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Booster Heat Pump, development of test procedure and calculation methodology in order to estimate the energy performance in various domestic applications

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Abstract

Increasing targets for building energy performance also stimulate manufacturers to further innovations. One of these innovations is the Booster Heat Pump (BHP); a heat pump for preparation of domestic hot water with a with variable and elevated temperature heat source.
The principle of the Booster Heat Pump (BHP) is appealing: Preparation of Domestic Hot Water, on the spot, with a heat pump that uses a heat source with moderate temperature level (sufficient to provide space heating). Thermodynamically it makes sense (exergy), but two questions need to be answered:

1. What is the overall energy efficiency, taken into account that the Booster Heat Pump uses electricity and thermal energy, that possibly both require primary (fossil) fuel?
2. How to assess the energy performance of the BHP in the Dutch standards (NEN7120 and NVN7125)?

By definition, innovations do not comply with the standards for energy performance assessment; For conformity, new rules must be formulated. Following previous projects focussed on air/water heat pumps and solar assisted heat pumps, this task has been executed in a joint governmental/industry working group.

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Nomenclature

$A_{g;zi}$	Floor surface area of the overall building, DHW-demand itself is, by default in NEN7120, assumed to vary linearly with the floor surface area.
$a_{C;red}$	Reduction factor for non-continuous operation of the cooling machine
$E_{W;el;ls;test}$	Electricity consumption to compensate standing loss [MJ]
$E_{SC;el}$	Electricity consumption for summer cooling
P_{source}	the nominal heat source power level of the booster heat pump.
$Q_{W;nd;zi;mi}$	Nett domestic hot water heat demand
$Q_{W;nd;spec}$	Specific net Domestic Hot Water heat demand, by default 3081 MJ/per person, per year
$Q_{W;dis;nren;mi}$	Annual heat demand.
$Q_{W;nren;test;mi}$	Heat demand as tested (mostly 14000 MJ/year)
$Q_{W;dis;nren}$	is the net heat delivered by the booster heat pump to the building distribution system (e.g. 14000 MJ for class 4 profile).

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$Q_{W;dis;dh}$	is the heat needed from the district heat network to power the booster heat pump.
$Q_{C;gn}$	Cooling load from solar input and internal heat dissipation
$Q_{C;ht}$	Cooling loss through the building envelope by transmission and ventilation
$Q_{C;nd}$	if applicable, is the heat that can be extracted from the building in cooling mode "C"
$Q_{C;nd}$	is the building cooling load, as calculated by the NEN7120 software.
$Q_{C;nd}$	Cooling load
$Q_{C;nd*}$	is the remaining cooling load, after subtraction of the thermal energy need to the booster heat pump
$Q_{C;nd}$	is the building cooling load, as calculated by the NEN7120 software.
$t_{C;on,mi}$	is the on-time of the system circulation pump.
t_{mi}	Total number of seconds in a month [Ms]
t_{an}	Total number of seconds in a year [Ms]
$W_{C;aux;gen;tot}$	if applicable, in building heat extraction mode "C": Electrical auxiliary energy needed for the circulation pump, valves & control.
$\eta_{W;gen;gi}$	Generation efficiency with correction for lower heat demand.
$\eta_{W;gen;test}$	Generation efficiency as tested (including losses).
$\eta_{W;gen}$	booster heat pump generator efficiency (=COP), including auxiliary energy for internal circulation pump and control. The COP is supply temperature and DHW demand dependent, and specified by measurements, see figure 2.3.
$\eta_{C;ls}$	Cooling loss utility factor
$\eta_{C;ls}$	Default cooling machine COP (3,0)

1. Introduction

The overall energy use for DHW can be improved by improving the devices and apparatus generating the DHW and by a smart design of the in house system. The knowledge of the possibilities are not yet widely known and applied. Technological developments with heat pumps almost always are looking into the heat pump technology itself. Although we think that is of importance, we also think that the overall efficiency can be increased firstly by choosing a sustainable generating system (solar water heater, heat pump water heater), and secondly by selecting an optimal combination with the storage water tank and its control strategy.
For the design and overall efficiency of the systems the main focal point is the length of distribution from generator to the final tapping point. We expect that a lot can be gained in existing buildings in renovation by low temperature distribution and individual booster heat pumps. Important is the observation that collective DHW options like in district heating systems, the distribution system year round (8760 hours) must be kept at the high temperature for the purpose of delivering DHW while for space heating these high temperatures only for a short period during the peak of the heating season are needed. A lower operating temperature also provides the possibilities of using cascaded geothermal heat, low temperature rejected condensing heat of power plant steam cycles or (industrial) waste heat. Depending on the hydronic connection to the domestic heating system, a (limited) amount of cooling can be provided during the summer season.

The booster heat pump is a small (~ 2kW – thermal capacity) heat pump, specifically designed to prepare hot water (~70°C), using a heat source with a temperature up to 40°C. Its concept originates from an innovative energy solution devised for a new district energy system "Waalsprong" by Braber c.s.[1], where a low temperature district heating network would provide thermal energy with a temperature sufficient for space heating purposes, and local (residential) booster heat pumps for domestic hot water. Recently two brands of booster heat pumps were introduced in the Netherlands and on international level this development is also picked up in Denmark.

