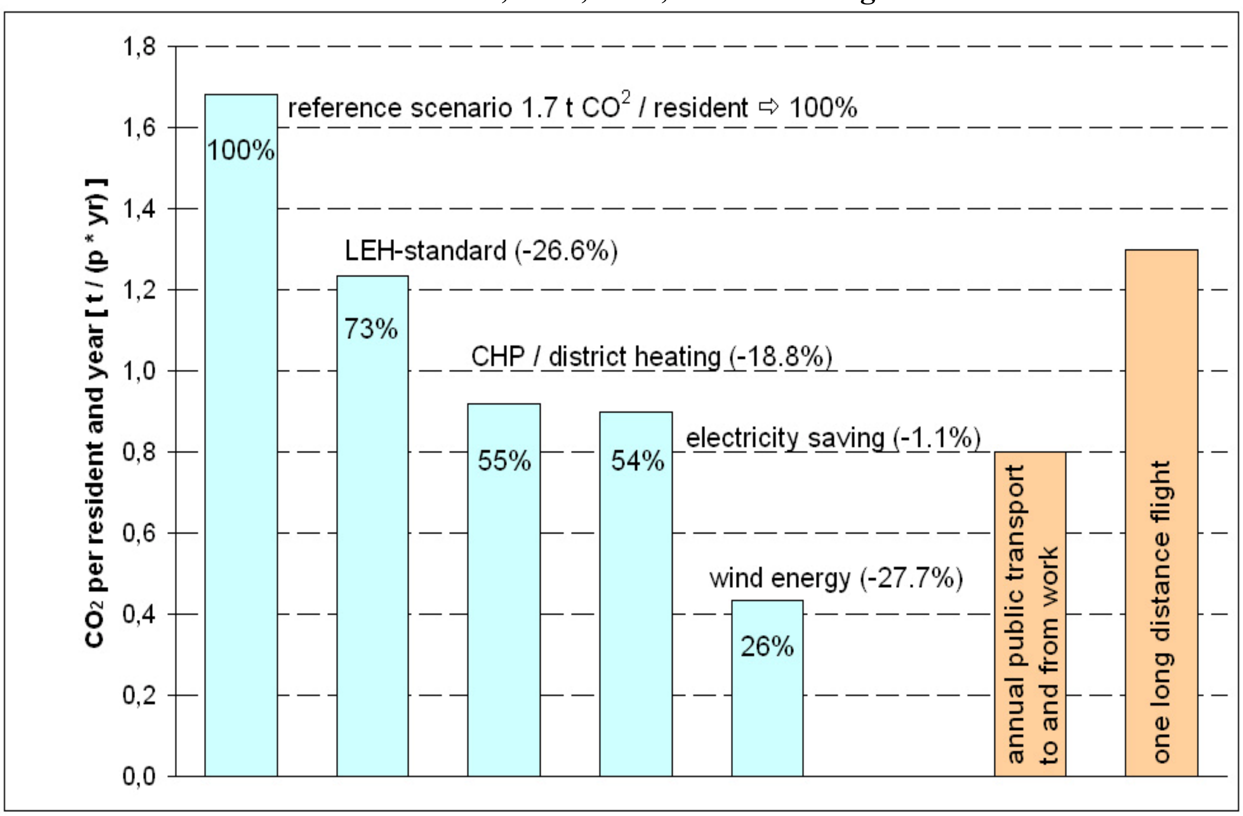
The overall CO_2 target index of 20.1 kg/(m^2*yr) is 60% below the reference scenario. This target can essentially be achieved if the electricity savings potential can be exploited to the extent that was originally expected.

CO_2 Emissions per Resident

The measures described above reduced the CO_2 emissions per Kronsberg resident by 46%, from 1.7 to 0.9 tonnes per year (see Figure 7). If in addition, the three wind turbine generators with a total capacity of 3.6 MW, which were installated on Kronsberg hill are accounted for, the per-capita CO_2 emissions would be further reduced by 28% to a total of 74% (0.4 tonnes per year), which is very close to the target savings of 80%.

To put this in proportion: the average commute to work of a Kronsberg resident is associated with 0.8 tonnes of CO_2 emissions per person and year; a single transatlantic flight causes 1.3 tonnes of CO_2. The CO_2 emission of the average German citizen is 11 tonnes per year.

Figure 7. Trends in CO_2 Indices at the Audited Hannover Kronsberg Development: Reference Scenario, 1999, 2000, 2001 and Target Indices



Source: H. Hertle 2004

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