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Integrating Low-temperature Heating Systems into Energy Efficient Buildings

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Abstract

Energy requirements for space heating and domestic hot water supplies in the Swedish building sector are responsible for almost 60 % of the total energy used. To decrease this enormous figure, energy saving measures are required, as well as opportunities to use low-temperature heating systems for increase sustainability. The present paper studies low-temperature heating systems, including heat production units (district heating or heat pumps) and heat emitting units in the room. The aim was to find an answer to the question of whether or not low-temperature heating systems are energy efficient and sustainable compared with conventional heating systems. To answer this question, we considered different efficiency aspects related to energy and exergy. The analysis showed that low-temperature heating systems are more energy efficient and environmentally friendly than conventional heating systems. This was attributed to heat pumps and district heating systems with lower temperature heat emitters using a greater share of renewable resources and less auxiliary fuels. This report discusses the pros and cons of different types of low-temperature heat emitters.

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Keywords: Low-temperature heating systems; Energy efficiency; Low-temperature district heating; Heat pumps

1. Introduction

In Sweden, energy consumption in the building sector accounts for almost 40 % of the total final energy use [1]. This high energy consumption in the building environment has raised the concern to undertake low-energy building in both newly-built buildings and in retrofitting old ones. The energy requirements for heating and hot water in a building are responsible for almost 60 % of the final energy use [1]. However, this enormous percentage provides the incentive to save energy by taking measures such as: using additional insulation, using tight building envelopes,

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or using energy-saving equipment in recycling heat from outgoing air; that is, using a heat recovery ventilation system or an exhaust air heat pump. All these potential measures lead to a reduction in the heating season and the space heating load, providing an opportunity to use low-temperature heating systems. Low-temperature heating systems usually work with a maximum supply water temperature of 45 °C [2]. Some studies [3, 4] showed that low-temperature heating systems provide better thermal comfort and indoor air quality due to less temperature stratification in the room and less air movement.

In Sweden, the number of heat pumps sold is increasing greatly. By 2011, nearly half of detached homes and semi-detached dwellings have had heat pumps installed [1]. Supporting a low-temperature heat emitter with a heat pump is thermally efficient. As a rule of thumb, the thermal efficiency of a heat pump improves by one to two percent for every degree reduction in the supply water temperature. Therefore, as the number of heat pumps sold in Sweden increases, there is a need to adjust the heating systems to this change in order to attain greater efficiency, that is, use low-temperature heating systems. In addition, in recent years some studies have focused on low-temperature district heating, known as the fourth generation of district heating [5]. This means that in the future the supply water temperature to heat emitters connected to district heating will also decrease. In Sweden, more than 90 % of apartment buildings are connected to district heating. Therefore, there is also a need to change the heat emitters in existing apartment buildings multi-family buildings to be adapted for a lower supply water temperature.

Using a low-temperature heating system is also more sustainable due to a reduction in the generation of carbon dioxide. For every degree reduction of the supply temperature in a heating system, the carbon dioxide emission decreases by 1.6 % [6]. Ploskic [6] showed that by using a water supply temperature of 40 °C instead of 55 °C, the heat pump efficiency would increase by 25 % and the carbon dioxide emissions would decrease by 24 %.

The literature study for this paper was conducted with regard to comparing conventional heating systems with low-temperature heating systems. Different aspects to be considered are: energy and exergy efficiency, thermal comfort, and the simplicity of installation of low-temperature heat emitters.

2. Building, Heat Emission and Heat Production Units

In this section, we consider two systems in terms of building a heat emitter and a heat production unit.

2.1. Building and Heat Emitter Perspective

There are two main ways to make the building and heat emitter compatible for a low-temperature supply. One way is to reduce the energy demand in the building by tightening the envelope, installing better windows, or recovering heat from ventilation air. Decreasing the heat demand allows a reduction in the temperature needed in the supply water to heat emitters. In this type of low energy building, an existing conventional heating system can be used with a lower supply temperature. Decreasing the space heat load to 15 $W/m^2_{floor\ area}$ allows a reduction in the supply temperature to 40 °C in conventional radiators [6].

Instead of decreasing the heat demand in the building, another way to supply low-temperature water is to increase the thermal efficiency of the heat emitter in the existing building. Thermal efficient radiators are able to cover the heat demand in a building of 20 $W/m^2_{floor\ area}$ with a supply water temperature of 40 °C [6].