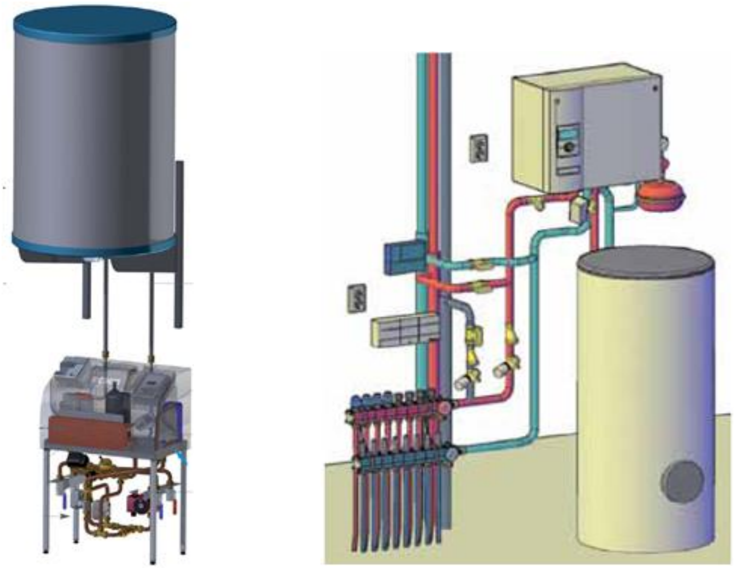

Figure 1.1 Booster heat pumps: Left: Econ and right:Alfa Innotec.

The core of the booster heat pump is small compression heat pump connected to a hot water storage tank.

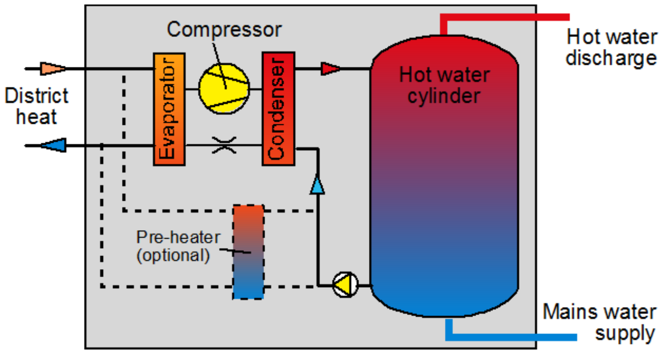

Figure 1.2 Basic layout of a booster heat pump.

In this configuration the heat pump lifts (boosts) the temperature from 20-40ºC to the desired hot water temperature of 65 ºC.

1.1 Booster Heat Pump performance

The test procedure to assess the energy performance of booster heat pumps has been defined in a previous project financed by the ministry of Economic Affairs through RVO [2]. In the test procedure a booster heat pump, integrated with the storage hot water tank is tested with a fixed hot water demand (class 2-4), with supply temperatures in the ranging from 24 to 40ºC. The tests give the generation efficiency, including parasitic energy consumption (e.g. to drive circulation pumps) and heat losses.

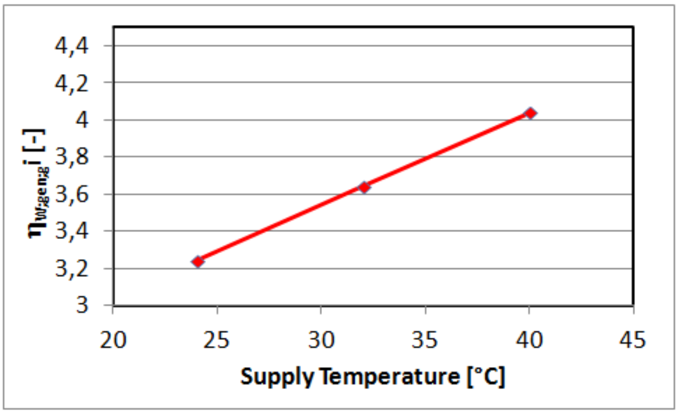

Figure 1.3 $\eta_{W,gen,gi}$ of a booster heat pump, as tested by KIWA for a tap water heat demand of 14 GJ(class 4, according to NEN 7120).

The generation efficiency (COP) can be in the range of 3-4. Given the conversion factor from primary energy (gas) to electricity (primary energy factor) of 1/2,15=46 %, this indicates that the efficiency from primary energy to hot water in principle could be in the range of 140 - 190%.
For traditional heat pumps with an ambient or ground heat source this calculation reflects nearly the full picture. For booster heat pumps however the heat source generally also requires primary energy for its generation, which reduces the overall generation efficiency.

The aspect of the generation efficiency of the district heat system illustrates that the energy performance assessment of the booster heat pump not only relates to the Dutch standard for energy efficiency for buildings EPG (NEN7120 [9]), but also to the EMG (NVN7125 [10]) incorporating other energy sources like district heating. This in fact makes the comparison of domestic hot water heat pumps to competing systems less simple. Geelen c.s. [3] did such a comparison for the Dutch market, which is now taken up under the HPT Annex 46. The ministry of Economic Affairs thereafter asked Berkel [4] to develop a calculation model to fit into the Dutch building standard.

