THE DUTCH EXERGY HOUSE DESIGN COMPETITION

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ABSTRACT
To realize the Dutch government’s objectives concerning energy saving and emission reduction the use of low valued energy of residual, ambient and renewable sources for space heating and DHW is necessary. In this strategy also the quality of the energy carrier in relation to the required quality of energy is important. Tuning these qualities is called exergy optimizing. Because Exergy is still a rather abstract understanding, a national competition in the Netherlands was organized. Objective of the competition was to develop new possibilities for energy-efficiency by applying the principles of exergy in realistic and affordable dwellings and to stimulate several parties in the building and installation sector to take into account the quality of energy flows in the design phase. The plans were assessed on qualitative and quantitative aspects of building, installation, energy, exergy and the coherency between these aspects. The competition showed that it is possible to build market-conform dwellings, using exergy principles. The five award winning plans are presented in this paper.

INTRODUCTION

Exergy and Town and Country Planning
The Dutch government has drawn up plans for construction of over 1.2 million new houses by the year 2015 to be built on green-field sites. These plants present every opportunity of employing optimum energy distribution systems using state of the art technology as well as to design the energy infrastructure to suit site-specific requirements. An exergy approach offers the opportunity to optimize the total energy infrastructure, from source, distribution system to the built environment. The exergy method calls for a high degree of synergy between spatial lay-out and the energy infrastructure. This means, for one thing, that exergy should be considered in an early stage of town and country planning procedures and that a particular energy infrastructure should be chosen, i.e. distribution systems for gas, electricity and/or heat. Urban areas, industrial estates and office centres should be projected logically in conjunction with the energy infrastructure. This cannot be realized without support by the authorities and existing structures must be ready to accept the method. If these conditions are met, the energy sector will be able to co-operate in the conceptual design phase with the responsible authorities, planners and policy makers concerned with regional development. Since at the present time the building sites are “green fields”, the designers are not bound by any traditional method of power supply (e.g. natural gas system, power stations or electricity grid) but can start from scratch. This raises the question how on such virgin sites residents can be provided with heat and power in the best energy-efficient manner. And how the available fossil fuels can be utilized as efficiently as possible. And in how far not only the supply, i.e. generation and distribution, but also the demand for and nature of the energy play a role. In other words, how can, in the first stages of town and country planning, the energy supply be designed on an exergetic basis so as to achieve substantial energy savings and reduce harmful emissions? These questions prompted, SEP (Dutch Electricity Generating Board), EnergieNed (Organization of Energy Distributors in the Netherlands) and two regional utilities NUON and GGR-GAS and the Ministries of Public Housing, Town and
Country Planning and Economic affairs in 1992 to launch an exergy pilot project in a new urban area. This project was aimed at providing a better understanding of aspects such as the following:

- the synergies between town and country planning, energy infrastructure and building and house designs;
- the quality levels of the energy streams (exergy).

An inventory was made of potential exergy applications; this showed that the demand for primary energy could be reduced by up to 35%. The design of optimum energy systems must cover not only the infrastructure but also the individual houses, where the synergy and exergy elements need to be fleshed out.

Late in 1996, the Exergy House Project Group, in which Novem (Netherlands Agency for energy and the environment), EnergieNed, GGR-GAS, NUON and SEP participate, launched the Exergy House Design Competition. This competition was designed to stimulate the development of new exergy-based energy conservation methods at acceptable cost. By its nature, the competition was intended for all professions concerned with the design of houses and service.

### What is exergy?

The second law of thermodynamics states that energy will always degrade to a lower level. Prime energy is the highest form of energy because it is the most universally useful. Exergy, in the USA also known as 'availability', is the proportion of the energy content of a resource that can be converted into work. The exergy factor of fossil fuels and electricity is unity, that of steam at 200°C is 0.41 and that of water at 80°C is only 0.21. Thus, the energy level of steam at 200°C is less than half that of fossil fuels and electricity.

