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The Impact of Alternative Heat Supply Options on CO_2 Emission and District Heating System

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The energy demand for space heating and ventilation has huge potential. The impact of three alternative energy supply solutions such as exhaust air heat pump coupled with district heating, district heating coupled with room based heat recovery ventilation unit, and air-to-water heat pump coupled with mechanical exhaust ventilation and district heating have been studied in the case of a refurbished Soviet time residential building. District heating coupled with room based heat recovery ventilation unit exhibits the lowest primary energy demand and CO_2 emission. Air-to-water heat pump coupled with mechanical exhaust ventilation and district heating and using the district heating coupled with mechanical exhaust ventilation (so called base scenario) are quite equal from the point of view of primary energy demand. The CO_2 emission is clearly higher for air-to-water heat pump option than for the base scenario and other studied alternatives. However for all alternatives the relative heat losses in district heating network are growing.

Introduction

The energy demand for space heating and ventilation has huge potential for energy saving not only in Estonia, but also in other countries (Fouih et al., 2012) and there is a growing call for energy efficient and environmentally friendly heating systems (Sakellari and Lundqvist, 2005). Since buildings have a long life span, lasting for 50 y or more (Wan et al., 2011), energy conservation and strategies to reduce energy consumption in buildings are strictly important (Mardiana-Idayua and Riffat, 2012).
Since the beginning of 2010s intensive refurbishment of residential buildings has taken place in Estonia. On the one hand the major stimulus forcing the refurbishment of residential buildings is the supporting system available through Fund KredEx, the maximum financial support was 35 % from the total investment cost. On the other hand, since 2006 the district heating price has increased over two times in the city of Tallinn, from 30 €/MWh to 79 €/MWh in 2012, incl. taxes (AS Tallinna Küte). The rapid increase of district heating price and available support mechanism makes renovation attractive for the flat owners of residential buildings.
It is well known that in case of regular mechanical exhaust ventilation, the air heating cost are relatively high (Kõiv et al., 2013) and alternative solution is preferred. The topic of heat recovery from exhaust air has been widely dealt with in literature and it will become increasingly more important, considering the need for improved insulation of envelopes with the consequent increase of the relevance of ventilation loads in the energy balance of a building in terms of modelling (Sakellari and Lundqvist, 2005) and further energy analysis (Fracastoro and Serraino, 2010).
The impact of three alternative energy supply solutions coupled with different solutions for ventilation on the district heating network and total CO_2 emission are studied in this paper. The alternatives are compared with respect to the usage of district heating for heat supply and regular mechanical exhaust ventilation in the refurbished residential building. The total heat consumption of different systems such as domestic hot water (DHW), space heating and ventilation are treated jointly, while some systems enable to transfer heat from one system to another and therefore the building must be considered as a whole.

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1. A building

During Soviet times, the residential buildings were in most cases built according to standard projects. There were several standard projects available, but in this study all calculations are made for a refurbished Soviet time residential house - the standard project No 111-121-E2 as shown in Figure 1. These types of buildings were mainly built in 70s and 80s of the last century. The data characterizing the building according to the standard project No 111-121-E2 is presented in Table 1.

Table 1: Main data of residential building of standard project No 111-121-E2

Item	Value
Number of apartments:	60
Number of floor:	5
Number of sections:	4
Apartments per section:	15
Heated floor area:	~3 315 m^2
Building volume:	~12 551 m^3
Inside volume of heated space:	~8 556 m^3

Figure 1: Illustration of refurbished soviet time residential building of standard project No 111-121-E2

The heat supply and ventilation systems alternatives studied in this work apply to a refurbished building, i.e. the following key refurbishment measurements have been taken into account:

- Insulation of external walls – 100 mm, λ = 0.04 W/(m^2K)
- Insulation of roof – 250mm, λ = 0.04 W/(m^2K)
- 2-pipe heating systems with thermostatic valves
- New double-glazed windows, U = 1.7 W/(m^2K) and g=0.65

The average indoor temperature of the building is usually 21-22 °C. The heat loss through the cellar is calculated according to the method described elsewhere (Staroverova and Shillera, 1990).