1.2 Booster Heat Pump Configuration (basic system)

In its basic layout, the booster heat pump extracts thermal energy source from a distribution heating network that is used for space heating purposes at low temperatures. This can be a district heating network, but also a distribution system in a multifamily building.
As illustrated in figure 1.4, the booster heat pump extracts thermal energy from the heating network, in parallel to the space heating system. It is assumed here that the heating network supplies hot water, with a supply temperature that depends on the ambient temperature, with a maximum temperature lower than 40^{o}C. This low supply temperature is sufficient to provide space heating of well insulated buildings and avoids the need for a pump circulated mixing system in the space heating system. The indoor temperature can be controlled e.g. by a room-thermostat, that actuates valve V1. Valve V2 allows water circulation through the booster heat pump, only when it is in operation for making hot water.
In the seasons when district heat is not needed for space heating, the temperature of the heating system can be lowered to the value of 20^{o}C for operation of the booster heat pump only.

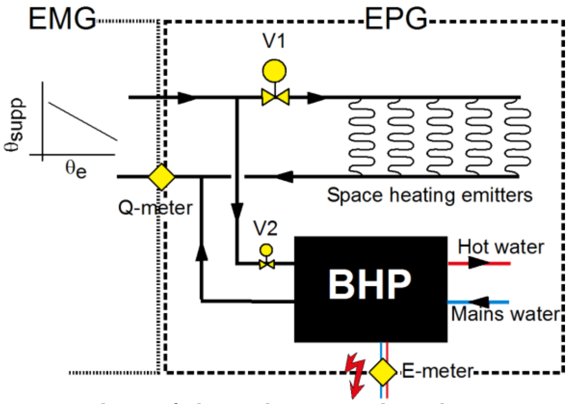

Figure 1.4 Basic layout of a booster heat pump a district heating network [4]

In an alternative system the residential system can be hydraulically separated from the district heating network by a heat exchanger. For calculating the energy performance, the heat exchanger is considered to be part of the district heating system; Effects of heat exchanger efficiency are included in the equivalent generation efficiency of the district heating system.

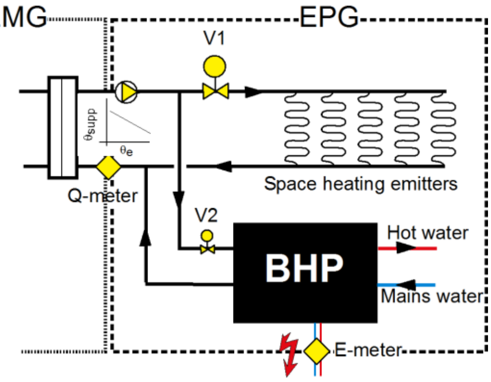

Figure 1.5 Basic layout of a booster heat pump a district heating network, with separating heat exchanger

When comparing the low temperature configurations of distribution with a high temperature (70ºC and higher) distribution system, engineered to provide hot water throughout the year, the advantages of a low temperature system are:

- Reduction of distribution losses in the district heating network, through reduction of supply temperature.
- Optimization of the generation efficiency of the primary heat generator (providing heat to the district heating network), in case its efficiency is temperature dependent (heat pumps, solar).
- 2nd law (exergy) optimisation: Purpose-targeted generation of heat, e.g. generator efficiency optimised for the target temperature level (rejected heat of power plants).

The introduction of the booster heat pump also has an effect on the energy performance assessment of the district heating network (NVN7125). The link between the EPG (NEN7120) and EMG NvN7125) is the equivalent generation efficiency of the district heating at the interface between EPG and EMG. Conform the standards and as indicated in figure 2.4 the interface lies at the location of the metering system.

1.3 Booster Heat Pump Configuration (extended system)

The booster heat pump can also be used to extract thermal energy from other sources than from district heating. One interesting option is the building itself, in case it doesn't need thermal energy from the district heating network, outside of the heating season, when active cooling is desired or demanded.

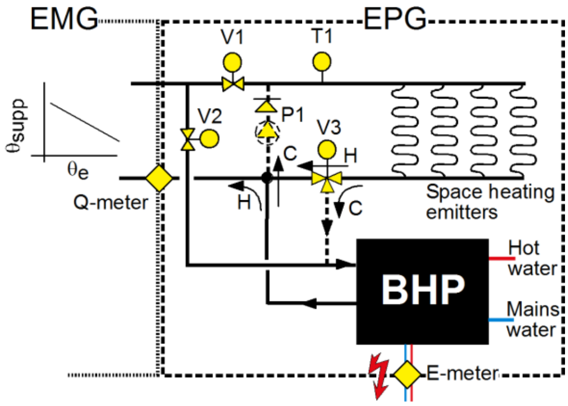

Figure 1.6 Extended layout (with building heat extraction) of a booster heat pump in a district heating network. The booster heat pump can be switched parallel with the emitters during space heating (H) mode or in series with the emitters during space cooling (C) mode. [4]

