212: Energy performance of energy conscious buildings; between design and reality…

Leo J.J.H.M. Gommans [1,2,3,4]

[1] *Climate Design Group, Faculty of Architecture, Delft University of Technology, the Netherlands.*
[2] *Chair of Environmental Design, Faculty of Architecture, Delft University of Technology, the Netherlands*
[3] *Faculty of the Built Environment / Readership New Energy, Hogeschool Zuyd, Heerlen, the Netherlands*
[4] *BOOM, Office for Research and Design for the Environment, Maastricht / Delft, the Netherlands*

Abstract

In The Netherlands, and in many other countries, energy performance simulation models are used to determine energy savings realised in the newly built environment. According to these models the use of sustainable energy, high levels of insulation, and efficient energy systems contribute significantly to good energy performance. However, the real energy savings achieved in practice usually remain unknown because measurements are rarely carried out.

We have investigated the energy-efficiency of buildings in numerous building projects over the years. Measurements clearly demonstrate that taken energy-saving measures often do not achieve the savings predicted by the energy performance simulation models. In our view, most of the time, the applied technology is not the cause of this under-performance. Errors in system design and dimensioning, control issues, implementation, maintenance, and supervision appear to be common and important reasons for poor performance of energy-saving technology. For example, the under-performance of solar water heaters due to pump failure often goes unnoticed for long periods of time because the secondary heater automatically takes over. We estimate that 50% of solar water heaters installed in the Netherlands give no or only insignificant energy savings. More examples of under-performing energy-saving measures are given.

In this paper we describe common problems and causes in the implementation of energy-saving measures. As a possible solution, we outline a plan involving performance guarantees by contractors implementing energy-saving measures.

Keywords: energy-saving, under-performance, solar heaters, heatpump, simulation models, dimensioning, maintenance

1. Introduction

In recent years we have monitored the energy performance of a number of housing and office buildings using sustainable energy technology, such as solar energy and heat pumps. The buildings under investigation have collective energy systems with bivalent heating: if for example, the solar collectors or heat pump produce insufficient heat, their task is (partly) taken over by conventional equipment, such as natural gas heating systems (in The Netherlands). The buildings have been monitored between 5 and 15 years on their energy usage and on the performance of separate energy system components. Measurements in the buildings have made it possible to investigate the performance of energy systems over time, from the time of building completion till years later.

Measurements that allow evaluation of the energy performance of buildings are not commonly carried out over an extended period of time. Even if measurements are done, problems that are found are not usually published, at least in part to avoid discrediting the sustainable energy technology in case and make widespread use difficult. While this is understandable it is also a lost opportunity to learn from mistakes, the more so, because in our experience the problems are rarely intrinsic to the applied technology. In this paper we discuss a number of problems that commonly arise in sustainable energy systems as implemented in (large) single buildings, and indicate solutions. The projects concerned remain anonymous, to avoid discrediting anyone.

2. Energy performance and calculations

The Netherlands, as does the European Union, has ambitious plans for the reduction of carbon dioxide emissions. In the built environment this reduction is to be realised for a large part with solar collectors and heat pumps. The EPBD (Energy Performance of Building Directive) is to be an important aid in carbon dioxide emission targets. One of the tools that the EPBD provides is a method to calculate an overall energy performance measure for buildings. In the Netherlands a standardised calculation method has been developed and adopted in the building code to determine the energy performance of buildings. Since 1995 all new buildings are legally compelled to satisfy certain energy performance requirements (NNI, 2004: *NEN 2916 & NEN 5128* [1,2]).

Input to the calculation method includes the performance of PV-cells, heat pumps and solar collectors. There are standard values for their performance, but for individual systems, better performance may be input if this is certified. The output is a scalar energy performance measure for the building in question, which is directly related to carbon dioxide emission. This type of procedure is the basis for determining carbon dioxide emission reductions in the context of national and European targets. The underlying assumption is that the calculated performance is achieved in practice, both in the short term and in the long run.

In practice, it appears that the calculated energy performance is seldom achieved If discrepancies between energy performance in theory and practice go by unnoticed and unremedied, we will be over-estimating the effectiveness of energy-saving measures and carbon dioxide emission reductions. If the incentive for taking energy-saving measures is primarily to obtain a building permit, the practical effectiveness of the measures, if at all measurable, will be an issue receiving minor attention. The ability to explicitly measure performance of energy-saving measures is a necessary condition in determining and improving the effectiveness.

