CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 3

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Heiselberg, P. K. (Ed.) (2016). *CLIMA 2016 - proceedings of the 12th REHVA World Congress: volume 3*. Department of Civil Engineering, Aalborg University.

Energy Saving Potential of Air-to-air Heat Pumps in Detached Houses in Nordic Climate

Ari Laitinen

VTT Technical Research Centre of Finland Ltd
P.O. Box 1000, FI-02044 VTT, Finland

ari.laitinen@vtt.fi

Abstract

This paper presents a simple calculation method proposed by the author to be used in the national regulations of Finland to determine the net heat production and seasonal coefficient of performance of an air-to-air heat pump. Moreover, the paper includes some results of the background studies made for the work. These studies include simulations with IDA-ICE software and the measurement data that were used in verifying the simulation model.

Keywords - Air-to-air heat pump, energy saving, simulation, SCOP

1. Introduction

Energy saving potential of the air-to-air heat pumps has been argued ever since they were introduced to the Finnish national building regulations with fixed annual net heat production of 1000 kWh/a in new buildings. In the national energy labelling legislation the granted annual net heat production is higher ranging from 1000 kWh to 6000 kWh depending on the building year. The regulations are under renewing process and this study gives background information for that but the results are also useful for the designers, heat pump dealers and common occupants on the real energy and economical savings that can be realized with air-to-air heat pumps.

2. Simulation Background

Air-to-air heat pumps were studied in the Finnish climate (Helsinki) in order to clarify the real energy saving potential as well as in old, present and tomorrows nearly zero energy detached houses.

The two detached houses chosen for the study were the same that were used in our national cost optimal evaluation [1] of the minimum energy efficiency requirements of the buildings. These two buildings represent the typical building layout and heating demand of their time: old building 1970s (Fig. 1) and new building 2010s (Fig. 2). The main heating system in both buildings was electric heating and heat pump was installed in the living room in both buildings.

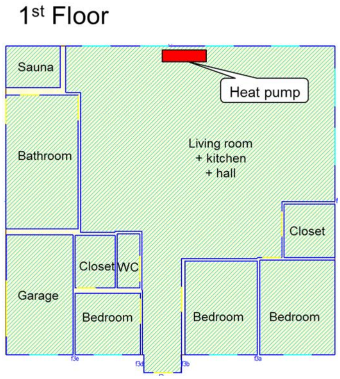

Fig. 1 Old building (1970s). Air-to-air heat pump was installed in the living room. Total floor area is 136 m^2 and annual space heating demand 25 000 kWh/a.

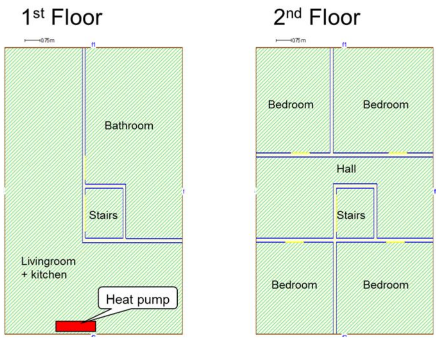

Fig. 2 New building, living room and bathroom downstairs (left) and bedrooms upstairs (right). Air-to-air heat pump was installed in the living room. Total floor area is 180 m2 and annual space heating demand 12 500 kWh/a.

2.1 Measured Data for Air-to-air Heat Pumps

IDA-ICE software has been used in the simulations and the air-to-air heat pump model has been verified and tuned by the measured data published by Scanoffice (Finland) [3], Energimyndigheten (Sweden) [4] and manufactures. Example of the available data for one air-to-air heat pump unit is presented in Fig. 3 and Fig. 4. The unit that was chosen for the study is one of the very few for which data could be found from different sources. The data published by Scanoffice is measured by VTT Expert Services Ltd and they measure the air-to-air heat pumps in a test room where the heat demand and the heat output of the heat pump varies along with the outdoor air temperature (-30 … +10 °C). This means that the heat pump runs at full load between outdoor air temperatures -30…-10 °C (Fig. 3 and Fig. 4). Between temperatures -10…+10 °C the unit runs at varying part load conditions. Moreover, VTT use fixed air flow rate of the indoor unit of the heat pump: the setting is in the middle position. Energimyndigheten runs the air-to-air heat pump mainly at full load regardless of the outdoor air temperature. They test the unit also at one outdoor air temperature (+7 °C) with 75 % loading and at two points (+7 °C and +2 °C) with 50 % loading. It is not common to find manufacturers data behind the energy label, one of the few that has published this data is Scanoffice at their web site [3].

