Field test of heat-fed washing machines and tumble dryers

Cadence Appendix K

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Summary

Application of heat-fed washing machines and tumble dryers is a promising fuel-switching option for households. It increases heat demand in district heating networks, it saves primary energy and it can save costs. In this way, it can benefit utilities, the environment and consumers at the same time.

In heat-fed washing machines and dryers, the source of heat is hot water from a district-heating or central-heating installation. As opposed to hot-fill applications for washing machines, the heat is supplied by a heat exchanger through which the hot water flows, rather than directly using the hot water for washing. In this way, the concept can also be used for drying. In addition, higher primary energy savings can be achieved.

The field-test
Prototype heat-fed washing machines and tumble dryers have been developed in a previous phase of this project. In this last phase of the project, utilities participated by buying prototype heat-fed machines. Thirteen households were selected for placement of the machines to conduct a one year field-test. The aim of the field-test was to establish the technical performance in practice and to examine how users would appreciate the apparatus.

At eleven of the thirteen participating households the heat-fed apparatus was connected to a district heating network. In one household the machines were connected to the central heating system. In another household the machines were connected to a central heating system that incorporated a solar domestic hot water system. For all systems solutions for connecting the apparatus to the heating network have been developed.

Energy and cost savings for district heating applications
From the technical monitoring of the machines during the field-test, the washing machine turned out to function well. Averaged over all households a yearly primary energy saving of 43% was calculated. The average cooling of the district heating water is 26ºC. The tumble dryer also functioned well. The yearly primary energy savings amounts to 52%. The average cooling of the DH-water is 16ºC.

Heat demand in district heating networks can increase by 2.5 GJ per house. For energy efficient homes this would be an increase of 12%.

A household can save € 42 in yearly electricity costs, based on the day-time electricity tariff currently used in the Netherlands. Based on the night-time tariff this would be € 9. For actively stimulating heat-fed apparatus it could be considered to change tariffs to make heat consumption more interesting for consumers.

Performance of heat-fed apparatus in central heating systems
The heat-fed apparatus has shown to perform as well when connected to central heating systems as to district heatings systems. However, the primary energy savings are lower. From the field-test data savings of 18 and 23% were calculated for the washing machine and the tumble dryer, respectively. On the other hand, the cost savings are higher: € 54 for the day-time tariff and € 21 for the night-time
tariff, respectively. In these calculations no solar contribution was taken into account.

**User appreciation**
From inquiries it is concluded that the participating households were very content with the washing machine. Appreciation of the dryer varies significantly from one household to another. Noise production appears to be the biggest factor causing the mixed feelings about the dryer. Some households find the drying cycles take too long. Some households find the dryer dries better than their previous machine, whereas others think its drying performance is inferior to their previous dryer.

**Heat loss**
The heat loss through the pipes averaged over a year is calculated to be at most 13% for the washing machine and 4% for the tumble dryer (based on 2x12 m pipe length). This has little influence on the primary energy savings that were calculated. However, it does affect cost savings. Therefore it is still important to reduce pipe length and to insulate the pipes.

**Further developments**
During the field-test technical problems have occurred every now and then. None of these were of a fundamental nature and all problems have been solved. From a technical viewpoint the field-test has shown there are no barriers for further development and large scale application of the heat-fed apparatus. In addition, users have indicated their satisfaction in using the heat-fed apparatus. A brief comparison of the heat-fed concept with other energy saving concepts (hot-fill washing machines, gas-fired dryers, heat-pump dryers) show that the heat-fed apparatus combine large energy savings with moderate cost, and therefore are promising options for fuel switching. A brief inquiry also showed interest by utilities Europe-wide for application of heat-fed apparatus.
# TABLE OF CONTENTS

1. INTRODUCTION ........................................................................................................... 1

2. THE FIELD TEST......................................................................................................... 2
   2.1 Introduction ............................................................................................................ 2
   2.2 Development of heat fed laundry apparatus .......................................................... 2
   2.3 Issues of connecting heat-fed laundry apparatus to different sources ................. 5

3. FIELD-TEST MEASUREMENTS ................................................................................... 8
   3.1 Set-up .................................................................................................................... 8
   3.2 Results washing machine ...................................................................................... 11
   3.3 Results condensing dryer ...................................................................................... 12
   3.4 Degree of cooling and influence of supply temperature ......................................... 14
   3.5 Transport losses ................................................................................................. 14
   3.6 Solar contribution ............................................................................................... 15
   3.7 Increased heat demand for heat distribution networks ......................................... 16

4. ENERGY AND COST SAVINGS .................................................................................. 17
   4.1 Efficiencies and costs ........................................................................................... 17
   4.2 Washing machine ............................................................................................... 18
   4.3 condensing dryer ............................................................................................... 19
   4.4 Heat-fed against other fuel switching options ..................................................... 21

5. EXPERIENCES USERS AND UTILITIES FROM FIELD TEST ......................... 24
   5.1 User appreciation ............................................................................................... 24
   5.2 Utilities ................................................................................................................. 25

6. CONCLUSIONS ............................................................................................................ 26

REFERENCES ................................................................................................................. 28
1. INTRODUCTION

Development of heat-fed laundry apparatus is a promising option for obtain CO₂-reduction in the household sector. In addition, utilities are interested in development of applications for increasing heat demand for households that are connected to district heating (DH). If, at the same time, the households can save money on their utility bills, environmental benefits and cost benefits for utilities as well as consumers are combined.

In a previous project, funded by EnergieNed and Novem, a prototype heat-fed washing machine and dryer have been developed. They showed to have a similarly good performance as their electrical counterparts. The heat-fed laundry apparatus was developed initially with the aim of connecting it to district heating networks. However, other heat sources, such as central heating (CH), heat pumps and solar domestic water heaters (SDWH’s) are suitable as well.

It was decided to further develop and test this apparatus by conducting a field test. The aim of the field test was

- To show that in practice heat-fed laundry apparatus would perform as well as conventional laundry apparatus
- That the amount of primary energy saving in the lab was realized in practice as well
- That, for the purpose of exploitation of district heating networks, the consumption of heat by the apparatus was sufficiently efficient
- That the heat loss in between the meter cabinet and the apparatus was sufficiently low.