The heat output (P) of a radiator is directly proportional to the heat transfer coefficient (k), the surface area (A) and the mean temperature difference between the heat emitting surfaces and the ambient air ($\Delta\theta_m$) – see Eq. (1).

$$P = k\ A\ \Delta\theta_m \qquad (1)$$

As shown by Eq. (1), decreasing the supply temperature to the radiator causes a decrease in the surface temperature of the radiator (Δθm). To compensate for this reduction while maintaining the same heat output, either the heat transfer coefficient or the area of the radiator must be increased. One way to increase the heat transfer coefficient is to change from natural to forced convection. This could be done, either by combining a ventilation intake with the radiator, as shown in Fig. 1a– this is called a ‘ventilation radiator’ [7] – or by putting some fans below the radiator – this is called an ‘add-on fan radiator’ [8], see Fig. 1b. These radiators are introduced in detail in the following section. Referring to Eq. (1), another way to compensate for surface temperature reduction of a heat emitter due to lower supply water temperature is to enlarge the surface area. Some examples are floor heating, wall heating, or ceiling heating.

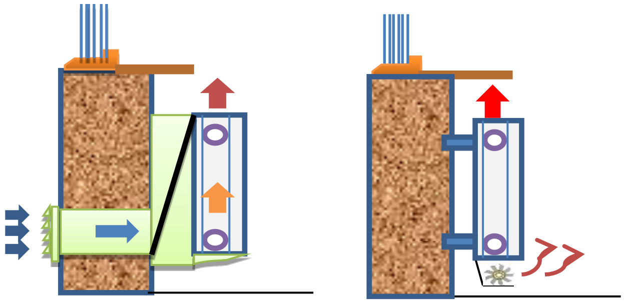

Figure 1 left: ventilation radiator, combining the supply intake and the radiator.: right: fan radiator where fans are placed below the radiator

2.1.1 Low-temperature Radiators

In this section, we discuss the two types of low-temperature radiator, the ventilation radiator and the add-on fan radiator. The main principle behind these two radiators is to enhance convection. Forced convection is the movement of a fluid by an external source, such as a fan in this case.

- Ventilation radiator:

In a ventilation radiator, the supply intake is placed behind the radiator. This combination allows preheating of the ventilation air before entering the room while increasing the heat output of the radiator. As the cold air passes through the radiator's panel first and then enters the room, the problem with cold down-draft is avoided as much as possible. In addition, a ventilation radiator is more thermally efficient than a conventional radiator. This is due to enhanced convection by blowing cold ventilation air behind the radiator, and by having a higher mean velocity and a temperature difference between the radiator's heated surface and the cold ventilation air. This shows that, during colder days when the temperature of the incoming ventilation air is low, the heat output of the radiator would increase without increasing the supply water temperature. A previous study [7] showed that a ventilation radiator operating with a supply temperature of 35 °C has the same heat output as a conventional radiator working with a supply temperature of 55 °C. The heat output was measured at 10 l/s of ventilation inflow with three different air temperatures – 0 °C, -7.5 °C, and -15 °C. In this system, the same as other heating systems, heat from ventilation air can be recovered for example by exhaust air heat pump. However, due to requiring supply vent behind the heating system in ventilation radiator, heat recovery ventilation system with exhaust and supply cannot be used to recover heat from outgoing air.

- Add-on fan radiator:

In the add-on fan radiator, fans are placed below the radiator panels. A previous study [8] showed that having five fans below the radiator increases the heat output to almost twice that of a conventional radiator. This is due to increasing the convection heat transfer along the radiator surfaces. Therefore, referring to Eq. (1), the supply temperature of the add-on fan radiator can be decreased without reducing the heat output. It should be noted that by adding fans below the radiator, however, the surface temperature of the radiator is decreased and consequently radiation heat transfer is decreased. However, the enhancement of forced convection is much larger than the reduction in radiation [9]. Added fans below the radiator consume very small amounts of electricity, that is, the ratio of electricity consumption by the fan to increasing the heat output of the radiator is between one and two percent. However, home occupants detected a noise problem with the fan radiator. So, this type of radiator is not preferred in bedrooms.