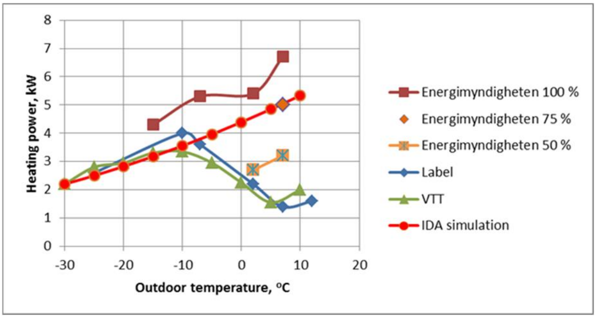

Fig. 3 Measured heating power data from different sources. Results by Energimyndigheten are based on full load measurements (100 %), one point at 75 % load and two points at 50 % load. Results by VTT are based on changing load and the air flow of the indoor unit is fixed (middle fan speed adjustment). Label data is based on the declared values by the manufacturer. IDA simulation model behaviour is also illustrated here.

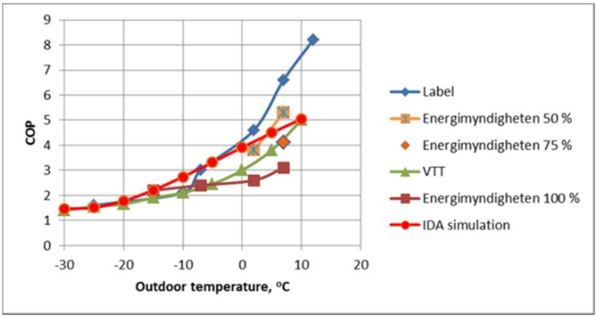

Fig. 4 Measured COP data from different sources.

The measured data clearly shows that the heating capacity of an air-to-air heat pump increases with increasing outdoor air temperatures. The other phenomenon is that the variable speed controlled unit reaches at some point the lowest controllable capacity, in our example approximately at the outdoor air temperature of +7 °C. According to the results COP values increases remarkably at part load conditions which can be seen by comparing the results (Fig. 4) of Energimyndigheten at full load (100 %) and the other results with part load. This could be explained by the lower condensing and higher evaporator temperatures under part load than under full load conditions. One observation is also important in our Nordic cold climate, namely that the measured unit is able to produce more heat than it consumes electricity (COP > 1) even at extremely low temperatures (-30 °C). This is not axiomatic especially for older units which can be deduced from measurement reports [3]. The measurements (Fig. 3 and Fig. 4) include also the energy needed to defrost the evaporator.

2.2 Simulation Model

The default simulation model of an air-to-air heat pump in IDA-ICE (versions 4.6 and 4.7 beta) is based on condenser and evaporator heat exchanger dimensioning data. The dimensioning is based on the heating capacity and specific temperatures at design conditions. The temperatures needed are the in and out air flow temperatures of the evaporator and condenser and also evaporating and condensing temperatures. The air temperatures can be calculated by the known data but evaporating and condensing temperatures are only good guesses because manufacturers don't publish this data. The cooling power ($P_{cooling}$) and the electrical power ($P_{electricity}$) are calculated from (1) and (2) which are functions of the evaporative (t_E) and condensing (t_C) temperatures in °C

$$P_{cooling} = A*\exp(B*t_E)*\exp(C*t_C), \quad (1)$$
$$P_{electric} = D*\exp(E*t_E)*\exp(F*t_C). \quad (2)$$

The parameters A and D can be calculated from the dimensioning data but the rest (B, C, E and F) must be adjusted according to the known data of the specific heat pump. In IDA-ICE there is no tool or advice how to do this. The tuning method used was" trial and error". Clearly there is a need for some tool to help in this work.

2.3 Net Heat Production

The simulation results of the air-to-air heat pump are presented later as net heat production. The net heat production is the gross production of the heat pump reduced by the increased heat losses of the building (Fig. 5). Heat losses of the building increase when the air-to-air heat pump is used at higher room air temperature setting than +21 °C. The principle in the simulations has been that the main heating system maintains the normal room air temperature level (+21 °C) in each room. The room air temperature setting of the air-to-air heat pump must be higher than the normal room air temperature to get any advantage. The used temperature settings of the heat pump (in living room) were 21.5 °C, 22 °C, 23 °C and 24 °C.