3. Where things can go wrong

3.1 Design

Things can start to go wrong in the design stage of a building and its climate system. The building's detailed construction may contain thermal bridges and ventilation leaks leading to energy loss. The influence of these losses is particularly large for highly efficient buildings when compared to their energy uptake. Incorrect dimensioning of systems or components is another factor that can lead to poorer performance than calculated. For instance heat pumps are sometimes dimensioned with too small underground heat exchangers to save on costs; or radiators are made too small, suitable only for higher system temperatures, which may dramatically reduce the efficiency of the heat-source. The efficiency of heating systems with solar collectors and heat pumps is particularly sensitive to incorrect dimensioning of components and so to different system temperatures.

The efficiency of a solar collector system for water or space heating is greatest when the temperature in the boiler reservoir is low. If for instance the temperature of return water from the central heating system is low, then the water temperature in the reservoir is low, and heat from the collector will be delivered to the reservoir more easily (at lower collector temperatures) than when the reservoir temperatures are high, due to say incorrect dimensioning of the radiators. The same principle goes for a heat pump: with a given fixed amount of electrical energy the heat pump delivers more heat if the output temperature is low, and the input temperature – e.g. that of brine from the underground collector – is high. As the temperature difference, output-input across a heat pump increases, its efficiency decreases (fig. 1). Incorrect dimensioning of the system - e.g. too small underground collectors giving too low input temperatures to the heat pump, or too little radiating surface in the space to be heated, leading to higher output temperatures to maintain comfort levels - lead to high temperature differences across the heat pump and so to low efficiency. Incorrect dimensioning but also incorrect settings of control parameters can easily halve the efficiency of a heat pump.

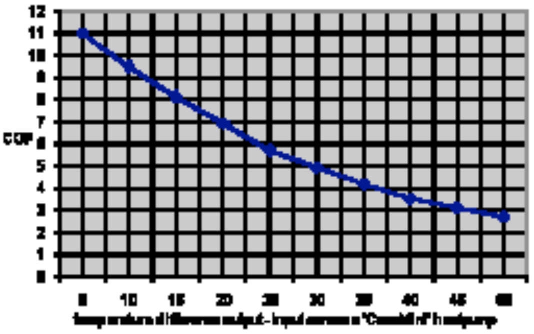

Figure 1: Graph of the temperature difference (output-input across heat pump) effecting the efficiency (expressed in COP for CasaMini heat pump).

3.2 Implementation

Besides good design and dimensioning of the building and its energy systems, the energy-saving measures must be well-implemented. Implementation is normally monitored during the building process, but for newer technologies and energy-saving measures requiring some expert knowledge, and perhaps an expensive advisor, this happens only infrequently. Regular fitters sometimes take on work, often at too low a price and as sub-contractor. They underestimate the technology, and install pumps and piping with too little capacity, place incorrect components or get the network connections wrong. Control system components are frequently installed incorrectly, given incorrect settings, or temperature sensors are placed in the wrong places. Even if there is some monitoring of the work, some things are difficult to check.

In any case, on completion of a building, an energy system should work as intended, and this can only be ensured by carrying out measurements. Oftentimes, this is not performed because of money costs in terms of wages as well as equipment. Thermal bridges or energy leaks in buildings can be detected with infrared cameras, slit ventilation leaks can also be detected. Energy systems in buildings can be monitored with temperature sensors, electricity-meters and flowmeters. Most of the time this is not done.

3.3 Maintenance

Following building completion there are often problems with a new building. Some problems become apparent straight away, for instance draughtiness, condensation, or inability to heat spaces to required comfort levels. However, sometimes the problems remain invisible: e.g. poor performance of a solar collector has no effect on warm water production or comfort levels because there is a secondary heat source available. Another example; low flow in heating pipes or wrong settings of controls can pull down the performance of heating/cooling systems without leading to complaints about comfort levels. Or office buildings may have an air-based cooling system and a heating system with radiators. The controls may be incorrectly set so that both systems are operational at the very same time: radiators heat air which is then cooled by the cooling system. These kind of errors often go by unnoticed because there are no complaints about comfort. Maintenance technicians also often do not spot such problems.

Many of such problems would be detected if measurements were carried out. But in practice, we have found that maintenance technicians take little notice of problems concerning energy-efficiency, even in the presence of an extensive building monitoring system with modem-based generation of error and alarm messages. In most cases adjustments to energy systems are made only on the basis of comfort complaints, and almost never to improve system performance. To the contrary, some systems are given settings that purposely lower the performance if this reduces the chance of comfort complaints. For example the temperature on the output side of a central heating system may be increased for this reason. This step is sometimes also taken to alleviate problems caused by too little flow, or too little surface area for delivering the heat energy in the space to be heated. For systems which produce sustainable energy at low temperatures, such as solar collectors, heat pumps and high-efficiency natural gas heaters, this dramatically decreases their efficiency. It can lead to higher energy consumption and carbon dioxide emissions than with conventional heaters, and amounts to destruction of capital.