During the space heating period, the booster heat pump is configured in parallel with the space heating emitters, identically as in figure 1.4; (Pump P1 is off). Three way-valve V3 is switched in direction "H" and valve V2 is open during booster heat pump operation for making hot water.
In case there is a surplus of heat available in the building, the system can be switched to cooling mode, by switching three way valve V3 to "C", closing valve V2 and starting pump P1. The booster heat pump than extracts heat from the emitters and from the building. If in any case the temperature inside the building (thermostat), or in the space heating system (sensor T1) drops below a pre-set value, the system configuration is set to switch to mode "H" ; the parallel configuration as in figure 1.4. If there is a space heating demand, valve V1 then admits district heat into the space heating system.
In this dual mode configuration, operation of the booster heat pump is secured and heat extraction from the building only is allowed when surplus heat is available, while maintaining the comfort level.
The amount of heat that can be extracted from a building (and saved on district heat) is subject to further research. The least to say here is that heat extraction from the building reduces the need for summer cooling, and therefore reduces the primary energy need (which otherwise in NEN7120 is considered to be provided by a cooler with default generation efficiency (COP=3,0).
In addition to the advantages of the baseline booster heat pump system outlined in section 1.2, the extended configuration has the added advantages:

- Saving on district heat, by usage of available "excess" energy from the building.
- Providing cooling whenever the room temperature would exceed a preset value.
- Reducing primary energy demand for cooling (default in the EPG NEN7120).

The extended system thus may result in an improved EPG of a building, as well as improved comfort level.

2. Compliance with the Dutch standards NEN7120 and NVN7125

The relevant question is how the booster heat pump fits in the Dutch standards for energy performance assessment. The two most relevant standards regarding energy performance in de built environment are NEN7120 (EPG) and NVN7125 (EMG). The EPG I considering the Energy performance of buildings (**E**nergie**P**restatie van **G**ebouwen), the EMG is about the Energy performance standard for provisions at district level; (**E**nergieprestatienorm voor **M**aatregelen op **G**ebiedsniveau).
Conform the Building Regulation 2012, item 5.2 and NEN7120 14.6.4.5, the two standards must be treated in a staged manner:

1. Starting with a 100 % reference generation efficiency for district heat $\eta_{H:gen;equiv;dh}$, EPG should give an Energy Performance Coefficient (EPC) which is maximum 1,33 times the currently admissible value (1,33x0,6 = 0,8). If this criterion is met, in a second stage:
2. Calculating the generation efficiency for (district) heat using EMG and substitution in EPG (replacing the reference generation efficiency) should give an EPC which is maximum equal to the currently admissible value (0,6).

Remark: the lower the value, the better the energy performance

2.1 Booster heat pump heat demand

In NEN7120, by default, the Domestic Hot Water heat demand is given by:

$$Q_{W;nd;zi;mi} = Q_{W;nd;spec}\left(1{,}28\ N_{W;zi} + 0{,}01\ A_{g;zi}\right)\frac{t_{mi}}{t_{an}} \qquad (2.1), (EPG19.11)$$

To obtain the gross demand ($Q_{W;dis;nren;an}$), the net-heat demand is to be divided by the delivery efficiency ($\eta_{W,em}$) and the distribution efficiency ($\eta_{W,dis}$).

2.2 Interpolation for lower heat demands

When a hot water appliance is used for a lower heat demand then it was tested for, the measured generation efficiency needs to be corrected to give a value representative for the actual application. Background is that the fraction of appliance energy demand that does not depend on the amount of hot water consumption (e.g. to compensate for standby losses), relatively becomes more important at lower heat loads. For other (generally lower) heat demands the generation efficiency (COP) must be corrected, either by:

1. As indicated in the KIWA measurement reports: Correction factors, according to table 19.18 NEN7120:

$c_{W;gen}$	$Q_{W;dis;nren;an}$ MJ			
Rendement gemeten volgens klasse	**≤ 6 500**	**9 000**	**11 500**	**≥ 14 000**
Klasse 1 (CW-1*)	1	n.v.t.	n.v.t.	n.v.t.
Klasse 2 (CW-2)	0,60	1	n.v.t.	n.v.t.
Klasse 3 (CW-3)	0,49	0,81	1	n.v.t.
Klasse 4 (CW-4/5/6)	0,45	0,75	0,92	1

2. Interpolation between measured heat demands (e.g. 14000 MJ & 9000 MJ, or interpolated between 14000 MJ and zero heat demand, where COP is reconstructed from the standing loss of the Booster Heat Pump.

In the booster heat pump calculation procedure option 2 is proposed: For the measured heat load $Q_{W;dis;nren;test}$ (mostly 14000 MJ), the generation efficiency $\eta_{W;gen;gi}$ excluding standing loss is reconstructed from the measured generation efficiency $\eta_{W;gen;gi;test}$ and the electricity consumption $E_{W;el;ls;test}$ necessary to compensate for standing loss.