In the second chapter, a general description of the preparation for the test, the development of the heat-fed laundry apparatus and application and installation issues are given. In the third chapter, a description of the measurements is given, together with the results of the measurements. In the fourth chapter the energy usage of the apparatus from chapter 3 will be used to calculate energy savings and savings of running costs for the households. The energy saving potential will be compared to other alternatives for electric laundry apparatus in relation the cost of the various options. In chapter 5 experiences of the cooperating households and utilities are discussed, together with a brief summary of the technical performance of the machines.
2. THE FIELD TEST

2.1 INTRODUCTION
In previous projects prototype heat-fed washing machines and tumble dryers were developed by adapting existing electric machines [VHK96a] [VHK96b]. The results of tests done with the machines in the lab were very satisfactory. For the washing machine, all requirements previously stated were fullfilled.

The time it took for the dryer to complete a standard cycle was somewhat longer than desired: 140 minutes instead of 120. The dryer was of the condensing type. This type was chosen because of the flexibility for placement in a home and for the large market share of this type of dryer. It was decided to make an effort to reduce the drying time for the dryer in the field test by changing the design slightly. The design of the machines will be discussed in § 2.3.

Seven utilities were part of the project. They recruited a total of thirteen households for participation in the field test. Out of these households, 11 homes were heated by district heating (DH) and two by central heating. From the households with central heating (CH), one home was equipped with a solar domestic hot water system, that was connected to the central heating. Details on the connection of the heat-fed laundry apparatus to the heating system will be given in paragraph 2.4.

The financing of the project was done by EnergieNed, Novem and Gasunie. Seven different utilities (at the time) bought sets of the heat-fed laundry apparatus and recruited households (Edon, Eneco, Enw, Gamog, Nuon, Pnem, Remu).

2.2 DEVELOPMENT OF HEAT FED LAUNDRY APPARATUS

The design of the prototypes and redesign for the field-test in case of the dryer was done by Van Holsteijn & Kemna.

The heat-fed washing machine [VHK98a]
The heat-fed washing machines were made by modifying the Miele comfortline W959. This is one of Miele’s top models.

The electronic circuitry of the machine has undergone some changes as well. For example: if there is insufficient power from the heat exchanger to achieve the desired washing temperature, the electrical heating element is turned on. This makes it possible to still do laundry at 95 °C, even though the temperature of the DH-water is only 70 °C.
The heat exchanger is connected to the so-called connection unit by flexible pipes, see Figure 2-2. This consists of connectors for the internal pipes and external hoses, a flow-setter, a solenoid valve, and a check valve. The connection unit was placed at the back of the machine.
The heat-fed laundry dryer was made by modifying the Miele comfortline T559C, one of Miele’s top models as well. Just as for the washing machine, the main change was the addition of the heat exchanger for the DH-water. The redesign of the prototype resulted in a larger condenser and higher power ventilators for the drying air as well as the cooling air. In the redesigned machine the program time was reduced from 140 to 120 minutes. This is still longer than the time it takes for its electric counterpart (80-100 minutes). However, in practice, less laundry is put in the machine, which will also result in cycle times that are less than 100 minutes.
Just like for the washing machine, the heat exchanger is connected to a connection unit with a solenoid valve, a flow-setter, a check valve and connectors for internal and external connections of pipes and hoses.

It is still possible to use electric heating by flipping a switch. This way it is possible to still use the dryer even when no DH-water is available.

In Figure 2-3 a drawing of the heat-fed tumble dryer is given. In Table 2-2 the most important technical specifications are summarized.

### Table 2-2: Technical specifications heat-fed tumble dryer

<table>
<thead>
<tr>
<th>Technical specification</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy consumption 1 electricity</td>
<td>Wh</td>
<td>770</td>
</tr>
<tr>
<td>Energy consumption 1 heat</td>
<td>MJ</td>
<td>15.1</td>
</tr>
<tr>
<td>Consumption DH-water 2</td>
<td>liter</td>
<td>180</td>
</tr>
<tr>
<td>Flow DH-water</td>
<td>liter/min</td>
<td>1.5</td>
</tr>
<tr>
<td>ΔT DH-water</td>
<td>°C</td>
<td>19</td>
</tr>
<tr>
<td>Power 2/3</td>
<td>kW</td>
<td>0.46 (3.6)</td>
</tr>
<tr>
<td>Cycle time</td>
<td>min</td>
<td>120</td>
</tr>
<tr>
<td>Size</td>
<td>mm</td>
<td>900 x 595 x 600</td>
</tr>
</tbody>
</table>

1 cotton cupboard dry cycle
2 at a supply temperature of 70°C
3 in between brackets: the input power of the electrical element

#### 2.3 ISSUES OF CONNECTING HEAT-FED LAUNDRY APPARATUS TO DIFFERENT SOURCES

As stated before, the heat-fed apparatus is suitable for connecting it to different hot water sources, such as district heating, central heating and tapwater circuits. However, a few technical aspects have to be taken into account upon connecting the heat-fed apparatus to a hot water source. Examples are: available pressure drop, minimal distribution temperature, ways of regulating room temperature (thermostaatkranen of kamerverstrooma met 2-wegklep). For a central heating solution frequent turning on and off of the boiler has to be avoided. These technical issues are discussed in detail [VHK98a]; a summary is given below for each connection method.

**Connection to district heating**

For connection to district heating the following measures have to be taken:

- The apparatus has to be connected to the circuit behind the pressure drop regulator.
- The pressure drop regulator has to be of the 20 kPa-type; the variation in pressure drop at full load and partial load should not be more than ±2 kPa.
- Upon replacement of the pressure drop regulators the radiators have to be tuned to this new pressure drop.
- If thermostats are used, the supply and return pipes for the heat-fed apparatus need to be connection to the main house connection (see Figure 2-4).
If all radiators have a thermostatic valves there will always be circulating water. Therefore, the pipes for the heat-fed apparatus can be branched off from the nearest supply and return (see figure 2-5).

A pipe diameter of 15 mm is recommended; insulation of the pipes is also strongly recommended.

Two way valves need to be connected where the heat-fed apparatus is branched off from the main line.

**Connection to a central heating system**
A requirement for connection a CH-system is the presence of a buffer. This implies that the CH-system with a buffer for hot tapwater should be used. It has turned out that the detailed solutions for connecting the heat-fed apparatus depends
to a large extent on the type of boiler and the exact configuration in the house. [VHK98b].