### Conceptual thinking

The exergy efficiency is the efficiency with which the energy available in the fuel is utilized. In a high-efficiency central heating boiler only one fifth of the fuel is energetically utilized in an optimum manner, which means that the energy degrades heavily. A much higher exergy efficiency is achieved in CHP systems operating in conjunction with a heat pump extracting energy from the soil or air. This can yield prime energy savings of up to 30% depending on local conditions. In this case, however, traditional central heating radiators usually are unsuitable because of the low water temperature. Floor or wall heating systems provide a solution here; this should be borne in mind already in the design phase of houses. Architects and services contractors should realize that it does not do to design a house on the basis of cost, comfort level and safety alone. Conceptual thinking about energy is an added aspect, which calls for early and close co-operation between the architect and the services contractor.

### Exergy in houses

Energy is needed in houses for space heating and many other purposes, each posing a particular energy demand and some producing waste heat. Example include hot domestic water, cooling, ventilation and lighting. Many appliances produce waste heat that can be re-used elsewhere. A familiar example is heat recovery from ventilation systems for space heating. Further examples include heat recovery from drain water from the bath tub, shower, washing machine and dish washer, and utilizing the waste heat of refrigerators for space heating. Mostly only minor amounts of energy are involved, but these can add up to substantial savings.

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DETAILS OF THE COMPETITION AND PROCEDURE
The Exergy House Design Competition met with a lot of response. Over 400 requests for application forms were received, especially from architects, project developers, consultancy firms, expertise centres, public utilities and numerous private individuals. 45 entrants were received on the closing date.
These were first rated as to acceptability and then presented to a jury on which sat experts in the field of services engineering, civil engineering, exergy and energy. The entrants were appraised as to the qualitative and quantitative aspects of the following items:
- services engineering proposals
- civil engineering proposals
- conjunction between services and architecture
- Energy Performance Coefficient and exergy calculations (The EPC was not to exceed 1.2.)

Energy Performance Coefficient (EPC)
The Dutch Building code uses the EPC as a value to express the total energy efficiency of a building, including energy use for heating, DHW, ventilation, cooling, humidifying and cooling. For new dwellings and residential buildings the EPC value is limited to 1.2; this approximately corresponds to a total primary energy use of 1200 m³ nat. gas equivalent for the above mentioned service functions. In 2000 the EPC will be lowered to 1.0.

Results
The quality of the entrants was spectacular. The EPCs in the five entrants nominated ranged from 0.5 to 0.8, the norm being 1.2. These low values were mostly attained by a combination of exergy applications, solar energy, heat pumps and energy storage. The exergy applications might best be described as particularly innovative ways of utilizing waste and residual heat streams hitherto mostly regarded as inevitable losses.
The jury then took a critical look at the practicability of these applications. These must not only be technically feasible, but also suitable for every-day use and commercially acceptable. If they require major adaptations to the architecture or result in a lower level of comfort for the occupants, that acceptability would be questionable. The prime aspect of commercial acceptability is the cost price of the houses. This criterion was applied rigorously throughout the selection procedure.
The results of the competition can be summarized as follows: Houses with an EPC of 0.5 and with a satisfactory level of comfort can be built at a competitive price.

THE FIVE WINNING DESIGNS
The following descriptions of the five award winning designs are based on the presentations of the finalists.

Fifth place “The Exergy House”
Submitted by: de Jong Gortemaker architecten en ingenieurs bv
Consultant: Ketel raadgevende ingenieurs bv

Design
Five houses are linked to one another energy-wise through the cellars so as to raise the energy demand to the point where combined heat and power generation is a viable option for family homes. In the cellar is the energy duct connecting five houses. It includes the combined heat power unit and the heat pump. The energy duct also serves to buffer, recover and redistribute all heat streams. All rooms requiring space heating and a water supply are located directly above the duct; these include the kitchen, laundry room, bathroom and toilet. Thus, thermal
losses in the plumbing are low, and the users can be cascaded in an optimum manner. The ground floor is just above grade level. After heat recovery, all drain water is directed to a helophyte filter (a plot of bog plants) partly extending beneath the houses. The downstairs living room and the upstairs bedrooms are on the south side. Water pipes for space heating and cooling are embedded in the floors and walls.