The procedure involves calculation of the efficiency figure excluding standing loss, to reconstruct the efficiency including standing loss, at a lower heat demand:

$$\eta_{W;gen;gi} = \frac{Q_{W,dis,nren,mi}}{\dfrac{Q_{W,dis,nren,mi}}{\dfrac{Q_{W,dis,nren,test}}{\left(\dfrac{Q_{W,dis,nren,test}}{\eta_{W;gen;test}} - E_{W;el;ls;test}\right)}} + E_{W;el;ls;mi}} \qquad (2.2)$$

As an example, figure 2.1 gives a graphical representation of eq. 2.2, for heat demand in the range of 0-14000 MJ, $\eta_{W;gen;gi,test}$=4 @ 14000 MJ and an electricity consumption to compensate for standing loss $P_{W;el;ls;test}$ of 15.

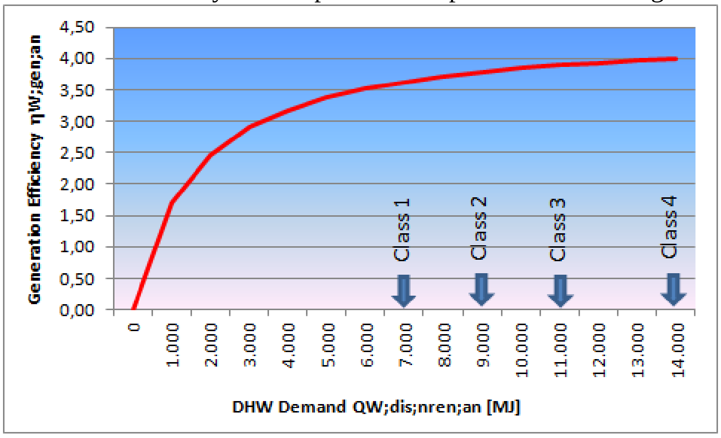

Figure 2.1 Generation efficiency according to eq. 2.2, for lower heat demands than tested (14000 MJ). Based on $\eta_{W;gen;gi,test}$=4 @ 14000 MJ and $P_{W;el;ls;test}$ of 15 W.

3. Booster heat pump heat sources

Before arriving at detailed treatment of calculations in the EPG, the heat source characteristics must be clear.
In parallel mode, the booster heat pump is supplied from the district heating network, with known capacity, known temperature and (from NVN7125) known generation efficiency.
For the building as a heat source the capacity and temperature level is not derived as easily. Though in principle it would be possible to calculate the available cooling load in a separate routine (using all relevant building parameters), a better strategy would be to make use of NEN7120 calculations that are done anyway.
To that end, NEN7120 evaluates the need for space cooling ($Q_{C;nd}$), according to equation:

$$Q_{C;nd} = a_{C;red}\left(Q_{C;gn} - \eta_{C;ls}\, Q_{C;ht}\right), \; with \;\; Q_{C;nd;net} \geq 0 \qquad (3.1), (EPG7.2)$$

All equations are evaluated on a monthly basis, with (monthly) values for ambient conditions and indoor setpoint temperatures of 24°C for cooling (EPG, 13.1).

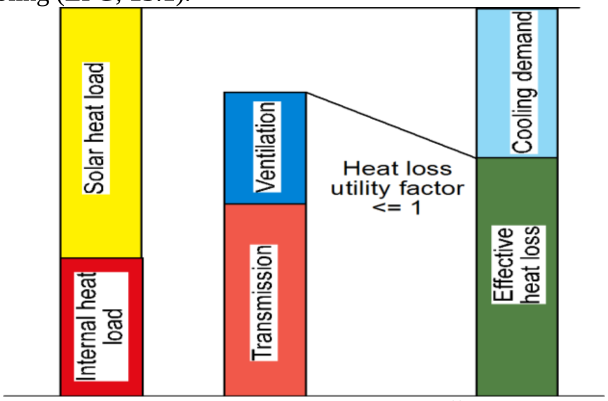

Figure 3.1 Cold demand depending on heat gain and effective heat loss [7]

Note that (cf. EPG8.1) heat transfer between indoor and outdoor are calculated on the basis of the indoor setpoint temperatures, not on actual indoor temperatures (which are not calculated in EPG). Correction for the difference between actual and setpoint temperatures (and dynamic effects) is done with the correction parameters for effective heat loss $\eta_{C;ls}$.
It appears that calculation of the building cooling load depends strongly on the specific building characteristics (transmission, ventilation, solar admittance and internal heat load) and a general rule cannot be given.

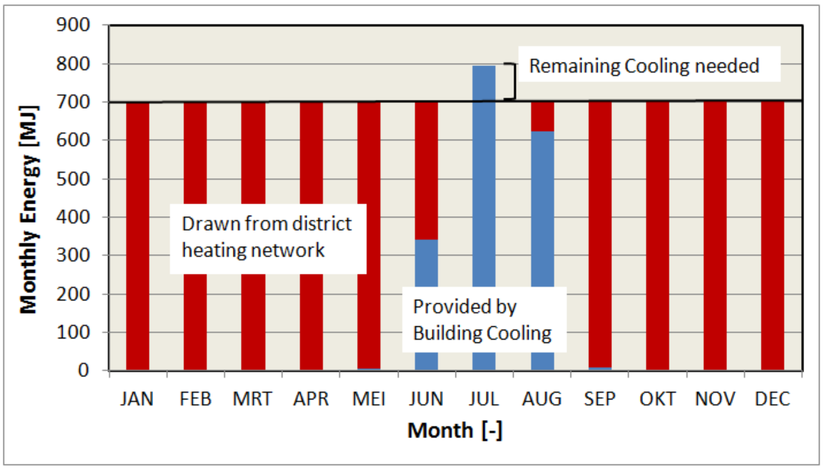

Figure 3.2 Graphical representation of thermal energy supply to the booster heat pump, either by the district heating network and/or building summer cooling. For this illustrative example, the booster heat pump thermal energy need is arbitrarily set at 700 MJ/month and cooling need adopted from a reference building calculation.