Connection to a hot tapwater network (not applied in Field Test)
The following measures need to be taken for this solution:
• The hot water temperature needs to be at least 70°C.
• It is recommended to apply a revolution controlled pump with sufficient head (depending on the number of heat-fed machines that will be connected to the network).
• The supply and return lines should be connected to the nearest domestic hot water-circuit connection (in most cases the meter cabinet).
• A pipe diameter of 15 mm is recommended; insulation of the pipes is also strongly recommended.
• Two way valves need to be connected where the heat-fed apparatus is branched off from the main line.
3. FIELD-TEST MEASUREMENTS

3.1 SET-UP

The energy use of the heat-fed apparatus has been measured before in the laboratory under controlled conditions. In practice, washing and drying conditions can be quite different. First of all, conditions such as water temperature, air temperature, DH-flow and temperature can vary from location to location and from moment to moment. Second, users use different washing and drying programs than the standard programs run in the lab, and use different loads. All of this affects energy consumption, and consequently energy savings. To gather useful data on the average energy use in practice:

- One needs to have a large test group
- One needs to measure all factors that influence energy consumption

The second option was chosen. Heat-fed apparatus would be installed at a limited group of households. Prior to installation the machines would be tested in the lab and their water- and energy consumption at standard conditions would be measured. This could then be compared to energy consumption patterns measured in practice. In order to calculate energy savings, energy consumption data at various programs and conditions were needed for the conventional apparatus as well. These data were obtained from the manufacturer and from previous lab measurements.

In table 3-1 an overview is given of the parameters registered in the field test.

---

Table 3-1 Measurements on heat-fed laundry apparatus

<table>
<thead>
<tr>
<th>Washing machine</th>
<th>Tumble dryer</th>
<th>Various</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Wash cycle number</td>
<td>• Wash cycle number</td>
<td>• heat loss at mains per cycle</td>
</tr>
<tr>
<td>• number household</td>
<td>• number household</td>
<td>• heat loss at mains per day</td>
</tr>
<tr>
<td>• date</td>
<td>• date</td>
<td>• temp. supply meter cabinet</td>
</tr>
<tr>
<td>• time</td>
<td>• time</td>
<td>• temp. return meter cabinet</td>
</tr>
<tr>
<td>• program choice(^1)</td>
<td>• program choice(^1)</td>
<td>• simultaneous use washer and dryer</td>
</tr>
<tr>
<td>• program temp.(^1)</td>
<td>• extra features(^1)</td>
<td>• hot tapwater demand</td>
</tr>
<tr>
<td>• extra features(^1,2)</td>
<td>• load before drying(^1)</td>
<td>• hot tapwater temp.</td>
</tr>
<tr>
<td>• number of revolutions(^1)</td>
<td>• load after drying(^1)</td>
<td></td>
</tr>
<tr>
<td>• load(^1)</td>
<td>• heat consumption</td>
<td></td>
</tr>
<tr>
<td>• heat consumption</td>
<td>• electricity consumption</td>
<td></td>
</tr>
<tr>
<td>• electricity consumption</td>
<td>• temp. air in drum</td>
<td></td>
</tr>
<tr>
<td>• cold water consumption</td>
<td>• ambient temperature</td>
<td></td>
</tr>
<tr>
<td>• temp. cold water</td>
<td>• temp. DH-supply</td>
<td></td>
</tr>
<tr>
<td>• ambient temperature</td>
<td>• ambient temperature</td>
<td></td>
</tr>
<tr>
<td>• temp. drum</td>
<td>• temp. DH-return</td>
<td></td>
</tr>
<tr>
<td>• temp. DH-supply</td>
<td>• flow DH-water</td>
<td></td>
</tr>
<tr>
<td>• temp. DH-return</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• flow DH-water</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) Punched in by user
\(^2\) Features such as prewash, soak, extra long or extra short
In Figure 3-1 a schematic overview of the measurement setup is given. Figure 3-2 shows an example of the setup of heat-fed apparatus together with the measurement equipment.

Parameters like electricity consumption, temperatures and the like were recorded every minute by the data logger whenever of the machines was turned on. Parameters like program used, laundry weight and spinning rate were punched in by the user on a keyboard and registered by the data logger as well.
Figure 3-1: Measurement set-up in field test

Figure 3-2: Heat-fed apparatus together with measurement equipment.

Via a separate phone line the data were collected every night. An automatic processing routine converted the raw data into data per wash and drying cycle. In this way, data of 5000 wash cycles and 3000 drying cycles have been collected.
3.2 RESULTS WASHING MACHINE

Results from the lab-test preceding the field-test show that the washing machine performs as well as the prototype from the previous project (phase 3b). This is displayed in figure 3-3. For the fully electric machine, the prototype heat-fed washing machine in an earlier phase (3b) and for the heat-fed machine in the field-test, the average final energy consumption as well as the average primary energy consumption are displayed.

![Energy consumption washing machine](image)

**figure 3-3:** Washing machine: results of the lab-test of the standard program before the field-test.

Details of primary energy consumption will be dealt with in the next chapter. The final energy comprises the sum of the electrical consumption and the heat consumption. The final energy consumption is larger for the heat-fed apparatus than for the fully electric machine, because the drum had to be enlarged in order to fit the heat exchanger.

In table 3-2 the parameters of a standard cycle (60 °C cotton) is given, for the lab-test preceding the field-test and the average for the field-test itself.
Table 3-2 consumption of energy and water, average of lab-test and field-test for the standard program (60 °C cotton cycle).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>unit</th>
<th>Lab-test</th>
<th>Field-test</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy consumption electricity</td>
<td>Wh</td>
<td>216</td>
<td>230</td>
<td>1050</td>
</tr>
<tr>
<td>Energy consumption heat</td>
<td>MJ</td>
<td>3.9</td>
<td>5.0</td>
<td>-</td>
</tr>
<tr>
<td>Total water consumption</td>
<td>l</td>
<td>64.7</td>
<td>16.3</td>
<td>15</td>
</tr>
<tr>
<td>Water consumption main wash cycle</td>
<td>l</td>
<td>16.3</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Flow DH-water</td>
<td>liter/min</td>
<td>1.9</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>ΔT DH-water</td>
<td>°C</td>
<td>17.6</td>
<td>19.3</td>
<td></td>
</tr>
<tr>
<td>Laundry weight</td>
<td>kg</td>
<td>5.0</td>
<td>4.5-5.5</td>
<td>5.0</td>
</tr>
<tr>
<td>Cycle time</td>
<td>min</td>
<td>117</td>
<td>121</td>
<td></td>
</tr>
</tbody>
</table>

The table shows that the lab-test and field-test are comparable as well. The heat consumption is higher in the field-test. Part of this is caused by the higher water usage in the main wash cycle in the field-test. The heat consumption also varies with parameters like DH-flow, supply-temperature and ambient temperature. Variations in these parameters cause the difference between the lab-test and field-test.