4. Case studies

4.1 Solar collectors for heating drinking water in a housing project.

We have monitored, since 1990, the collective drinking water heating system of a housing project containing 10 clusters of 7 residences of various sizes for roughly 180 people [3]. For every cluster of 7 residences, tap water is heated with solar collectors, stored in a central boiler reservoir and distributed though a circulation net to the residences. The hot water in the circulation net is kept at a constant temperature of 70°C by continuously circulating it through this net, so that hot water is instantaneously available when a tap is opened: this is a common set-up for collective drinking water heating systems (fig. 2). One of the reasons to choose for collective water heating was that with low investments high solar energy yields could be achieved. For comparison, each residence had on average 1.5 m^2 solar collector surface, which yielded per m^2, more than an individual system with 2.5 m^2 collector surface. The high yield is caused by a more efficient use of the solar energy due to collective use and a lower amount of hot water covered by solar energy. In favourable years the annual system yield of some collectors has been almost 700 kWh per m^2 of collector surface, more than twice commonly achieved yields! Thus solar energy technology need not be the limiting factor in system performance.

However, the majority of the captured solar energy was lost in the circulation net. The losses can be partly accounted for by the fact that the hot water circulated continuously through the net. The losses were certainly exacerbated by the fact that the distribution ring had some serious shortcomings introduced when it was laid out. The brackets holding the distribution pipes were placed directly in contact with the piping (instead of on the outside of the insulation), thereby forming thermal bridges leaking energy to the walls by conduction. Where the pipes passed through walls there was no insulation. The circulation net also contained sections that were badly insulated or not at all. These shortcomings in implementation could be remedied only in part at acceptable costs.

The continuous circulation of hot water at 70°C through the circulation net was another source of significant energy losses. However the demand for hot water varies throughout the day and there are commercially available control systems, consisting of a couple of temperature sensors at the reservoir in- and outlet plus a simple control unit, that can significantly reduce pump operating time and thus circulation losses. These control systems need to be checked regularly for proper functioning and to optimise the settings, particularly if they are time-dependent. Maintenance technicians typically do not pay much attention to such controls.

Gradually a number of adjustments were made to the water heating system, resulting in high solar energy yields (more than 600kWh per m^2) with relatively low losses. A certified building services company with experience with solar collectors was contracted to carry out maintenance. The system performed well for several years but then some solar collectors started to show poorer performance or broke down altogether. This was not noticed by residents whose hot water supply was ensured by a secondary gas heater. Maintenance technicians also did not spot any malfunctioning. The error signalling system in place consisted of a red LED on the control panel mounted on the reservoir that lit up only when the temperature in the collector was higher than in the reservoir, which is not the case on cloudy days. Thus, maintenance technicians who came on cloudy days could not encounter an error in the system. There was no error signal for malfunctioning of the pump between the collector and the reservoir. Poor pump performance due to wear and tear of the pump or too little water in the circuit leads to poor system performance. In some cases the performance of the system ducked below the energy uptake by the failing pump. Energy destruction with a solar heater!

After 2 more years without monitoring, it appeared that 40% of the solar collectors performed poorly or not at all, without anybody knowing. By virtue of measurements we could demonstrate the under-performance of the system.

The under-performance of the solar heating system described is not an isolated event. In our daily research practice we encounter this more often than just regularly. Especially in small solar water heating systems which are not always properly maintained, and which have been installed primarily to meet energy performance requirements stipulated by the building code, under-performance and system breakdowns are frequently ignored or left unfixed. Measurement devices, such as heat flow gauges, to monitor system performance are hardly ever installed, because this is not required by the building code and increases system costs. The users and building supervisors are not always interested in proper functioning of the system, and oftentimes do not have sufficient expertise to spot and fix problems.