The EPC is extremely low, only 0.48. This is accomplished in particular by the large fenestration area on the south side and the conservatory extending over almost the full width of the house as well as the large solar collectors and preheating of ventilation air in the conservatory. The lowest possible energy level is used for each load so that waste heat can be re-used over and over again at the next lower level, as in an energy cascade.

A glass-covered air cavity one to two metres wide extends along the south facade and the roof, ensuring that practically no heat is transmitted from the house. Next to the living room the air cavity is two metres wide and here it can be used as a conservatory or winter garden. Sunshades are placed within the glass shell, allowing heat to enter. Outside air enters via the floor of the conservatory and rises through the cavity past the first floor and the roof to exit through a grid. The north facade is thoroughly sealed and insulated. Solar collectors and PV cells are mounted on the roof over the bedrooms. They can freely rotate in a semicircular frame for optimum utilization of solar energy.
Energy streams
The basic idea is to use energy of the lowest possible level for each application and to re-use the waste energy. This has been achieved as follows.

1. Steam is used for cooking, and the condensate forming here is used for preheating stored rainwater for the washing machine and the dish washer. The steam is generated using the exhaust gases of the micro CHP unit. Additional steam can be raised with electrical power.

2. Electricity usage for laundry and dish washing is reduced by feeding hot water (95°C). This is heated by the CHP unit, solar collectors and steam. Waste water from the machines is used for space heating and for aiding the heat pump.

3. Domestic water is heated by the CHP unit and the solar collectors. Drain water from the sinks and bathrooms is directed to the heat pump.

4. Ventilation air is preheated in the conservatory by 'floor heating' using geothermal and solar heat. Heat from incident solar radiation can be added, so raising the temperature of the 'source' system and improving the COP of the heat pump. Stale air otherwise expelled is also directed to the heat pump.

5. Heat transmission from the interior is limited due to the conservatory acting as an extra buffer and large heating surface areas in the rooms, floor heating and (outer) wall heating. Heated wall and floors do not transmit any heat at the expense of the room temperature. This allows a very low temperature level to be used for space heating and enables the heat pump to achieve a high COP, so affording a very comfortable and stable atmosphere. The low temperature differentials between the heating surfaces and the air make for a low convection factor and high natural stability of the system.

6. The heat pump receives heat not only from sources in the house but also from 'active' foundation piles and the floor of the energy duct. These sources, acting as a heat source in winter and as a cold source in summer, are also directly linked to the floor heating system in the conservatories so that ventilation air can be preheated or cooled with a minimum of (pump) energy. In addition, there is a direct link to the floor and wall heating system so that air can be mildly cooled in summer while at the same time heating the soil.

7. Electrical power is supplied partly by the CHP unit and partly by PV cells. On an annual basis, the supply practically meets the demand, and on balance power is exported to the public grid.

Fourth place: “Synergy Dwelling”
Submitted by: Mosaic, Buro voor architectuur en interieur
Consultant: Boom Milieukundig onderzoek en ontwerpburo

Design
The Synergy Dwelling is really two houses under one roof, designed to house two friendly families, relatives, several generations in a family or other groups. Heat is stored just below the ground floor, with the floor acting as a radiator. It is self-regulating because of the low temperature differentials.

Cost
All of the above benefits do not lead to higher cost. The cost per dwelling is estimated at NLG 170,000 exclusive of land and VAT, inclusive of hot-fill washing machine, PV-powered refrigerator, low-energy light bulbs and water heater. The energy users add up to a very low bill, keeping the cost of living low, too.
Brief description of features
- Draught barriers
- Thermal insulation, $R_c = 5$
- Glazing, $U = 1.1$
- High-efficiency heat recovery (90%) from ventilation system
- Fresh air taken from conservatory
- Heat recovery from shower
- Refrigerator behind insulating door
- Good compartmentalization
- Two dwellings sharing services and energy storage
- Roof tiles suitable for recycling
- Masonry with bricks placed on edge
- Round timber used for load-bearing structure
- EPC = 0.55
- Daylight reflectors
- Skylight over staircase
- Passive solar energy
- PV-powered refrigerator
- Heat storage combined with floor heating
- Flexibility in use and lay-out