Three months after installation some tuning was done to some of the washing machines:
- For a few machines the flow was not set well, this was corrected.
- For a number of machines the electrical heating element turned on too quickly when a 60 °C cycle was done. To correct this, the lag time for the electrical element to turn on was increased (if the desired temperature is not reached yet, it turns on 2 – 6 minutes after the temperature rise per minute is below a given value).

3.3 RESULTS CONDENSING DRYER

The redesigned dryer has a significantly lower energy consumption compared the the prototype from phase 3b. This is shown in figure 3-4.

Consumption data and other parameters for the lab-test preceding the field-test and for the field-test itself are given in table 3-3 for the standard drying program. In the field-test hardly any drying at the standard load of 5.0 kg was done. Therefore, energy consumption and cycle time data for lower weight categories were calculated for 5.0 kg dryweight using the weight-dependency found earlier in lab-tests. This is how the data for the field test in the table were obtained.

Comparison of the lab-test and field-test show that electricity consumption is somewhat higher in the field-test while the heat consumption is somewhat lower. However, given the large number of parameters that influence energy consumption in the field test, such deviations from the results in the lab-test can be expected.
Figure 3-4 lab-test results tumble dryer

Table 3-3: consumption of energy and water, average of lab-test and field-test for the standard drying program (cupboard dry).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>unit</th>
<th>Lab-test</th>
<th>Field-test</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy consumption electricity</td>
<td>Wh</td>
<td>747</td>
<td>845</td>
<td>3500</td>
</tr>
<tr>
<td>Energy consumption heat</td>
<td>MJ</td>
<td>13</td>
<td>11</td>
<td>-</td>
</tr>
<tr>
<td>Moisture content before drying</td>
<td></td>
<td>70</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Spinning speed</td>
<td>rpm</td>
<td>900</td>
<td>900</td>
<td></td>
</tr>
<tr>
<td>Flow DH-water</td>
<td>liter/min</td>
<td>1.9</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>ΔT DH-water</td>
<td>°C</td>
<td>17.3</td>
<td>16.4</td>
<td></td>
</tr>
<tr>
<td>Dryweight laundry</td>
<td>kg</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Cycle time</td>
<td>min</td>
<td>115</td>
<td>115</td>
<td>88</td>
</tr>
</tbody>
</table>

**Relationship between energy use and moisture content.**
The drying cycles that were used for the data in table 3-3 all had a moisture content around 70%. The moisture content before drying of the laundry depends on spinning speed, load and type of laundry. In the field test, a spinning speed of 1600 was mostly used, resulting in a moisture content of 20-50%.

According to energy consumption data from the manufacturer, energy consumption increases linearly with the amount of moisture. This turned out not to be the case in the field-test. In the field-test, energy consumption per unit moisture decreases with increasing moisture content. In other words, the amount of energy needed to evaporate a given amount of water depends on moisture content. This finding made it difficult to compare heat-fed drying cycles and conventional drying cycles at spin speeds other than 900. For calculation of energy savings in practice, it is assumed that the energy saving of the standard cupboard dry program with laundry spun at 900 rpm is representative of the energy savings of other programs and spinning speeds.
3.4 DEGREE OF COOLING AND INFLUENCE OF SUPPLY TEMPERATURE

Cooling of district heating water by the washing machine
The cooling of the DH-water in the field-test for the 60°C cotton cycle of the washing machine is 20°C. For all programs together this turns out to be 26°C. The larger cooling for the average program compared to the standard program is caused by the fact that the average program has a lower washing temperature than the standard program, and therefore needs less DH-water.

Additional electrical heating
In the field-test it turned out that in 17% of the total number of standard 60 °C cotton cycles the electrical heating element turned on at the end of the heating period. In these cases, the supply temperature of the DH-water was too low: the average supply temperature of these cycles was 64 °C, whereas this was 70 °C for the other cycles. This confirmed what was found earlier (during lab-tests in earlier phases): the supply temperature for the heat-fed washing machine should be at least 70 °C. The 17% of the cycles where additional electrical heating took place were not taken into account in calculating average energy consumption data.

Cooling of district heating water by tumble dryer
The cooling in the field-test by using the standard cupboard dry cycle at average load (this was 2.0 kg instead of the standard 5.0 kg) was 17.4°C. In the lab 17.3°C was found. Averaged over all programs used in the field-test the cooling was 14.6°C. However, just like for the washing machine, a supply temperature below 70 °C negatively affects the energy performance of the dryer. If all cycles that took place at a supply temperature below 70 °C are filtered out, a cooling of 18.1°C results for the standard cupboard cycle and a cooling of 16.1°C for the field-test as a whole.

3.5 TRANSPORT LOSSES

Heat loss per cycle outside the heating season
Calculations show that heating losses through piping can vary widely, depending on pipe length, pipe diameter and whether they are insulated or not. For example, for a maximal pipe length of 2x12 m (supply and return) the losses in uninsulated pipes can be up to 52% of the useful heat consumption in the washing machine and up to 16% for the tumble dryer (insulating would bring this back to 13 and 4%, respectively). At the thirteen households in the field-test pipe length varied from a few meters up to 2x18 m. Consequently, the losses vary as well: the lowest measured loss per cycle is 5%, while the highest losses are over 100%. This illustrates the importance to limit pipe length. However, even if heat loss through the pipe per cycle is large, the heat loss averaged over a year that should be contributed to the laundry machines is small. The reasons for this are:
• In half of the total number of cycles, the washing machine and tumble dryer are used at the same time.
• If the space heating is turned on heat loss through the pipe should not be attributed to the heat-fed laundry apparatus.

Heat loss on a yearly basis
For a loss per cycle of 52% for the washing machine the loss averaged over a year will not exceed 13%. For a loss per cycle of 16% for the tumble dryer the loss averaged over a year will not exceed 4%. This includes the assumption that in 50% of the cycles the washing machine and tumble dryer are used simultaneously, and that the space heating season is eight months long.

3.6 SOLAR CONTRIBUTION
In one of the households the heat-fed apparatus was connected to a central heating system with a solar domestic hot water system. It serves to produce water for space heating as well as tap water. From a technical viewpoint it is no problem to have a heat-fed washing machine and dryer connected to this setup. This is the result of one year experience with such a combination. By means of a simulation an estimate is made of the solar contribution to the heat-demand of the heat-fed apparatus (see figure 3-3).