2. Base scenario and alternative solutions

Three alternatives solution are compared with the so called base scenario from the economic point of view. In each case, the total primary energy demand for space heating, ventilation and DHW is calculated and compared, in addition total CO_2 emission were calculated. The building chosen for this study is connected to the district heating network. The alternatives depict the commercial solutions available in the market.

2.1. Base scenario

In the case of base scenario, the total heat for ventilation, DHW and space heating is supplied from the district heating network. The fresh air enters the building through the fresh air valves and is exhausted by the exhaust air ventilator as illustrated in Figure 2.

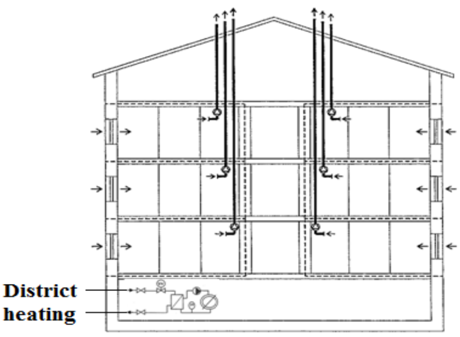

Figure 2: Basic schema of base scenario

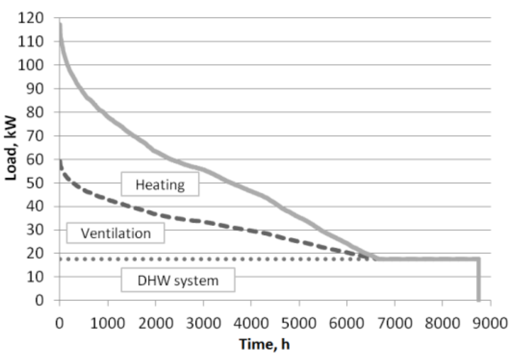

Figure 3: Annual heat load curve

The data on energy consumption in 2011 were gathered by actual measurements of the building equipped with an exhaust air heat pump (EAHP) supplying heat for space heating, ventilation and DHW together with district heating as described in section 2.2. For the base scenario an assumption was made that all the heat produced by heat pump and consumed from district heating network is 100 % equal to the heat consumed from the district heating network.

Based on the measured data the energy balance was composed using the standard steady-state calculation method based on the reference year. The method is described elsewhere (EN ISO 13790:2008). The total heat demand was 393 MWh/y: heating – 139MWh/y, ventilation – 99MWh/y, hot water – 155MWh/y.

The heat demand for DHW with losses was estimated based on the summer months when there was no heating in the building. The estimated total heat gain for the residential building was 58 kWh/(m^2a) (EN ISO 13790:2008), and the utilisation factor 0.65 (Kõiv and Rant, 2013). The heat loss through the envelope was estimated according to the areas and thermal transmittance of different parts of the building. Based on the measured values of energy consumption, the estimated energy demand for the DHW system and heating, and that for ventilation were calculated. According to the above described calculation route, the average air change rate of the building is 0.5 h^{-1}(with the floor height of 2.5 m), which matches the air change rate of the indoor climate class III (EN 15251:2007) or 0.35 L/(s m^2). The calculated balance temperature was 13 °C.

Based on the reference year of energy calculation, the register data of heat consumption and distribution of heat, the heat load curve was found as seen in Figure 3. We can see that the maximum heat load is 117 kW.

2.2. Alternative 1

Alternative 1 consists of an exhaust air heat pump (EAHP) for heat supply to heating, ventilation and DHW system along with district heating (as seen in Figure 4). The fresh air enters the building through fresh air valves and is exhausted by an exhaust air ventilator. The EAHP system covers the base load and additional heat demand is covered by the district heating network, i.e. if EAHP is unable to raise the supply water temperature in the heating or DHW system to the desired level, additional heat is supplied form the district heating network. The system is described in more detail elsewhere (Kõiv et al., 2012). The technique of heat recovery from ventilation air started already in late 1970s due to an energy crisis (Fehrm et al., 2002).