NEN7120 uses the 24°C setpoint temperature for calculation of cooling loads.
Though, using equations from NEN7120, in principle it would be possible to reconstruct the cooling load for a setpoint temperature lower than 24°C:

1. This is not a standard routine.
2. It would lose conformity with NEN7210 and would be subject to debate.

For convenience and promptness, for this moment, the cooling load ($Q_{C;nd}$, as quantified by NEN7120 with 24ºC setpoint temperature) is adopted as the secondary heat source for the booster heat pump. Adopting the setpoint temperature of 24ºC facilitates easy determination of the cooling load as it part of the standard calculation routine in NEN7120. It is also standard calculated (and output of the NEN7120 software) and thus can be retrieved easily. If desired, the potential and conformity aspects of a lower setpoint temperature can be evaluated in a parallel project.

Figure 3.2 illustrates the advantages of using building cooling load:
1. Reduction of district heat demand.
2. Reduction of summer cooling need.

The elaboration in NEN7120 compliant equations is given in the next chapter.

3.1 Implementation in NEN7120

Starting point in the assessment of the Energy Performance in EPG is:

$$E_{PTot} = \sum_{ci} E_{P;del;ci} - \sum_{gi} E_{P;\exp;T;gi} - \sum_{gi} E_{P;\exp;el;gi} - \sum_{gi} E_{P;pr,nEPus;el} \qquad \text{(4.1) (EPG5,7)}$$

Where, with respect to the booster heat pump, only the first term on the right hand side is relevant, for energy carriers (ci = el and Q).
The primary energy delivered for energy carrier (ci) depends on the primary energy factor:

$$E_{P;del;ci} = E_{EPdel;ci}\ x\ f_{P;del;ci} \qquad \text{(3.5) (EPG5,8)}$$

Where $E_{EPdel;ci}$ is energy per energy carrier. For the booster heat pump two energy carriers are relevant:
1. Electricity (el): Needed to drive the compressor and auxiliary systems (circulation pumps, valves, control)
2. Thermal energy (heat) extracted from the district heat network ($Q_{w;dis,dh}$) and heat supplied as hot water ($Q_{w;dis,nren}$).

The amount of electricity required to power the booster heat pump depends on the generation efficiency $\eta_{W;gen}$ (=COP):

$$E_{EPdel;el} = \frac{Q_{W,dis,nren}}{\eta_{W;gen}} + W_{C,aux,ngen,tot} \qquad \text{(4.2)}$$

The Booster Heat Pump $\eta_{W;gen}$ (COP) is calculated on basis of the monthly average value of the district heating temperature (which in its turn depends on the variable ambient temperature). This is assumed to be a valid approach as the COP is a linearly dependent on district heat supply temperature and in addition, the DHW demand and temperature do not vary significantly.
The amount of thermal energy as a heat source to the booster heat pump also depends on the COP ($\eta_{W;gen}$):

$$Q_{W,dis,dh} = MAX\left[0, \left(1 - \frac{1}{\eta_{W;gen}}\right) Q_{W,dis,nren} - Q_{C,nd}\right] \qquad \text{(3.7)}$$

The max.-criterion in above formula accounts for cooling loads that may exceed the BHP-source demand. If the cooling load is in the same range as the BHP-source demand, synchronicity may be violated and the monthly-average basis may not be valid. On hot days the cooling load, which may be much higher than monthly-average, cannot be utilised as a heat source for the Booster heat Pump and a "cooling utility factor", similar as displayed in figure 3.2 should be accounted for.
As explained, the project specific cooling load must be derived from the NEN7120 software.

The amount of thermal energy actually extracted from the building reads:

$$Q_{....} = MIN\left[Q_{C,nd}; \left(1 - \frac{1}{\eta_{W;gen}}\right) Q_{W,dis,nren}\right] \qquad \text{(3.8)}$$

By default, the auxiliary energy is calculated on the basis of a specified use (per m^2 building area) $P_{C;aux;ngen;spec}$ = 2 W/m^2.
The "on" time for the system circulation pump is derived from the extracted thermal energy from the building [MJ], divided by the nominal thermal power of the booster heat pump.