![Simulation temperature in a solar collector with 4 m² collector-area](image)

A solar contribution to the heat demand occurs when the solar heat is produced at a temperature higher than 50°C (the return temperature of the heat-fed apparatus). The solar heat will only contribute its heat to the laundry apparatus if the heat is transferred to the zone when the additional heating is done. This happens
• When the solar heat part is warmer than the part where the additional heating takes place (convection)
• When water is tapped
A rough estimate of the upper limit of the solar contribution has been made on the basis of the number of days in a year that the average storage temperature is high-
her than 50 °C at an average water tapping pattern of 100 l/day. This turns out to be 95 days or 26% on a yearly basis.

3.7 INCREASED HEAT DEMAND FOR HEAT DISTRIBUTION NETWORKS
The total heat demand in district heating networks could increase through the use of heat-fed laundry apparatus. The yearly increase of heat consumption per household would be approximately 2.5 GJ. The total heat consumption of an energy efficient house (heat consumption for central heating 14 GJ, for tapwater 7.3 GJ) could increase by 12% through the use of heat-fed apparatus.
4. ENERGY AND COST SAVINGS

4.1 EFFICIENCIES AND COSTS

For calculating primary energy savings one has to decide how much primary energy is ‘assigned’ to the production of heat and to the production of electricity in a power plant. The assumptions used here are based on agreements in the Netherlands on how to do this for calculating CO$_2$-reduction potentials[CO2-98]. They are explained below.

A modern gas fired power plant can reach 54% efficiency for electricity production. If heat is used from the plant for district heating, this efficiency will drop down to 49%. The primary energy that is needed to generate the extra electricity to compensate for this drop in efficiency is assigned to the heat production. This is shown in figure 4-1. The 49% efficiency in electricity production is accompanied by a 40% efficient heat production. For every unit of heat from the plant an additional 0.25 units are necessary to bring the heat up to a temperature level that can be used at the district level (90 °C). Taking into account 20% transport losses, one arrives at the following balance: for every unit of heat at the district level, 0.48 units of primary energy are used. In other words, the heat production efficiency is 208%.

![Figure 4-1 Efficiency heat production in district heating (the numbers are arbitrary units).](image)

This assumes a temperature of 90 °C at the district level. A lower temperature at the district level would result in lower transport loss, less additional heating and possibly less efficiency reduction at the power plant. This would decrease the primary energy consumption of the district heating. On the other hand, if a coal plant would be used to generate electricity this efficiency would be lower (42%). All these factors cause the heat efficiency to vary. Using reasonable assumptions for these variations, the heat production would vary between 175% (coal plant) and 340% (lower temperature level, 70/40 instead of 90/50). In the primary energy savings calculations a 200% efficiency is taken. To indicate the sensitivity of
the energy savings for this efficiency, the same calculations are made with 300% efficiency. Energy savings are also calculated in the case central heating is used locally with high efficiency gas boilers. In this case, an efficiency of heat production of 90-100% of the lower heating value is used.

In the table below, input data for energy savings and cost saving calculations are summarized:

<table>
<thead>
<tr>
<th>Efficiency electricity generation</th>
<th>49% (steam and gas) [CO2-98]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary energy use district heating</td>
<td>500 MJprimair/GJ end user [CO2-98]</td>
</tr>
<tr>
<td>Efficiency heat from central heating</td>
<td>90-100% on lower heating value</td>
</tr>
<tr>
<td>Running cost electricity for households</td>
<td>€ 0.145/kWh daytime and € 0.082/kWh night-time tariff (VAT included; more than 3000 kWh consumed) [ENE99]</td>
</tr>
<tr>
<td>Running cost heat for households</td>
<td>€ 13.28/GJ (VAT included) [ENE99]</td>
</tr>
<tr>
<td>Running cost natural gas for households</td>
<td>€ 0.2936/m$^3$ (VAT included; more than 2100 m$^3$/year consumed) [ENE99]</td>
</tr>
</tbody>
</table>

All tariffs include an energy tax (REB, Regulerende EnergieBelasting’). If this tax would not be channeled to the consumer in the case of heat production, the tariff would be € 9.69/GJ (VAT included). To indicate the sensitivity of the cost savings for the cost of heat, the cost savings are also calculated using this tariff.

4.2 WASHING MACHINE

Comparing energy saving in practice with lab-results

For the 60 °C cotton cycle a primary energy saving of 45% is achieved and an electricity saving of 76%. The average heat consumption turns out to be larger in the field-test compared to the lab: 5.0 MJ compared to 3.9 MJ per cycle. The primary energy saving would be 52% based on the lab-tests. The differences between reality and lab can be explained from differences in flow, supply temperature, ambient temperature and cold water temperature.

Energy- and cost saving in practice

The average primary energy saving in practice, averaged over all different programs and temperatures and loads used in practice amounts to 43%. This primary energy saving can be considered to be representative for an average dutch household because

- The washing behavior of the thirteen households in the field-test does not differ much from that of the average dutch household
- The dependence of the primary energy saving on washing behavior is not very strong

In Table 4-1 the results on energy consumption, energy savings and cost savings on a yearly basis are given.
Table 4-1 Energy consumption, energy saving and cost saving on a yearly basis for the washing machine, based on the behavior of the households in the field test (350 cycles per year)

<table>
<thead>
<tr>
<th>Energy consumption, energy saving and cost saving on a yearly basis</th>
<th>Conventional</th>
<th>Heat-fed</th>
<th>Heat fed, green tariff and 333 MJ/GJ</th>
<th>Heat-fed for central heating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary energy (GJ)</td>
<td>1.60</td>
<td>0.92</td>
<td>0.78</td>
<td>1.54-1.67</td>
</tr>
<tr>
<td>Heat consumption (GJ)</td>
<td>-</td>
<td>0.83</td>
<td>0.83</td>
<td>0.83</td>
</tr>
<tr>
<td>Electricity consumption (kWh)</td>
<td>218</td>
<td>68</td>
<td>68</td>
<td>68</td>
</tr>
<tr>
<td>Primary energy saving with respect to conventional (%)</td>
<td>-</td>
<td>43%</td>
<td>51%</td>
<td>4-18%³</td>
</tr>
<tr>
<td>Electricity saving (%)</td>
<td>-</td>
<td>69%</td>
<td>69%</td>
<td>69%</td>
</tr>
<tr>
<td>Running cost saving with respect to conventional (%) - day-tariff</td>
<td>-</td>
<td>34%</td>
<td>43%</td>
<td>47%</td>
</tr>
<tr>
<td>Running cost saving with respect to conventional (%) - night tariff</td>
<td>-</td>
<td>7%</td>
<td>24%</td>
<td>30%</td>
</tr>
<tr>
<td>Absolute running cost saving / yr – day tariff</td>
<td>-</td>
<td>€ 11</td>
<td>€ 14</td>
<td>€ 15</td>
</tr>
<tr>
<td>Absolute running cost saving / yr – night tariff</td>
<td>-</td>
<td>€ 1</td>
<td>€ 4</td>
<td>€ 5</td>
</tr>
</tbody>
</table>