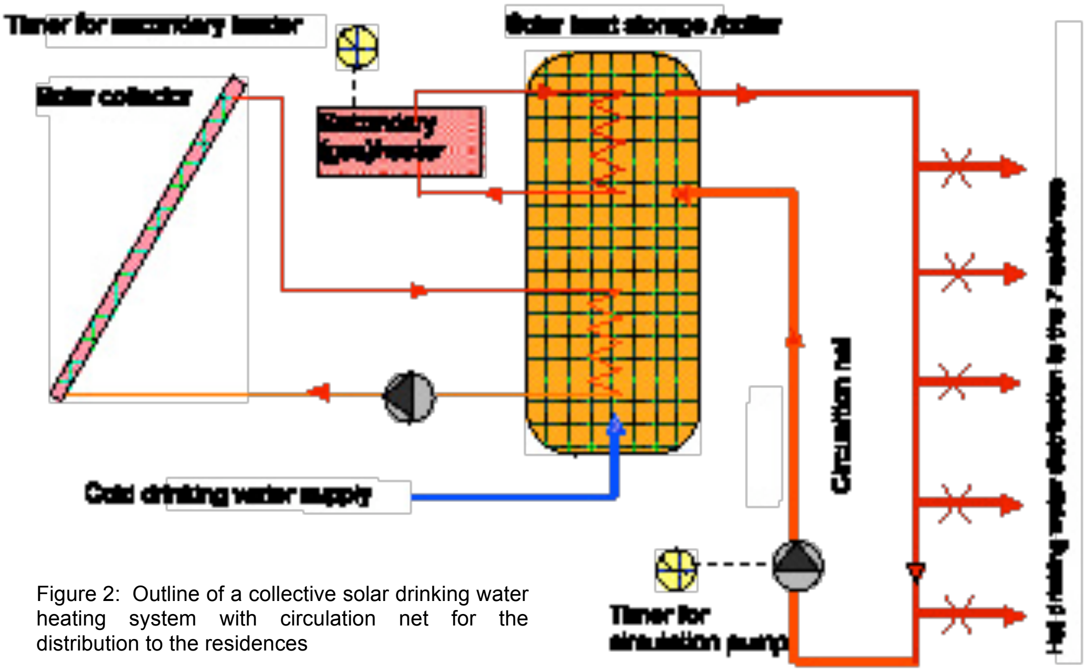

Figure 2: Outline of a collective solar drinking water heating system with circulation net for the distribution to the residences

4.2 Decreased efficiency of heat pump and solar collectors

Another project concerns a collective heating system with solar collectors and a heat pump for 13 residences and an office. A layered reservoir, to which solar collectors, a heat pump, and a gas heater are connected, ensures appropriate temperatures for space and water heating. The solar collector and heat pump heat the water at the bottom of the reservoir, where the temperature is at its lowest level. For best performance of the solar collector and heat pump it is essential that the water at the bottom of the reservoir is as cold as possible, as explained earlier.

The temperature of the space heating system had to be set higher than the design-value because a number of residences could not be heated comfortably. Later, after an "over-pressure test", it appeared that slits and gaps in the external construction of these residences allowed a ventilation leakage 5 times higher than assumed during design, and input in energy performance calculations. So the residences did not meet design specifications, leading to increased energy consumption firstly because their energy demand was higher than planned, and secondly because as a consequence the efficiency of the heat pump and solar collectors decreased.

In this housing project measurement devices were placed from the start allowing rapid detection of under-performance of the system. Hence, it soon became apparent that the yield of the 40m^2 of solar collector was too low. Replacement of the pump between the collectors and the reservoir with a larger pump was necessary to remedy this. Also, adjustments to the control settings of the system have led to improvements in performance. This would have been impossible without the presence of the measurement devices.

In the course of time we have noticed poor performance or breakdowns on several occasions. However, maintenance technicians did not detect these breakdowns despite their availability to their building services firm via automatic error message generation by modem. As it was, we were the ones who had to inform them several times of problems with the heat pump, solar collectors or even in traditional building services. For example, the measurements showed that after 3 years of good performance, the efficiency of the heat pump had dropped by 75%. The solution was simple, but the point is that the problem would not have been noticed without continuous registration of the heat pump performance. It seems that this is a task for which maintenance technicians are not (yet) quite suited.

4.3 Implementation faults and dimensioning

Some remarkable problems have also arisen in a building project with underground collectors for a heat pump, also used for cooling during summer [4]. The floor heating system was used in summer to extract heat and dump this underground via separate underground heat exchangers. In the heating season the heat pump is connected by (a set of) valves to an underground collector to extract heat and deliver this to the spaces to be heated. Both the cooling and heating process are typically very efficient. However, it appeared that during the summer the heat pump incessantly switched on and off thereby decreasing its efficiency and also inflicting more wear and tear on it than necessary. Measurements demonstrated that there was too little flow through the floor-heating system so that the heat pump could not get rid of the energy it generated and hence switched off. There were no comfort complaints because of the presence of a secondary heat source, albeit much less efficient. Measurements on the underground collector of the heat pump also demonstrated too little flow there, which meant temperatures on the input side of the heat pump were on the low side thereby decreasing its efficiency. The low flow in the underground collector was due to the type of valves used in a section of the collector. To save on costs cheaper valves had been used which offered higher resistance to flow, leading to lower flow and worsening the heat pump performance.