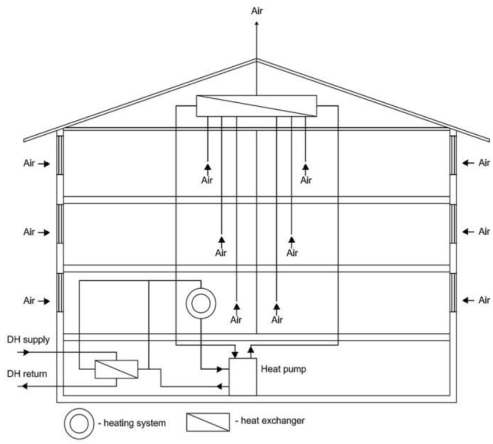

Figure 4: Basic schema of alternative 1

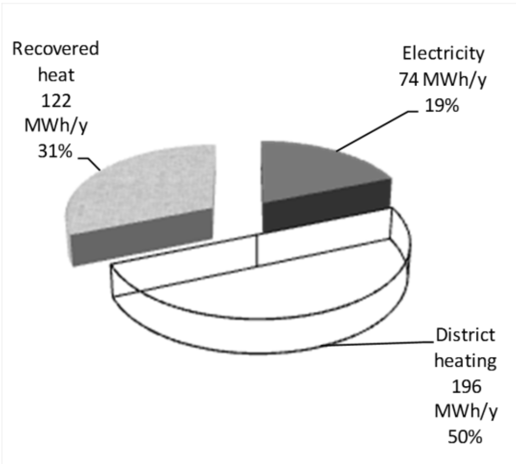

Figure 5: Distribution of heat by sources (alternative 1)

The above described actual measurements of the building were carried out in 2011. The gathered data was recalculated for the reference year. The average air change rate of the building is 0.5 h^{-1} as described in the previous chapter. Based on the measurements, the heat balance was composed for the reference year as seen in Figure 5: recovered heat – 122 MWh, district heating – 196 MWh, electricity – 74 MWh.

2.3. Alternative 2

In the case of Alternative 2, heat is totally supplied from the district heating network. The room based small ventilation units equipped with a plate heat exchanger for heat recovery are used. Figure 6 illustrates the concept of heat supply Alternative 2. The heat recovery temperature ratio for this type of heat exchangers is 60 % (Abel and Elmroth, 2007). Taking into account the heat recovery temperature ratio, supply air temperature of 16 °C and climate conditions in Tallinn, the energy efficiency of annual heat recovery for the ventilation unit is estimated to be 78 % (Abel and Voll, 2010), also offered commercially (Meltem, 2013). The average air change rate of the building is 0.5 h^{-1} as described above.

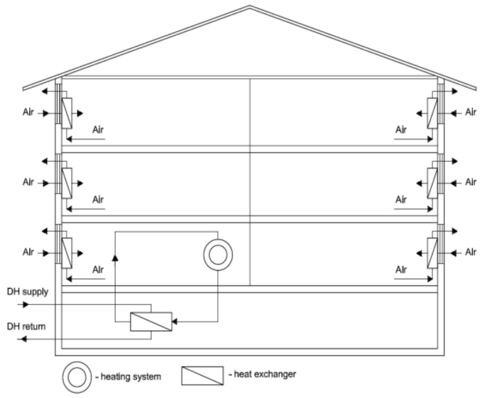

Figure 6: Basic scheme of alternative 2

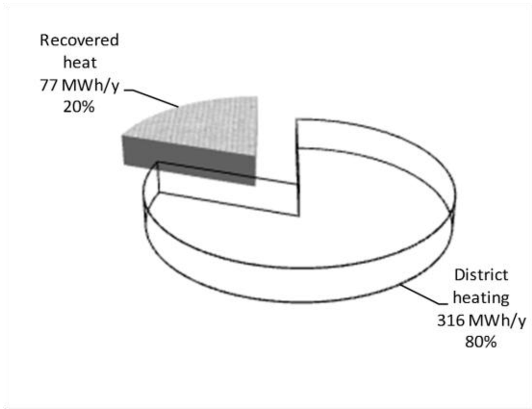

Figure 7: Distribution of heat by sources (alternative 2)