In the table, the first column gives the electricity consumption and primary energy consumption in case these 350 cycles per year would have been done using the conventional fully electric machine. In the second column, energy use, energy savings and cost savings are given for the heat-fed machine, using the assumptions of the previous paragraph. Naturally the cost savings depend on whether the washing is done in the hours where the night-tariff for electricity is in place or in the hours when the day-tariff is in place. Both options are presented here. The relative savings of running cost are less than the primary energy savings. The reason for this is that district heat is relatively expensive.

In the third column, the sensitivity for two parameters is shown. At first, an efficiency of 333 MJ_{primary}/GJ is assumed instead of 500. This positively affects the primary energy and the primary energy savings. Second, it is shown how changing the tariff for heat can positively affect the running cost savings.

In the last column the primary energy savings and running cost savings are calculated in case heat from a central heating system in a home is used. This results in lower primary energy savings but higher running cost savings.

Although the relative energy savings and cost savings are representative of an average household, the absolute running cost savings are not representative. This is because the average number of persons per household in the field test is 3.6 whereas the national average is 2.3.

### 4.3 CONDENSING DRYER

*Energy- and cost saving in practice*

³ Spread caused by variation in efficiency heat production central heating (90-100% of lower heat value).
The average primary energy saving for the drying behavior found in the field-test (with respect to programs used, average weight, moisture content, cycles per year) is 52%. In Table 4-1 the most relevant results on energy consumption, energy savings and running cost savings are for the dryer are give, based on the 250 cycles per year found in the field-test.

Table 4-2 Energy consumption, energy saving and cost saving on a yearly basis for the tumble dryer, based on the behavior of the households in the field test (250 cycles per year)

<table>
<thead>
<tr>
<th>Energy consumption, energy saving and cost saving on a yearly basis</th>
<th>Conventional</th>
<th>Heat-fed</th>
<th>Heat-fed, green tariff and 333 MJ/GJ</th>
<th>Heat-fed for central heating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary energy (GJ)</td>
<td>3.54</td>
<td>1.69</td>
<td>1.41</td>
<td>2.95</td>
</tr>
<tr>
<td>Heat consumption (GJ)</td>
<td>-</td>
<td>1.68</td>
<td>1.68</td>
<td>1.68</td>
</tr>
<tr>
<td>Electricity consumption (kWh)</td>
<td>481</td>
<td>116</td>
<td>116</td>
<td>116</td>
</tr>
<tr>
<td>Primary energy saving with respect to conventional (%)</td>
<td>-</td>
<td>52%</td>
<td>60%</td>
<td>17-23%</td>
</tr>
<tr>
<td>Electricity saving (%)</td>
<td>-</td>
<td>76%</td>
<td>76%</td>
<td>76%</td>
</tr>
<tr>
<td>Running cost saving with respect to conventional (%)-day-tariff</td>
<td>-</td>
<td>44%</td>
<td>53%</td>
<td>56%</td>
</tr>
<tr>
<td>Running cost saving with respect to conventional (%)-night tariff</td>
<td>-</td>
<td>19%</td>
<td>35%</td>
<td>40%</td>
</tr>
<tr>
<td>Absolute running cost saving / yr – day tariff</td>
<td>-</td>
<td>€ 31</td>
<td>€ 37</td>
<td>€ 39</td>
</tr>
<tr>
<td>Absolute running cost saving / yr – night tariff</td>
<td>-</td>
<td>€ 8</td>
<td>€ 14</td>
<td>€ 16</td>
</tr>
</tbody>
</table>

Because the fractional primary energy savings is hardly dependent on the type of program used, the determination of the absolute energy savings is based on the energy savings of the standard cupboard program.

In the table, the first column gives the electricity consumption and primary energy consumption in case these 250 cycles per year would have been done using the conventional fully electric machine. In the second column, energy use, energy savings and cost savings are given for the heat-fed machine, using the assumptions of the previous paragraph.

In the third column, the sensitivity for two parameters is shown. At first, a efficiency of 333 MJ\textsubscript{primary}/GJ is assumed instead of 500. This positively affects the primary energy and the primary energy savings. Second, it is shown how changing the tariff for heat can positively affect the running cost savings.

In the last column the primary energy savings and running cost savings are calculated in case heat from a central heating system in a home is used. Again, this results in lower primary energy savings but higher running cost savings.

\footnote{Variation caused by variation in efficiency central heating (90-100% of lower heatint content).}
4.4 HEAT-FED AGAINST OTHER FUEL SWITCHING OPTIONS

In table 4-3 an overview is given of energy savings and estimated time for return on investment for the heat-fed apparatus in comparison with competing concepts for washing and drying.
### Table 4-3: Energy savings and estimated time for return on investment of heat-fed apparatus and competing concepts for washing and drying (on the basis of lab tests with standard program).