$$t_{.C;on;mi} = \frac{Q_{C,nd}}{P_{source}} \qquad \text{(3.9)}$$

In the first stage of the EPC calculation (EPC <1,33x0,6 = 0,8), the generation efficiency for district heat is assumed as:

$$\eta_{W;gen;equiv;dh} \equiv 100\ \% \tag{3.10}$$

In the second stage of the EPC calculation (EPC < 0,6), the generation efficiency for district heat is derived from the EMG NVN7125 calculation:

$$\eta_{W;gen;equiv;dh} \neq 100\ \% \tag{3.11}$$

3.2 Implementation in NEN7120 software

Regarding implementation in the existing NEN7120-software, the booster heat pump is represented with an equivalent generator efficiency $\eta_{W;gen}$, according to (see eq. EPG5.30 and EPG 19.3):

$$\eta_{W;gen;equiv} = \frac{\sum_{zi}\sum_{mi} Q_{W,dis,nren}}{E_{W;el}\ x\ f_{P;del';el} + E_{W;dh}\ x\ f_{P;del';dh} + E_{W;aux}\ x\ f_{P;del';el}} \tag{3.12}$$

The equivalent generator efficiency can be specified in a sheet for hot water preparation, together with its primary energy source (electricity, gas, coal, wood), see figure 3.3.

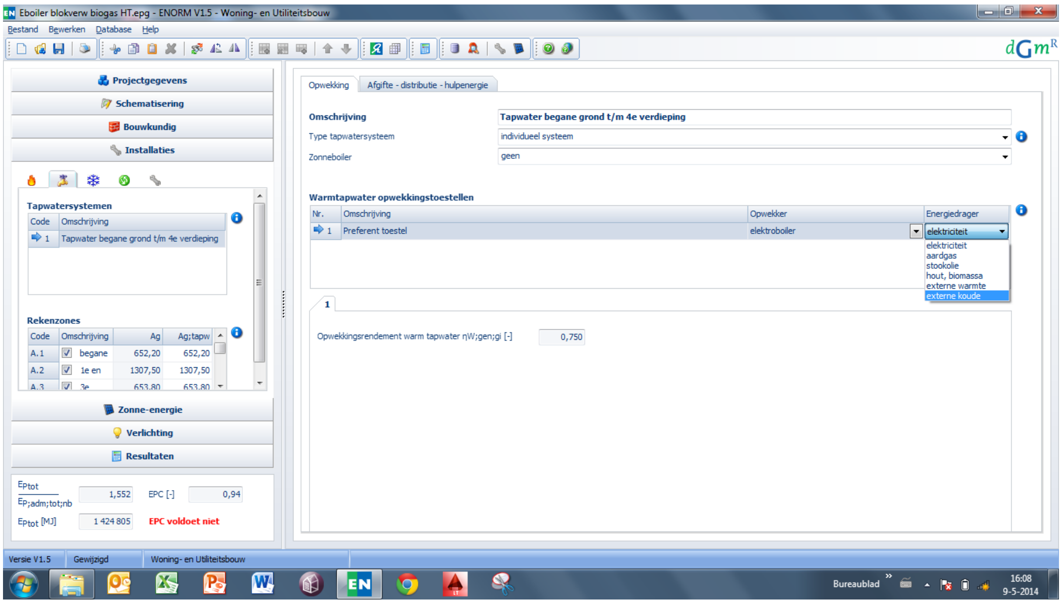

Figure 3.3 NEN7120 Input sheet according to ENorm [8], which can be used to specify equivalent generator efficiency and energy carrier

As the equivalent generator efficiency refers to primary energy, the energy carries ci to be selected accordingly is "gas", with a primary energy factor of 1,0.

3.3 Reducing summer cooling

One of the advantages of using building cooling as a secondary source of thermal energy for the booster heat pump is that the energy required (default) for summer cooling reduces.
In NEN7120, the energy required for summer cooling equals:

$$E_{SC;el} = \frac{Q_{C;nd}}{\eta_{C;gen;SC}} \tag{3.13) (EPG17.1}$$

Note that the indices and summation for months (mi) and for zones (zi) have been dropped.
In case a booster heat pump extracts heat form the building, the cooling load reduces to (see figure 3.2):

$$Q_{C;nd*} = MAX\left[0, Q_{C,nd} - \left(1 - \frac{1}{\eta_{W;gen}}\right) Q_{W,dis,nren}\right] \tag{3.14}$$

Assuming that the remaining cooling load is provided by a cooler with default COP of 3,0, the electricity needed for summer cooling is:

$$E_{SC;el*} = \frac{Q_{C;nd*}}{\eta_{C;gen;SC,default}} \tag{3.15}$$

And the new generator efficiency (to be substituted in the NEN7120 software):

$$\eta_{C;gen;SC} = \frac{Q_{C;nd}}{E_{SC;el*}} = \frac{Q_{C;nd}}{Q_{C;nd*}}\eta_{C;gen;SC,default} \tag{3.16}$$

In case $Q_{C;nd*}$ would be equal to zero (total cooling load covered by the booster heat pump), the equivalent generator efficiency would be infinite and for stability of the numerical procedures could be replaced by e.g. 9999.

4. Booster heat pump calculation sheet

The relevant equations, elaborated in the previous chapters have been incorporated in a Excel calculation sheet.