Based on the energy efficiency of annual heat recovery, the annual heat demand from the district heating network could be calculated. Heating and DHW are 100 % covered by district heating, but the heat for ventilation only partially. The recovered heat by room based ventilation units contributes 20 % to the total heat demand as seen in Figure 7.

2.4. Alternative 3

In the case of Alternative 3, the base heat load is covered by an air-to-water heat pump. In our study the peak load was covered by district heating during colder days. Regarding to ventilation, fresh air enters the building through the fresh air valves and is exhausted by an exhaust air ventilator as illustrated in Figure 8. The average air change rate of the building is 0.5 h^{-1} as described above.

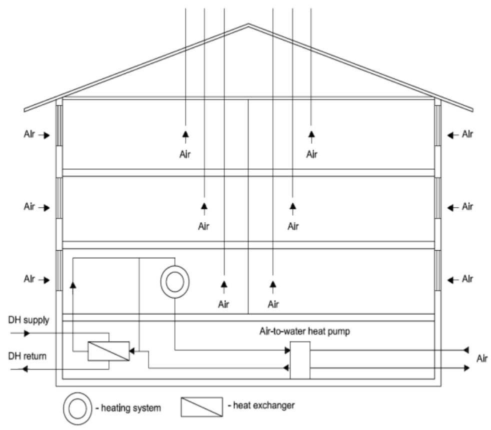

Figure 8: Basic schema of alternative 3

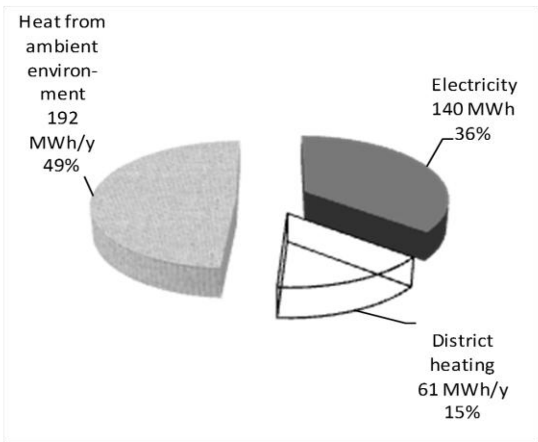

Figure 9: Distribution of heat by sources (alternative 3)

In the case of Alternative 3, the output and power consumption of heat pump were determined based on the Alpha-InnoTec LW310A heat pump unit, in particular case two units were foreseen. The calculations were made based on the Estonian reference year for energy calculation on an hourly basis. The air to water heat pump (AWHP) data in the case of different supply water temperatures, such as output vs ambient temperature and AWHP coefficient of performance vs ambient temperature were used, taking into account the electricity consumption for de-frosting cycles as well. The first priority for an AWHP unit was set to be heating and ventilation and if there was an excess of load, the AWHP was used for heating DHW as well.

The bivalent point could be seen at 0.1 °C which in general, is considered to be the optimum range 0±2 °C for residential buildings in the Estonian climate.
The seasonal coefficient of performance (SCOP) describing the performance of heat pump's average annual efficiency for heating and ventilation was found to be 2.66. For DHW the SCOP was found to be 2. The SCOP values were in good accordance with the national decree on the calculation methods for energy performance of buildings (MEC, 2012).
In the case of refurbished residential building as described above, the share of heat taken from the ambient environment could reach as high as 49 % from the total heat demand for heating, ventilation and DHW.