<table>
<thead>
<tr>
<th></th>
<th>electricity consumption kWh/cycle</th>
<th>gas consumption m³ gas/cycle</th>
<th>heat consumption MJ runtime/cycle</th>
<th>primary energy consumption MJ</th>
<th>primary energy savings %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Washing machines (60°C cotton, 5 kg)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional washing machine, av.)</td>
<td>1.10</td>
<td></td>
<td>8.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat-fed washing machine - DH</td>
<td>0.22</td>
<td></td>
<td>3.9</td>
<td>3.5</td>
<td>56%</td>
</tr>
<tr>
<td>Heat-fed washing machine - CH</td>
<td>0.22</td>
<td></td>
<td>0.12</td>
<td>5.5</td>
<td>32%</td>
</tr>
<tr>
<td>Heat-fed washing machine - CH + solar</td>
<td>0.22</td>
<td></td>
<td>0.09</td>
<td>4.5</td>
<td>44%</td>
</tr>
<tr>
<td>Hot-fill washing machine</td>
<td>0.50</td>
<td></td>
<td>0.06</td>
<td>5.5</td>
<td>32%</td>
</tr>
<tr>
<td><strong>Tumble dryer (cupboard dry, 5kg)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional condensing dryer (av.)</td>
<td>3.49</td>
<td></td>
<td>25.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat-fed tumble dryer - DH</td>
<td>0.75</td>
<td></td>
<td>13.0</td>
<td>12.0</td>
<td>53%</td>
</tr>
<tr>
<td>Heat-fed tumble dryer - CH</td>
<td>0.75</td>
<td></td>
<td>0.41</td>
<td>18.5</td>
<td>28%</td>
</tr>
<tr>
<td>Heat-fed tumble dryer - CH + solar</td>
<td>0.75</td>
<td></td>
<td>0.31</td>
<td>15.2</td>
<td>41%</td>
</tr>
<tr>
<td>Heat pump tumble dryer</td>
<td>1.75</td>
<td></td>
<td></td>
<td>12.9</td>
<td>50%</td>
</tr>
<tr>
<td>Conventional air dryer (av.)</td>
<td>3.27</td>
<td></td>
<td>24.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat-fed tumble dryer - DH</td>
<td>0.45</td>
<td></td>
<td>12.6</td>
<td>9.6</td>
<td>60%</td>
</tr>
<tr>
<td>Gas-fired tumble dryer</td>
<td>0.25</td>
<td></td>
<td>0.41</td>
<td>14.8</td>
<td>39%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>additional cost Euro/machine</th>
<th>running cost running cost savings Euro/cycle</th>
<th>running cost savings Euro/cycle</th>
<th>return-on-investment time Euro/year</th>
<th>year</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Washing machines (60°C cotton, 5 kg)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional washing machine, av.)</td>
<td>0.16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat-fed washing machine - DH</td>
<td>111</td>
<td>0.08</td>
<td>0.08</td>
<td>27</td>
<td>4.1</td>
</tr>
<tr>
<td>Heat-fed washing machine - CH</td>
<td>157</td>
<td>0.07</td>
<td>0.09</td>
<td>32</td>
<td>4.9</td>
</tr>
<tr>
<td>Heat-fed washing machine - CH + solar</td>
<td>157</td>
<td>0.06</td>
<td>0.10</td>
<td>35</td>
<td>4.4</td>
</tr>
<tr>
<td>Hot-fill washing machine</td>
<td>66</td>
<td>0.09</td>
<td>0.07</td>
<td>25</td>
<td>2.7</td>
</tr>
<tr>
<td><strong>Tumble dryer (cupboard dry, 5kg)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional condensing dryer (av.)</td>
<td>0.51</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat-fed tumble dryer - DH</td>
<td>211</td>
<td>0.28</td>
<td>0.23</td>
<td>56</td>
<td>3.7</td>
</tr>
<tr>
<td>Heat-fed tumble dryer - CH</td>
<td>211</td>
<td>0.23</td>
<td>0.28</td>
<td>69</td>
<td>3.0</td>
</tr>
<tr>
<td>Heat-fed tumble dryer - CH + solar</td>
<td>211</td>
<td>0.20</td>
<td>0.31</td>
<td>77</td>
<td>2.7</td>
</tr>
<tr>
<td>Heat pump tumble dryer</td>
<td>454</td>
<td>0.25</td>
<td>0.25</td>
<td>63</td>
<td>7.3</td>
</tr>
<tr>
<td>Conventional air dryer (av.)</td>
<td>0.48</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat-fed tumble dryer - DH</td>
<td>204</td>
<td>0.23</td>
<td>0.24</td>
<td>60</td>
<td>3.4</td>
</tr>
<tr>
<td>Gas-fired tumble dryer</td>
<td>238</td>
<td>0.16</td>
<td>0.32</td>
<td>79</td>
<td>3.0</td>
</tr>
</tbody>
</table>

**Assumptions**

1. primary energy use district heating 500 MJprim/GJfinal
2. Efficiency central heating 100% on lower heating value
3. Efficiency tap water heating 65% on lower heating value
4. Efficiency electricity consumption 49%
5. Solar contribution (4 m² collector, 45° South) 25%
6. Water use main washing cycle hot-fill 11.4 liter
7. Heating main cycle hot-fill 25°C (15°C -> 40°C)
8. gas price 0.29 Euro/m³
9. electricity price 0.15 Euro/kWh
10. heat price 13.28 Euro/GJ
11. number of washing cycles per year 350
12. number of drying cycles per year 250
It should be noted that the data in the table is based on energy consumption figures from lab-tests at a standard program and load [VHK94], [VHK98d], [VHK99], for the heat-fed apparatus as well as the competing concepts. The additional cost for the heat-fed apparatus includes additional cost for the machines as well as for installation of the machines.

For the washing machine, it can be concluded that

- Heat-fed washing machines connected to district heating results in the highest energy savings, much more than hot-fill machines. However, the extra investment cost for the hot-fill machine is paid back more easily.
- The energy savings of heat-fed washing machines connected to central heating are comparable to hot-fill machines
- The time for return-on-investment of a heat-fed washing machine is less than five years (assuming the day-time electricity tariff).

For the tumble dryers the conclusions are as follows:

- Heat-fed dryers connected to district heating save similar amounts of energy as the heat-pump dryer. However, the time for return-on-investment is half that of the heat-pump dryer.
- The heat-fed dryer connected to district heating has higher energy savings than the gas-fed dryer, with a return-on-investment time that is slightly longer.
- The time for return-on-investment of the heat-fed tumble dryer is less than four years ((assuming the day-time electricity tariff).

The return-on-investment times are based on the average number of cycles per year for washing and drying in the field-test, with an average household-size of 3.6 persons. It should be kept in mind that a return-on-investment time is strongly dependent on how much the machines are used, and this again depends largely on the number of persons per household.
5. EXPERIENCES USERS AND UTILITIES FROM FIELD TEST

5.1 USER APPRECIATION

To gain insight into the user appreciation of the heat-fed laundry machines surveys were conducted by a market research agency. A visit was paid to the participating households at the time of installation, and two surveys were conducted by telephone, during the field-test and upon completion of the field-test. The first survey served to establish user appreciation of the conventional laundry machines. The second and third survey served to investigate user appreciation of the heat-fed laundry machines. Issues like comfort, washing and drying performance, aggravation because of malfunctioning of the machines, leakage, noise were examined. In addition, the participating households had a logbook, in which they could jot down any comments that came to mind while doing laundry. The overall view obtained from the enquiries and the logbooks is given below.