Energy cascade
1 gas-discharge lamps
2 boiling water (110°C)
3 hot water (60°C)
4 bath water (45°C)
5 bottom geothermal heat storage
6 top geothermal heat storage
7 warm rooms (22°C)
8 cold water (20°C)9 cool rooms (18°C)
10 refrigerator (5°C)

Wood cascade
- round timber
- square timber
- chip board
- fibre board
- cellulose insulation

Third place: “Energy-Exergy”
Submitted by: Architectenburo Hopman bv
Consultants: Cauberg Huygen Raadgevende Ingenieurs bv, Techncco bv

Design
The application of energy / exergy principles in houses calls for synergy between the architecture, the house design and the energy streams via water and air. This is not a dwelling requiring the occupants to change any habits, indeed, self-evidence is paramount, even though its services are of a different order than those found in today's 'average' houses. If the somewhat negative term 'commercial acceptability' translates into a comfortable, low-energy, environmentally compatible house, then the objectives of the present design have been achieved.
The EPC = 0.8.
The designers felt they had to pursue an integrated approach from town planning through to demolition. This involves creating at each scale level conditions that are to provide possibilities and opportunities at the next scale level. This is in effect a cascade principle yet forming part of a loop. For the purposes of the present competition we have descended to the low scale level, the living quarter, which plays an important quantitative role in energy usage and, so, is equally essential at the local level.
Being vertically compartmentalized, the house needs to be oriented north-south. Solar energy is integrated in the design. The facade facing south is larger, with optimum fenestration area in combination with passive air collectors and collectors for domestic hot water. Heat-producing appliances and services are concentrated in a central area in which energy flows are ducted. Skylights allow light to enter deep inside. The facade facing north has appropriate fenestration and is heavily insulated for minor temperature fluctuations.
Being integrated as they are, all options as to the modes of energy supply have been left open, but are incorporated in the design. The cross-section and plan views have been developed with an eye to such aspects as water management, waste streams, orientation relative to the sun, retrofit PV systems, daylight and geothermal energy.

Energy streams
Heat streams are combined in the house, especially those related to two resources: air and water. Air movement and ventilation have been in the limelight for quite some time; examples include balanced ventilation, heat recovery, preheating and circulation from warm to cold areas. Water can be used for more purposes than conveyance alone. Waste water produced in homes is not normally given much attention even though spent domestic hot water comes only second to space heating in terms of energy usage. As well as buffering the primary domestic water via the solar collector, we have sought to extract heat from the non-drinking water circuit by means of heat pumps. Energy supply has been optimized through the use of incident solar radiation, a heat pump extracting heat from the soil and multifunctional storage whilst energy usage has been optimized by a cascade arrangement of the loads. The following media are used for space heating:
- water at 50-35°C in low-temperature radiators for the south facade with rapid change-over to solar heating by means of thermostat control;
- water at 35-28°C for floor heating in the thermally stable north section of the house;
- air at 20°C for heating ventilation air;
- drain water for preheating cold water.
The combination of heat sources and good mass distribution contribute to a high level of comfort and, so, indirectly to further energy savings. Use is made exclusively of materials included in the Dutch National Programme for Sustainable Building and of renewable energy, which is why this design helps save our environment.

Second place: “Energy Captured”
Submitted by: Pepping Vastgoed bv
Consultant: Blesgraaf bureau voor bouwen & milieu

Design
This design is centred on a pleasant, saleable house, characterized by sustainability with limited usage of fossil fuels. The design is based on an integrated approach reconciling the architecture with services. The use of waste energy streams and, thus, exergy, is a focal point. This dwelling has an extremely low energy usage approx. 25,000 MJ of natural gas and electricity per year. This corresponds with savings of 26,000 MJ relative to the reference design without any exergy measures. Its EPC is only 0.52.
All materials used in the design conform to the range specified in the Dutch National Programme for Sustainable Building. Also, it includes water-saving appliances and toilet flushing systems as well as rainwater collection systems for domestic use. The design concerns a semi-detached family house with the garage joining the neighbour’s garage. It is oriented north-south. The north facade contains practically no openings, but does not look too closed thanks to its curvature. It is very open on the south side. All normally occupied rooms border on this facade and, so, on the back yard. In this way, maximum use is made of passive solar energy. The
open character of the facade is moderated by the inclined, overhanging roof structure. The overhang prevents excessive temperatures in summer. The inclined roof areas accommodate PV cells and solar collectors. The geometry of the cross-section gives a particular spatial effect and allows sunlight to reach the garage.