3. Results and Discussion

The emissions of CO_2 and need for primary energy were calculated for the base scenario and alternatives as seen in Table 2. Natural gas is the main fuel used for district heating in Tallinn. The data on relative network loss in the Tallinn district heating network (17 %) and annual efficiency of boiler houses (92 %) (AS Tallinna Küte) is used in the calculation of primary energy demand for district heating. The CO_2 emission for district heating is calculated according to the method described in the national decree (Environment).

Table 2: Primary energy need and CO_2 emission

Item	Unit	Base scenario	Alternative 1	Alternative 2	Alternative 3
Consumption of district heating	MWh/y	393	196	316	62
DH Primary energy	MWh/y	509	254	408	80
Consumption of electricity	MWh/y	0	74	0	140
Electricity primary energy	MWh/y	0	228	0	430
DH CO_2 emission	t/y	109	55	88	17
Electricity CO_2 emission	t/y	0	81	0	152
Total primary energy	MWh/y	509	482	408	510
Total CO_2 emission	t/y	109	135	88	169

The data on the relative power network loss in the Estonian power grid (7.1 %) (Statistics Estonia, 2013) and annual average net efficiency of the circulating fluidized bed (CFB) power unit (35 %) are used in the calculation of primary energy demand for electricity production. Approximately 90 % of supplied electricity is produced from oil shale in Estonia. The estimated specific CO_2 emission factor per produced MWh of electricity by the CFB unit is 1.01 t/MWh_e (Plamus and Soosaar, 2011).
Alternative 2 exhibits the lowest primary energy demand and CO_2 emission. Alternative 3 and base scenario are quite equal from the point of view of primary energy demand. The CO_2 emission is clearly higher for Alternative 3 than for the base scenario and other studied alternatives.
In order to analyse possible relative heat loss in network the assumption were made that all buildings in city were implement Alternative 1 to 3 solutions and the proportion of used energy will remain. The total heat consumption in the district heating network of Tallinn city is 1,638 GWh, 74 % of these is consumption of residential building sector. The yearly absolute heat loss of the Tallinn district heating network is 343 GWh. According to previous experiences the total district heating consumption after renovation of building envelope and improving ventilation is expected to decrease by 35 %, which is taken into account converting existent consumption to consumption for base scenario. Applying the base scenario and alternatives on the whole residential building sector in Tallinn the relative heat loss will change as it is seen in Table 3, and as a result for all alternatives relative losses will increase.

Table 3: Alternative effects on relative heat losses

Item	Unit	Today	Base Sc.	Alt. 1	Alt. 2	Alt. 3
Total heat production	GWh	1,981	1,557	1,162	1,403	891
Heat consumption by residential sector	GWh	1,212	788	393	634	122
Heat consumption by others	MWh	426	426	426	426	426
Absolute heat loss	MWh	343	343	343	343	343
Relative heat loss	%	17.3	22.0	29.5	24.4	38.5

4. Conclusions

Alternative heat supply solutions coupled with different ventilations systems such as EAHP coupled with district heating, district heating coupled with room based heat recovery ventilation unit, and air-to-water heat pump coupled with mechanical exhaust ventilation and district heating have been studied. District heating coupled with room based heat recovery ventilation unit exhibits the lowest primary energy demand and CO_2 emission. Air-to-water heat pump coupled with mechanical exhaust ventilation and district heating and using of district heating coupled with mechanical exhaust ventilation (so called base scenario) are quite equal from the point of view of primary energy demand. The CO_2 emission is clearly higher for air-to-water heat pump option than for the base scenario and other studied alternatives. The alternative energy supply units applied by the consumers reducing the consumption of heat from district heating network and clearly increases the relative heat losses and may change economically unperceptive to run DH in area. It must be considered that actual relative heat loss calculation is much more complicated, however it is clear, that such alternative solutions have negative effect on DH network. The more detailed analysis of effects on DH network and production site, especially for cogeneration issues is under study, and will be performed in the future. One solution to avoid such a parallel heat supply units is to lower the district heating price or introduce two-tariff price system, i.e. MW and MWh bases as it is applied e.g. in Helsinki.

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