Performance of the heat-fed washing machine
The heat-fed washing machine performed very well. Most households had a positive opinion on the machine as it comes to washing performance, drying after spinning, noise production, stain removal, technical reliability, user friendliness, avoidance of wrinkles. The technical reliability was judged to be inferior by one household. However, this is related to technical problems at the startup of the experiment. These problems were not inherent to the design of the machine and have all been resolved. In a test like this one can expect technical problems.

Overall, the heat-fed laundry machine was judged to perform better than the machines the households were using before the start of the field-test. It should be noted there that the heat-fed machines are built from a top model conventional machine. Thus, the opinion might be influenced by this more than the fact that it is a heat-fed machine. In any case the fact that it is heat-fed does not negatively affect the opinion on performance.

Performance of the heat-fed tumble dryer
The opinion of the households with respect to the performance of the tumble dryer varies widely from one household to another. This may be related to the amount of technical difficulties each household has experienced with the dryer, but also with other factors, such as the type of laundry used and program choice. Comparing performance of the conventional tumble dryer the households used to the heat-fed tumble dryer, it is noticed that almost all households were disturbed by the noise the heat-fed dryer makes. The speed of drying and technical reliability are also judged to be somewhat less than their conventional counterparts, on average.

It can be concluded that the noise production should be a point of attention for a next series.
Installation issues
Installation into existing buildings of the heat-fed laundry apparatus requires some effort and changes to the house that should be considered.

- New pipes have to be installed in the house, which may not always be a pretty sight. Proper attention should be paid to esthetic integration of the extra pipes.
- The installation activities require a professional installer and, due to the plumbing activities, take more time than installing conventional machines.
- A few households in the field-test were afraid of leakage of the DH-water.
- One participant remarked that he usually shuts off the main valve of the DH-water in the summer, when no space heating is necessary. With the heat-fed laundry machines this was not possible anymore. This causes DH-water to run through the system year round and may cause heat loss due to leaky radiator valves.

No interference of heat demand by the heat-fed laundry apparatus and supply of hot tap water was detected at any of the households.

5.2 UTILITIES
As part of the evaluation of user appreciation, the expectations and experience of the seven utilities involved were also examined by means of an enquiry by telephone. This has resulted in the following summary:

1. They are enthusiastic about the large potential for primary energy savings.
2. There is no consensus as to whether the dryer or the washing machine has the biggest market potential. A small majority favors the dryer in this respect.
3. A point of attention for the dryer is the noise production.
4. The largest market potential for heat-fed apparatus is for newly built homes on locations with district heating.
5. For existing buildings the perspective of heat-fed apparatus is limited.
6. It is unclear to what extent the heat-fed apparatus can positively affect exploitation of district heating networks.
6. CONCLUSIONS

The field-test

The purpose of the field-test was to establish the technical performance in practice of newly developed heat-fed washing machines and tumble dryers and to examine how users would appreciate the apparatus. In both aspects, the field-test was successful.

Product development preceding the field-test has resulted in a reduction of the drying time of 20 minutes (down to 115 minutes) compared to the earlier prototype. Some technical problems were found, but none were of a fundamental nature and all have been solved.

At eleven of the thirteen participating households the heat-fed apparatus was connected to a district heating network. In one household the machines were connected to the central heating system. In another household the machines were connected to a central heating system that incorporated a solar domestic hot water system. For all systems solutions for connecting the apparatus to the heating network have been developed.

Energy and cost savings for district heating applications

From the technical monitoring of the machines during the field-test, the washing machine turned out to function well. Averaged over all households a yearly primary energy saving of 43% was calculated. The average cooling of the district heating water is 26ºC. The tumble dryer also functioned well. The yearly primary energy savings amounts to 52%. The average cooling of the DH-water is 16ºC.

Heat demand in district heating networks can increase by 2.5 GJ per house. For energy efficient homes this would be an increase of 12%.

A household can save € 42 in yearly electricity costs, based on the day-time electricity tariff currently used in the Netherlands. Based on the night-time tariff this would be € 9. For actively stimulating heat-fed apparatus it could be considered to change tariffs to make heat consumption more interesting for consumers.

Performance of heat-fed apparatus in central heating systems

The heat-fed apparatus has shown to perform as well when connected to central heating systems as to district heating systems. However, the primary energy savings are lower. From the field-test data savings of 18 and 23% were calculated for the washing machine and the tumble dryer, respectively. On the other hand, the cost savings are higher: € 54 for the day-time tariff and € 21 for the night-time tariff, respectively. In these calculations no solar contribution was taken into account.

Heat loss

The heat loss through the pipes averaged over a year is calculated to be at most 13% for the washing machine and 4% for the tumble dryer (based on 2x12 m pipe length). This has little influence on the primary energy savings that were calcula-
ted. However, it does affect cost savings. Therefore it is still important to reduce pipe length and to insulate the pipes.

Supply temperature
It is important that the supply temperature to the heat-fed apparatus is at least 70°C. If this is not the case, the washing machine will turn on its electric heating element at a 60°C wash cycle and the tumbly drying cycles will take longer. In both cases the cooling of the network will decrease. For some households, supply temperatures lower than were 70°C found.

User appreciation
From the inquiries it is concluded that the participating households were very content with the washing machine. Appreciation of the dryer varies significantly from one household to another. Noise production seems to be the biggest factor causing the mixed feelings about the dryer. Some households find the drying cycles take too long. Some households find the dryer dries better than their previous machine, whereas others think its drying performance is inferior to their previous dryer.

Further developments
During the field-test technical problems have occurred every now and then. None of these were of a fundamental nature and all problems have been solved. From a technical viewpoint the field-test has shown there are no barriers for further development and large scale application of the heat-fed apparatus. In addition, users have indicated their satisfaction in using the heat-fed apparatus.
A brief comparison of the heat-fed concept with other energy saving concepts (hot-fill washing machines, gas-fired dryers, heat-pump dryers) show that the heat-fed apparatus combine large energy savings with moderate cost, and therefore are promising options for fuel switching. A brief inquiry also showed interest by utilities Europe-wide for application of heat-fed apparatus [ECO99b].
REFERENCES


[VHK98c] Warm witgoed, meetrapport 0-serie, c