2.1.2 Large Surface Heat Emitters

In a large surface heat emitter, the heating system is integrated within the building envelope, such as in the ceiling, the floor or the walls. The supply temperature to these heating systems is less than 35 °C. This type of heating system creates a more uniform indoor temperature because of the large surface area. Floor heating is preferred by home occupants since the feet are exposed to higher temperatures, whereas the feet usually have a lower temperature than other parts of the body. These hidden heating systems also favour the room design without interfering with the room decoration. However, the large mass of water flowing through pipes makes maintenance of the system challenging. For floor heating, the temperature difference between supply and return is decreased due to the preferred homogenous temperature along the floor. This would require a higher flow rate, followed by increasing auxiliary hydraulic pressure loss for the circulation pump compared to a hydronic radiator system. In addition to higher circulation pump work, higher primary energy consumption in floor heating could be due to high heat loss to the ground because the heating system is not completely interior and is embedded in the envelope. Therefore, the overall energy performance should be considered when evaluating different heating systems.

2.2. Heat Production Unit Perspective

In terms of heat production, the heat producing unit should be able to supply water at a low temperature for the heat emitter. In most Swedish buildings, heat production is provided by a heat pump or by district heating. These two methods are recognised as the two most environmentally friendly and the most efficient heat production methods. In the following sections, we discuss these two systems.

2.2.1. Heat Pumps

Compared with direct electrical heaters, heat pumps typically use a quarter to a third as much electrical energy to deliver the same amount of heat. The reason is that heat pumps use renewable energy stored in ambient air, in outgoing air from the building, in the ground, or in ground-water, and increases their temperature which cannot be used directly for heating. For example, if the coefficient of performance of a heat pump is three it means that the heat pump uses one kilowatt-hour direct electricity and two kilowatt-hours renewable energy to deliver three kilowatt-hours of heat. As the number of heat pumps sold increases, the proportion of used renewable energy as a primary source of energy for heating increases.

The lower the temperature of the heating system, the less effort is required by the heat pump and the more efficient the system becomes. The coefficient of performance (COP) of a heat pump is equal to the ratio of produced useful heat to the electricity consumed by the heat pump. The COP depends on many factors, for example, the temperatures of the heat source (renewable energy) and the heat sink (heat emitter), the efficiency of its compressor, and the type of its working medium. Above all, the temperature of the heat source and heat sink are very important factors influencing the COP value. Lowering the temperature difference between the heat source and the heat sink for a heat pump results in a higher COP value. A combination of a low-temperature heating system and high-temperature heat source is therefore beneficial.

2.2.2. District Heating

As more buildings are becoming more energy efficient due to renovation, there is no need to supply water with the same temperature as before. Therefore, one way to adapt an existing district heating network to a new and retrofitted building is to lower the primary supply temperature. It is estimated that low-temperature district heating, known as fourth generation district heating, will be in use between the years 2020 and 2050 [5]. In this network, the produced water temperature would be between 50 and 60 °C, and it uses more renewable and sustainable sources for heat production. Compared with current district heating, in low-temperature district heating there is less heat loss to the ground due to a lower temperature difference between the pipes and the surroundings. However, due to low-temperature water in the pipes, heat loss from the network should be kept as low as possible. Therefore, more insulation is needed in the network. In buildings connected to a low-temperature district heating network, supplying hot water for domestic usage might be a challenge and could be supplied from other sources.

In the current generation of district heating, that is the third generation, the produced water temperature is around 90 °C which is, however, high for buildings with thermal efficient heat emitters or buildings with low heat demand. One possible way to adapt those buildings with a low-temperature water supply in an existing district heating system is to use the return temperature from other buildings as a supply temperature for them. In this way, low energy buildings are supplied with a maximum of 40 °C of return water temperature from other buildings

3. Analysis of Different Aspects of Efficiency

In this paper, different aspects of efficiency to be considered are energy and exergy efficiency of low-temperature heating systems from the perspectives of both the heat emitter and the heat production unit.

3.1. Energy Efficiency:

Due to the scarcity of energy, both non-renewable sources and renewable sources during the cold season, the energy efficiency of the heating systems in buildings is becoming very important. Energy efficiency differs from energy conservation. Energy efficiency means, for example, that by reducing the temperature of a heating system, the same heat demand with the same thermal comfort can be met in the building as when it has a conventional heating system. However, energy conservation means, for example, that reducing the supply temperature of the heating system causes a reduction in the room temperature in order to save primary energy. When considering low-temperature heating systems, our aim is the efficient use of energy and not to sacrifice thermal comfort for energy conservation.