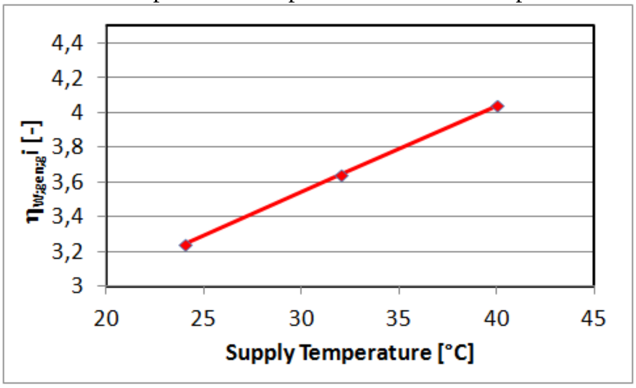

Figure 4.1 Sample generation efficiency, for 14000 MJ heat demand..

Conform NEN7120, the calculation sheet uses a monthly evaluation of the relevant temperatures and energy flows. Input in the calculation sheet is:

1. Generation efficiency of the booster heat pump, according to a declaration of conformity, as an example: both supply temperature and DHW demand dependent.
2. Generator efficiency of district heat (with primary energy factor)
3. District heat supply temperature (ambient temperature dependent).
4. Monthly building cooling load, in this case as an example given by figure 4.2 (sample), to be derived from the NEN7102 software program.

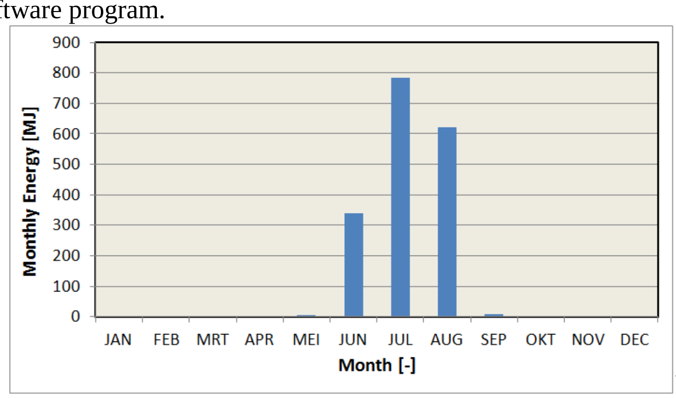

Figure 4.2 Building cooling load, adopted from a reference building calculation.

The above input, substituted in the calculation sheet, see figure 4.3

5 Conclusion

Figure 4.3 gives the booster heat pump equivalent generator efficiency, using the assumptions according to the previous chapter, depending on the district heating generator efficiency.

Figure 4.3 indicates that using the building as a heat source for the booster heat pump does result in a higher efficiency, from 5-7 %, depending on the district heat efficiency. This benefit is due to the reduced primary energy demand and is tempered by the increased auxiliary energy for a circulation pump.

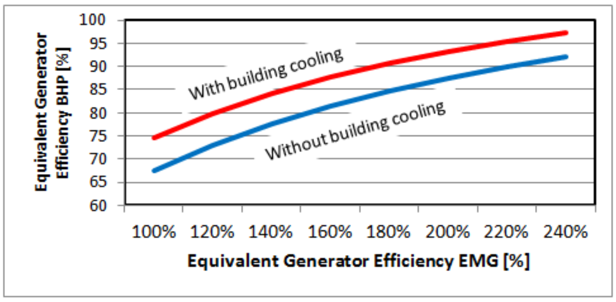

Figure 5.1 Booster heat pump efficiency, with and without building cooling, depending on district heating generation efficiency, for A_g=150 m^2, COP=4,04 @14000 MJ.

The increase in efficiency however does not reflect the roughly 20 % reduction of energy need from the district heating network, and associated financial savings.
In addition to the efficiency benefit, the need for summer cooling effectively annihilates, see figure 4.4, which may provide an extra ~0,02 EPC-points.

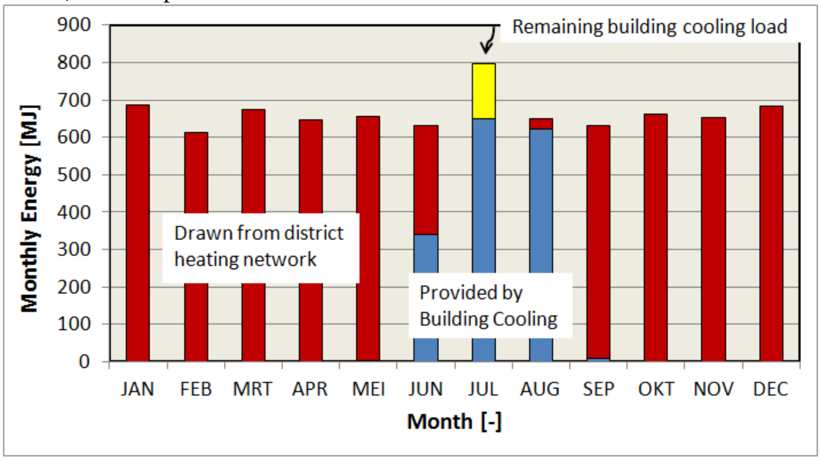

Figure 5.2 Graphical representation of energy need from the district heating network (red), thermal energy provided by building cooling (blue) and remaining cooling demand (not utilised as heat source for the booster heat pump, yellow). In this case (Ag=150m^2), the equivalent COP for summer cooling = 3660.

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