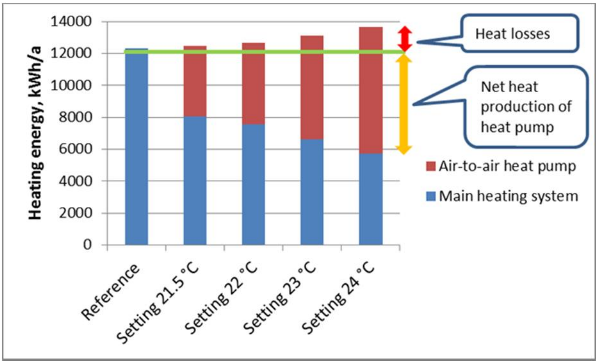

Fig. 5 Total heating energy consumption, net heat production of the heat pump, gross heat production of the heat pump (= net heat production + extra heat losses of the building). The room air temperatures in reference case are +21 °C. The room air temperature setting of the heat pump varies from 21.5 °C to 24 °C.

2.4 Heat Emission Efficiencies

The space heating emission efficiency takes into account the increased heat losses of the building due to the higher room air temperature when using the air-to-air heat pump. The heat emission efficiency of a heat pump is defined (3)

$$\eta_{emission} = 1\text{-}\ (Q_{b,heat\ pump} - Q_b)\ /\ Q_{gross\ production}. \qquad (3)$$

Here $Q_{b,heat\ pump}$ is the heat consumption of the building with air-to-air heat pump, Q_b is the heat consumption of the building without the heat pump, $Q_{gross\ production}$ is the total heat emission of the heat pump.

The total emission efficiency includes also the thermal losses caused by the temperature stratification, resulting in an increased internal temperature under the ceiling and upper parts and possible extra heat losses of heat emitter embedded in the building structure (4)

$$\eta_{total} = \frac{1}{\left(\frac{1}{\eta_{emission}} + \frac{1}{\eta_{strat}} + \frac{1}{\eta_{embed}} - 2\right)}. \qquad (4)$$

In equation (4) the emission efficiency $\eta_{emission}$ is calculated from (3), the stratification efficiency, which was not studied in our work, is by default η_{strat}

= 0.95 and efficiency of embedded system is assumed to be η_{embed} = 1. This method is based on standard EN 15316-2-1:2007 [2].

3. Simulation Results

3.1 Old Building

The layout of the old building is presented in Fig. 1. The annual space heating demand of the old building is very high, 25 MWh/a (185 kWh/m2). The ventilation is mechanical exhaust system without any heat recovery.

The results are presented in figures 6 – 9. Net heat production of the air-to-air heat pump (Fig.6) is the gross heat production minus the extra heat losses of the building due to the higher room air temperature than in the reference case as explained earlier. Annual net heat production varies from 12.5 MWh/a to 17 MWh/a, which covers from 50 % to 68 % of the space heating demand of the building. The higher the room air setting of the heat pump is the higher the heat production is. The total emission efficiency of the heat pump varies from 0.93 to 0.85.

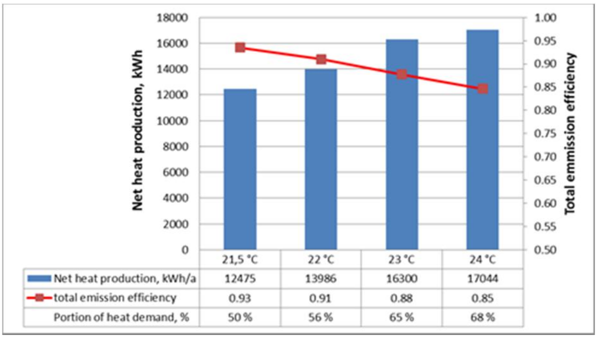

Fig. 6 The net heat production, the total emission efficiency of the heat pump and the proportion of the heat pump of the space heating demand of the building. Results are presented for different room air temperature settings of the heat pump.

The annual net savings of purchased heating energy (= renewable energy utilisation) varies from 8 MWh/a to 9 MWh/a depending on the room air setting of the heat pump (Fig. 7). The renewable energy covers about 32 – 36 % of the space heating demand of the building.

