LOW TEMPERATURE HEATING SYSTEMS: IMPACT ON IAQ, THERMAL COMFORT AND ENERGY CONSUMPTION

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ABSTRACT
The Netherlands Agency for Energy and the Environment (NOVEM) is conducting a program for the implementation of Low Temperature Heating (LTH) systems in buildings. The primary goal is to enable the use of *Low Valued Energy* as a heating source. Major savings in energy consumption can be realised by fully utilising the potential of *Low Valued Energy*. Besides the argument of savings in energy supply, there are additional benefits in the fields of:

- Indoor Air Quality (particles, mites, lower air temperature, annoyance and dust);
- Thermal Comfort (radiant heat, temperature gradient, radiant heat asymmetry, floor temperature, temperature fluctuations, heating up period, cooling, air velocities and draught);
- Energy Consumption (transmission/venting losses, transport energy, utilisation of gains).

This study (lit [1]) shows that by lowering the temperatures for heat distribution systems, mainly advantages on the above mentioned aspects were found. By highlighting these additional benefits an easier introduction of LTH-systems might occur. Application on a broader scale will also lower the prices of these systems.

INTRODUCTION
To realise global objectives of energy saving and emission reductions in the built environment the use of *'Low Valued Energy'* is necessary. *Low Valued Energy* is available from residual heat, ambient heat and renewable sources. It can be used for Low Temperature Heating (LTH) in residential and commercial buildings. For this purpose the buildings and installations should be designed for low temperature distribution systems. Appropriate distribution systems, like floor and wall heating, have a life cycle of 40 to 50 years. So to implement *Low Valued Energy* sources within the next half of a century heat distribution systems should as soon as possible be designed for lower temperatures. Aware of this need the NOVEM initiated a program of conducting studies (feasibility and theoretical), field experiments, demonstration projects, etc.

The heating of buildings often is accomplished by a heat distribution system operating at high temperatures (90-70 °C). In the Netherlands the most common heating systems (especially in residential buildings) are built up from the following components:

- gas boiler with improved or high efficiency;
- piping system based on hot water as a heat transport medium and
- radiators or convectors as heat supply elements.

To realise an indoor air temperature of about 20 °C, the system water is heated up to a maximum of 90 °C, by a gas flame in the boiler of approximately 1200 °C!

The actual design methods for heating systems are based on the utilisation of this huge temperature drop. From sustainable heat sources (like solar, geothermal and waste heat) a much smaller temperature interval is available. Heating systems only can utilise these sustainable sources, when they are able to properly operate at significant lower temperatures. Wall and Floor heating systems fit specific well into a LTH-design. But also Air heating, Enlarged Radiators and Enlarged Convectors can be applied.

Due to a better insulation of new and retrofitted buildings and new techniques for reducing ventilation losses the heating demand of modern buildings is decreasing. This ongoing trend enables a broader application of LTH-designs for the smaller heating capacities needed. To qualify LTH-designs a distinction in design temperature ranges is given in Table 1.

Table 1. Definition of temperature ranges for heating designs (from lit [2])

System	**Supply flow**	**Return flow**
High temperatures (HT)	90 °C	70 °C
Medium temperatures (MT)	55 °C	35 - 40 °C
Low temperatures (LT)	45 °C	25 - 35 °C
Very low temperatures (VLT)	35 °C	25 °C

Other benefits come forth from LTH designs. In general a better thermal comfort and better indoor air quality is reached due to lower temperatures and larger surfaces. Furthermore additional energy saving occurs through a better efficiency of boilers, less pipe heat losses and lower venting losses. In an initial study the qualitative aspects of LTH designs have been investigated, mainly based on literature reviews. This study has been reported (in Dutch) in lit [1]. In Table 2 an overview of the regarded aspects is presented.

Table 2. Overview of the impact of lowering design temperatures on several aspects

LT- Heat Distribution System	**Floor Heating**	**Wall Heating**	**LT Radiators**	**LT Convectors**	**LT Air Heating**
HT-Reference	**90/70 Radiators**	**90/70 Radiators**	**90/70 Radiators**	**HT Convectors**	**HT Air Heating**
Thermal Comfort					
Radiant heat	+++	++	+	0	0
Temperature gradient	+++	++	++	++	++
Radiant heat asymmetry	0	0	0	0	0
Floor temperature	+++	0	0	0	0
Temperature fluctuations	++	+	+	+/0	+/0
Heating up period	-	-	-	-	0
Cooling options	+++	++	0	0	+
Air velocities and draught	+	+	+	+	0
Indoor Air Quality					
Particles	+++	++	+	+	0
Mites	+++	+	0	0	0
Enthalpy	+++	++	+	0	+
Annoyance and Dust	++	++	+	+	+
Energy Consumption					
Transmission losses	-	-	0	0	0
Venting losses	++	++	+	0	0
Transport Energy	-	-	-	0	0
Utilisation of Gains	+	+	0	0	0

The performance of several heating supply elements on each aspect has been validated by a quotation from "---" to "+++". A better performance is always indicated by "+", so for instance lower venting losses are quoted by "+" instead of "-". The starting point for the insulation degree is state of the art building in the Netherlands (R_c = 3.00 m²K/W; $U_{windows}$ = 1.80 W/m²K; air tight envelope and high efficiency installations). In the next paragraphs the quotations from Table 2 will be shortly explained.