Energy conservation
The overall energy demand is reduced first of all by the compact design, the orientation, the conservatory, thorough scaling of cracks and joints, heavy insulation and domestic water conserving features. Waste energy streams and solar energy are utilized wherever possible. The remainder of the demand is met by fossil fuels.

Inside environment and comfort
Air quality is assured by a simple, adjustable ventilation system with grids and windows that can be opened. There are no air intake ducts. Overheating is prevented by wall cavity ventilation, heat absorption and storage in the walls and floors, and by fixed and adjustable sunshades. Occupants receive instructions for use of the conservatory.

Energy and exergy
The systems for power generation and waste heat recovery are cascaded as follows.
1. The system is based on passive solar energy systems, an integrated solar collector/boiler unit and heat recovery from warm drain water. Recovery is augmented by a heat exchanger between the hot domestic water supply and the drains from the shower and bath, washing machine and dish washer.
2. When the gain from these sources is inadequate, the heat pump is called upon. Stale ventilation air to be expelled is first passed through the heat pump, the recovered energy being stored in an integrated solar collector/boiler. The latter is used for producing hot domestic water and for low-temperature space heating. The efficiency of the integrated system is increased by feeding hot water to the washing machine and the dish washer (hot fill). Electrical power for the heat pump is produced to the extent possible by a PV system operating in conjunction with the mains.

3. The balance of the energy demand is met by fossil fuels. The integrated solar collector/boiler has a high efficiency in order for the balance to be as low as possible.

First place “The Energy Roof”
Submitted by: Architecten en ingenieursbureau Kristinsson bv
Consultants: Hebutech bv, Technisch adviesbureau EWG Techniek bv

Design
The design guarantees an optimum level of comfort combined with novel services systems and durable materials. Exergy is considered as utilizing low-temperature heat and waste energy. Energy requirement for space heating is reduced from 52 GJ/year to 5 GJ/year. Energy requirement for domestic hot water is reduced from 14 GJ/year to 5 GJ/year. The EPC = 0.84 to 0.58

Better space utilization
The crawl space is enlarged to serve as garage, store room and for water storage. The lay out of the house is wide, with a small heated core. The orientation of this design concept makes no difference. The construction and design of this house make it possible to add-on roof structures if desired.

Innovation
Storage in crawl space and hollow, water-filled foundation piles for improved heat pump performance. The design offers 15% more space, seasonally modifiable facades, light-weight parabolic solar dishes integrated with central heating boiler and water heater.
Follow up
By organizing this competition several parties in the building and installation sector were stimulated and involved to take into account the quality of energy flows in the design phase of dwellings. The most important result of the competition is the fact that architects and consultants tried to translate the principles of exergy into designs and ideas. The competition also showed that it is possible to build market-conform dwellings, using exergy principles. This conclusion is emphasized by the fact that two of the award winning designs, the first and third price, will be built, not as demonstration houses, but as “normal” commercial houses. However the working of all the exergy principles will be monitored and evaluated.

ACKNOWLEDGEMENTS
The author would like to thank all the participants in the Exergy Design House Competition, especially the Exergy House Project Group, in which the following organizations participate:

- EnergieNed: Organization of Energy Distributors in the Netherlands
- GGR GAS: Gas supply company for the river area in the province of Gelderland
- NOVEM: Netherlands Agency for Energy and the Environment
- NUON: Power company for the provinces Gelderland, Friesland and Flevoland
- SEP: Dutch Electricity Generating Board

REFERENCES