The low flows in the collector and through the floor led to reduced cooling capacity and increased energy consumption during the cooling season. There were two additional reasons for poor cooling performance: the heat exchanger for cooling was firstly too small (cheaper), and secondly, the way it was mounted made it a parallel-flow heat exchanger instead of counter-flow. Adjustments to the heat exchanger to counter the flows increased cooling capacity by 50%. All these implementation faults again would have been undetected without measurements.

In this project the problems did not reside in the sustainable energy technology as such. If well-implemented the heat pump can be extremely efficient, using 1 kWh of electrical energy for the pump to extract 40 kWh of cold energy from underground. Cooling this amount of energy normally costs 20 to 80 kWh of electricity. So this performance for cooling is very high and exceeds that predicted by energy perfomance calculations.

5. Conclusions

The performance of sustainable energy technologies and energy-efficient building is very sensitive to design and implementation faults. The efficiency of solar collectors, heat pumps, but also of cooling with underground heat exchangers can vary widely from values used in energy performance calculations. Also optimal control of climate systems, which is an on-going process, and the maintenance and supervision determine the performance in the long run. For bivalent systems in particular, under-performance of sustainable energy components easily goes by unnoticed. Continuous monitoring and optimisation of efficiency after building completion should become a standard part of the building process.

Monitoring will entail some extra initial costs for temperature sensors, electricity-meters and flow-meters and for detection of thermal bridges, slit ventilation leaks and checking the ventilation system on delivery of the building. For a single residence this would be about 1.000 to 1.500 Euro extra costs but for delivery of a lot of residences or larger buildings at once, these costs go down. Benefits of scale also arise for the yearly cost of expert monitoring and analysis of the measured data, which will be about 300 Euro for a single residence, but less when more residences are involved.

Measurement of relevant parameters (temperatures, flows) is essential for monitoring and optimising performance. While measurement carries extra initial costs, this will easily pay back in saved energy costs from better performance of buildings and climate. Depending on the situation, this payback period could be a few years but in some cases it will be tens of years.
As long as building partners are not very careful in designing, accomplishing and maintenance, the investment will be worthwhile.

Building services firms could also guarantee the performance of climate systems they install, in combination with a services contract in which they monitor and optimise the performance. In this case, the firm is forced to deliver good work and do good maintenance, especially when the building supervisor is able to check the performance on indicators.

Bivalent systems are interesting because they allow great energy savings at relatively low initial costs. Because these systems are more sensitive to underperformance, as we have seen, part of the savings can be used for buying a kind of energy performance warranty.

All in all this could lead to better performance than predicted by energy performance calculations because the performance of many sustainable energy systems depends on many components that must be well-matched. This is an important reason to give certified performance warranties, not on systems components but on whole systems. If such performance warranties can be guaranteed by building services contractors and monitored by building owners or supervisors, then the specified performance could be used as input to energy performance calculations that are adopted to the building code. In the Netherlands this are the energy performance directives [1 and 2] which are part of the European Union's EPBD (Energy Performance of Building Directive).

A certified performance warranties adopted in the building code, could be a boost to the use of sustainable energy technology because the effect on the energy performance would be greater than with the current standard practice. Moreover, the energy performance is guaranteed, also on the long term. In this way energy performance calculations can contribute more effectively to lower energy consumption in the built environment and also to national and international political agreements to reduce carbon dioxide emissions.

6. References

1. NNI (2004) *NEN 2916 Energy performance of non-residential building – Determination method* (Delft; The Netherlands Standardisation Institute) [Dutch written]

2. NNI (2004) *NEN 5128 Energy performance of residential building – Determination method* (Delft; The Netherlands Standardisation Institute) [Dutch written]

3. Gommans L. (2002), *Lange termijn monitoring collectieve zonneboilers vernieuwend Wonen Maastricht – Definitieve eindrapportage* (Delft University of Technology, Faculty of Architecture and BOOM-Maastricht for SenterNovem, Utrecht, NL) [Dutch written]

4. Gommans L. (2007), *Verhogen kosten- en energie-efficientie met warmtepomp door serieschakeling bodemcollectoren bij Trevianum scholengroep te Sittard – openbaar eindrapport* (Delft University of Technology, Faculty of Architecture and BOOM-Maastricht for SenterNovem, Utrecht, NL) [Dutch written]