THERMAL COMFORT

Radiant heat transmission

The radiant heat transmission component of LT-systems is much higher than for other systems. Due to large surfaces and low temperatures the radiant component of floor and wall heating is about 50–70 %. For conventional HT-radiators this is 20–40 % (lit [3]). Therefore the heat transfer by air is reduced and the air temperatures can be 1–2 °C lower at the same comfort level. Experimental studies show a high appreciation by building occupants for heating systems that work primary on radiant heat (lit [4]). It is presumed that radiant heat transfer (so relatively cold air and warm surrounding surfaces) better fits to comfort needs of human beings because it is more 'natural' (like solar radiation on the skin).

Vertical temperature gradient

In computer simulations, laboratory and field experiments a clear difference was found in vertical temperature gradients between floor and HT-radiator heating. With floor heating practically no gradient is found in well-insulated buildings (lit [2], [5], [6]). Radiator, wall and other heating systems are much more dependent on a good design. Normally gradients range from 2–3 °C between floor and ceiling. Bad designed systems show gradients up to 7 °C. In particular the gradient between ankle and head level has influence on the perceived thermal comfort.

Temperature asymmetry

Cold window surfaces can cause discomfort by radiant heat losses, which are not in balance with radiant heat flows in other directions. Complaints occur when differences exceed 23 W/m² or 10 °C (lit [7]). Conventionally compensation was provided by placing hot radiators close to the cold surfaces. Due to better glass types with a high insulation grade, this aspect is loosing importance. At U-values of the glazing under 1.5 W/m²K no significant differences between heating systems occur (lit. [8]). At higher U-values the height of the window can be restricted or compensation, for instance by extra heating in the outer circle of floor heating system, is recommended. Discomfort from heated floor or wall surfaces does not occur.

Surface temperature of heated floors

A heated floor raises the comfort for all kinds of uses. Floor covering, like carpets, is not needed for walking bare foots or sitting on the floor (at home, nurseries, swimming pools, etc). Optimal floor temperatures range from 20-28 °C with shoes and 23-30 °C bare foots depending on the flooring material (maximum 28 °C recommended for all purposes; lit [5]). Besides the living zones (e.g. within 0,60 m from the walls) up to 33 °C is allowed. A study for increased bacteria growth on feet with heated floors showed no significant result (lit [9]).

Temperature fluctuations

Quick temperature fluctuations around a constant mean value give annoyance. LTH-systems have a greater inertia than HT-radiator or air heating. Moreover the driving forces are smaller due to large surfaces and low temperature differences. For these reasons less fluctuations occur. The inertia is often considered to giving discomfort at incoming solar or sudden changes in internal gains. To this aspect LTH-systems take profit from the 'self-regulating' abilities. Due to the small temperature ranges at which they operate, heat supply does react instantly on temperature changes in the interior (lit [5], [10], [11]).

Heating up period

Conventional heating systems have a shorter heating up period (after cooling down e.g. for 8 hours) due to the inertia of direct connected thermal mass for floor and wall heating systems. Important is the connection between the tubes and surrounding material and the mass of the material. The temperature raise for LTH-systems however is much lower than for HT-systems. Moreover heating up is often associated with air temperatures. Regarding operative temperature (mean value of air and radiant temperature) reduces the differences between LT and HT-heating systems. For (very) well-insulated buildings the energy gain from a night set back is small due to limited cooling down of the thermal mass within the insulation envelope. Therefore a minor set back is recommended in combination with LTH systems (lit [1], [12]).

Cooling abilities

Increasing the insulation grade of buildings together with reduction of ventilation losses and utilisation of solar gains causes the risk of overheating during summer time (lit [13]). LTH systems often give easy opportunities for cooling. Especially when combined with a ground collector (and heat pumps) a limited capacity of (high temperature) cooling can be accomplished by little means (lit [5]). A ground collector can be regenerated from the cooling load. Other costing overheating devices can be avoided.

Air velocities and draught

Draught can be caused by cold (window) surfaces, at which the air in the boundary layer cools down and flows downwards. This might be avoided for instance by placing hot radiators under the window. Laboratory studies show that mean air velocities for HT radiators and floor heating are in the same order within the living zones. The fluctuations around the mean value however (turbulence-degree) are about 20 % higher with HT radiators (lit [11], [14]). Applying well-insulated glazing and limited window heights (max. 1.7 m for clear double-glazing) reduces sufficiently the risk of draught with floor (and likely for other LT) heating systems. Special attention is needed for natural supply grills in the facade for venting.