3.2. Exergy Efficiency

Exergy is defined to be the quality of an energy source, showing a potential of a given energy quantity to perform work in the sense of transforming it into another form of energy. In buildings, there are different levels of exergy demand. There is a high exergy demand for appliances and lighting, which are powered by electricity or by burning fossil fuels. On the other hand, the exergy demand for space heating and domestic hot water is low; this is due to a low temperature level, that is, a maximum of 55 °C for the water supply, and thermal comfort of around 20 °C in a room. This low exergy demand should not be provided by high exergy sources, such as using direct electricity or by burning fossil fuels (which cause more than 95% destruction in exergy since we create more than a 1000 °C flame to heat up the room to only 20 °C). These low exergy demands could be met by renewable energy, or from other low quality energy sources, such as waste heat from industry.

The main principle of exergy efficiency in designing the energy systems is to match the quality levels of the energy supply with the energy demand. In the exergy efficiency approach, the exergy is produced as much as it is consumed. In this method, the low exergy supply (low-temperature sources, for example, solar heat, ground heat or waste heat) is adapted to low exergy demand (a low-temperature heating system and hot-water supply). On the other hand, high exergy supply (fossil fuels, natural gas or electricity) is assigned to high exergy demand (appliance and lighting). In this approach by using both fuels and renewable sources the exergy efficiency of the buildings is increased. Matching the exergy level by managing the energy supply and demand rationally leads to increasing the sustainability and reducing the environmental impact and CO_2 emissions.

4. Discussion

Due to increasing electricity price and scarcity of fossil fuels with environmental aspects, renewable energies could be an important alternative energy source. Preparing water with lower temperature allows a greater use of renewable sources with less required auxiliary fuels in heat pump or district heating. This indicates that low-temperature heating system are more efficient and sustainable due to less CO_2 emission in primary energy compared to conventional heating system. In addition, in terms of exergy efficiency there is lower temperature difference between heat source (renewable energy), heat emitter (less than 40 °C) and room temperature (thermal comfort of 21 °C) in low-temperature heating system compared to conventional heating system. All these analysis of energy and exergy aspects in perspectives of heat production and heat emitter show that low-temperature heating system are more energy and exergy efficient and beneficial to use compared to conventional heating system.

Regarding the ease of installation of low-temperature heat emitters, here we take a look at two examples – the ventilation radiator and floor heating. To install the ventilation radiator, it is necessary to make a hole behind the radiator in an external wall which needs to be connected to the radiator. However, if it is not possible to change the façade of the building, some fans can be placed below the radiator in order to enhance the convection heat transfer coefficient; this is referred to as using an ‘add-on fan radiator’. In addition, a type of floor heating has recently been introduced to the market which is very easy to install; it is like a carpet embedded with very thin and light pipes. This system can be placed on the existing floor with no need for reconstruction. Table 1 shows the pros and cons of all the heat emitters mentioned in this report.

Table 1: Pros and cons of all the heat emitters mentioned

Heat emitter	Supply temperature	Advantages	Disadvantages
Conventional radiator	45 to 55 °C	- Adapted to current district heating network temperature.	- More thermal stratification in the room than a low-temperature heat emitter.
Ventilation radiator	35 to 45 °C	- Pre-heated ventilation air. - Energy efficient due to a low supply temperature.	- Need a hole in an external wall behind the radiator. - Clogging of the air filter.
Add-on fan radiator	35 to 45 °C	- Energy efficient due to a low supply temperature. - No need to change the existing radiator.	- Noise problem.
Surface heating	29 to 33 °C	- Energy efficient due to a low supply temperature. - Uniform room temperature. - Invisible heat emitter with no need to adjust the room decoration.	- Difficult maintenance of the system due to a massive amount of water trapped in the pipes. -more auxiliary energy use in terms of pump work

5. Conclusion

This report presented low-temperature heating systems from the perspective of the heat emitter and heat production. This report introduced two types of low-temperature radiator, which were the ventilation radiator and the add-on fan radiator. Another type of low-temperature heating system which benefits from the large surface area of walls, floor and ceiling is the integrated building envelope heat emitter. District heating and heat pumps were considered as heat production units. This paper considered two aspects of efficiency for low-temperature heat emitters – energy efficiency and exergy efficiency. We showed that low-temperature heating systems are more efficient and beneficial to use compared with conventional heating systems. As mentioned in the report, by using a low-temperature heating system, more renewable energy will be used together with less auxiliary fuels being required and a higher efficiency of the heat pump. This would meet all the criteria of this policy, that is, by reducing energy consumption in buildings, by making buildings more sustainable with a greater use of renewable sources, and by reducing their carbon dioxide emission. All these trends regarding supplying lower temperatures to the heating system provide a move towards having a more sustainable society with a reduction in greenhouse gases.

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