INDOOR AIR QUALITY

Suspended particles

In a field study in Finland visible dust on floors was found to correlate to neurotic complaints like headache, fatigue, concentrating problems etc. LT-heating was found to give less eye-irritation and throat and other mucous diseases (lit [15]). Also a correlation was found between the temperature of the heating surface and particle deposition. It is assumed that the lower grade of air fluctuations from LTH systems causes a lower quantity of suspended particles in buildings (lit [16]).

Mites

Many studies show a positive effect from floor heating on reduction of the mite population in dwellings (e.g. lit [17]). This is mainly caused by a lower RH in the boundary layers above the floor (within the floor covering). The mite survival threshold is a RH under 45 % during long term. The influence of a floor heating system on the RH in the boundary layer is calculated to be in the order of 10 %. This reduction just suffices to bring the RH under the threshold value.

Room Air temperature
As a result of the high contribution of radiant heat the room air temperature can be 1-2 °C lower for LTH systems. Several studies show a better performance for stuffiness and perceived air quality at lower air temperatures (e.g. lit [18]). Mucous irritation complaints increase significantly at air temperatures over 22-24 °C (lit [19]). The annoyance from all kinds of emissions (TVOC etc) is correlated to the air temperature. A correlation also was found for Sick Building Syndrome and the air temperature.

Dust singe and odour annoyance
Inhaling dust can cause allergic reactions (lit [20]). The sensitivity of humans for inhaled particles is more dependent on the quality of the particles than on the quantity (lit [18]). At temperatures exceeding 55 °C the process of dust singe starts. The particles get more reactive and irritating from the higher temperatures that occur at HT heating elements (lit [15]). So LTH systems not only give less suspending particles in the air but moreover the particles spread are less aggressive due to absence of dust singe.

ENERGY CONSUMPTION

Transmission losses
Due to floor and wall heating the mean temperatures in the heated constructions are higher during the heating season. Extra heat losses to the backside of the constructions will occur. For heated floors above a crawl space this is about 40 MJ/m² per year with U_{floor}=0.36 W/m²K and for average Dutch Climate (5 % of the supported energy flow). Heated walls in the outer envelope show even up to 50 % increase of losses (lit [2], [5], [11], [12]). Applying a thicker insulation layer (plus 2.5-5.0 cm) in heated constructions can easily compensate these extra losses. Transmission losses from hot air flowing along window surfaces are reduced with LTH.

Venting and infiltration losses
In buildings with LTH the ventilation losses are lower due to the lower air temperatures. Especially infiltration and natural venting cause less energy consumption. In a new Dutch standard dwelling the saving is about 1.6 GJ (5 % of total consumption) per year (lit [2], [5], [11]). For ventilation systems with balanced air exchange and heat recovery the saving is smaller.

Transport energy
Larger flows of the heating medium might needed to be transported because of lower temperature intervals (especially with floor heating). In combination with a heat pump a continuously heat flow is preferred at the lowest possible supply temperatures. Therefore the duty cycle of the transport pump often will be higher for LTH systems. Extra transport energy can be restricted by a good hydraulic design to about 400 MJ electricity per year (on an average domestic electricity consumption of 10 GJ/year).

Utilisation of gains
In averaged insulated buildings solar and internal gains are utilised 100 % for reduction of auxiliary heat demand. In light mass buildings with a improved insulation the utilisation of gains decreases. In simulation and laboratory studies energy savings of 3 % were found for floor heating systems under these circumstances (lit [10]). Theoretically the savings can reach to about 5-12 %. The energy saving from better utilisation is also dependent on the layout of the heating system and thermal zoning in the building (e.g. through transport of solar gains by a floor system from south to north zones).

CONCLUSIONS

Low Temperature Heating (LTH)-systems mainly show advantages in qualitative aspects:

- Thermal Comfort increases on many aspects (greater share of radiant heat transfer, less temperature gradients, better floor contact-temperature, less draught and air turbulence);
- The IAQ is also positively influenced (less dust singe and house dust mites, less stuffiness and odours through lower air temperature, less suspended particles);
- In addition to the ability to use Low Valued Energy savings are gained from better performances of boilers and heat pumps, less piping heat loss and less ventilation losses.

Other benefits might occur like avoidance of burning risk, extra space due to absence of radiators etc, avoidance of mould growth, etc. Many disadvantages can be avoided by means of a proper design and compensating measures. Arguments against LTH-systems often appear to be based on negative experiences in the past (bad design or insulation) or a lack of knowledge.

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