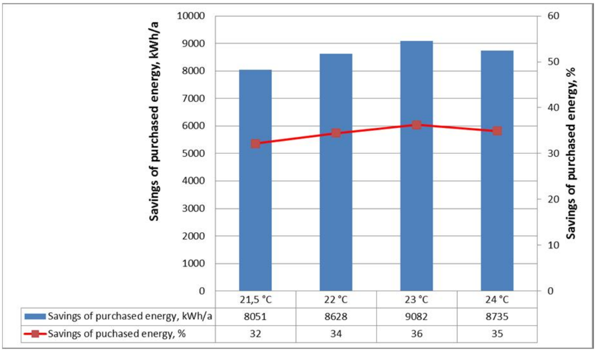

Fig. 7 Net savings of purchased energy (= renewable energy use) with different room air temperature setting of the air-to-air heat pump.

The seasonal coefficient of performance (SCOP) is presented without and with the total emission efficiency of the heat pump (Fig.8). The values with the efficiency are calculated by multiplying the SCOP values with the total emission efficiency presented in Fig. 6.

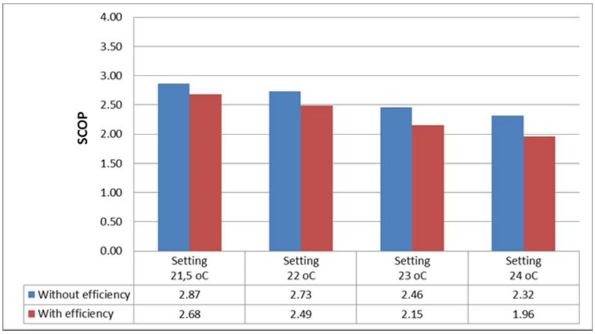

Fig. 8 Seasonal coefficient of performance without and with total emission efficiency. Results are shown with different room air settings of the heat pump.

The heat pump not only heats the space where it is installed but the heat is transferred also to the neighbouring rooms by convection. The higher the room air temperature setting of the heat pump is the higher the convection is. The heat pump can cover practically all of the heat demand of the living room where it has been installed. The doors to the bedrooms are open all the time and thus the heat pump can cover also a reasonable proportion of the heat demand of those rooms (Fig. 9). The doors of the bathroom as well as the other doors are kept closed during the simulation which affect to the heat diffusion. It is reminded that the main heating system maintains the room air temperature in each room at the minimum +21°C.

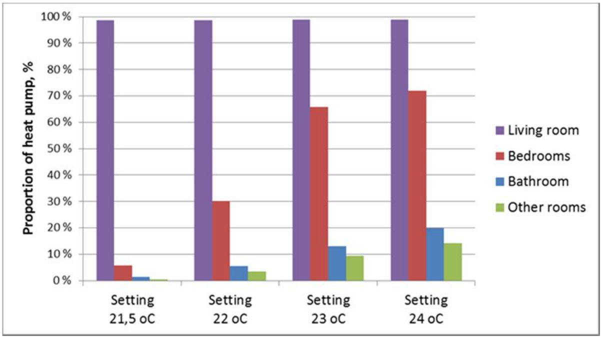

Fig. 9 The fractions of the heat pump of the space heating consumption in different rooms. The results are shown for different room air temperature settings of the heat pump.

3.2 New Building

The layout of the new building is presented in Fig. 2. The annual space heating demand of the building is 9 MWh/a (51 kWh/m2). The ventilation is mechanical supply and exhaust system with heat recovery ($\eta_{recovery} = 0.45$).

The results are shown in Fig. 10 – 13. Annual net heat production (Fig. 10) varies from 4.3 MWh/a to 6.3 MWh/a, which covers 35 % to 51 % of the space heating demand of the building. The higher the room air setting of the heat pump is the higher the heat production is. The total emission efficiency of the heat pump varies from 0.93 to 0.81.

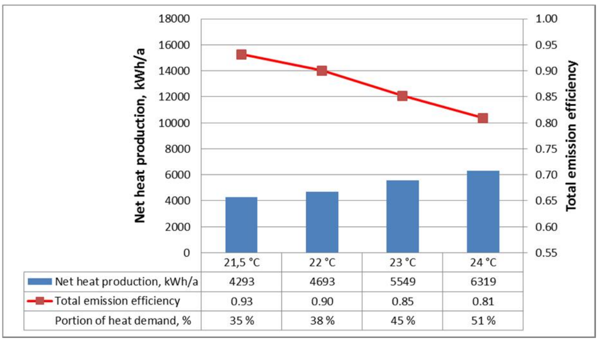

Fig. 10 The net heat production, the total emission efficiency and the proportion of the heat pump of the space heating demand of the building. Results are presented as a function of the setting of the room air temperature of the heat pump.

The savings of purchased annual heating energy (= renewable energy utilisation) varies from 3 MWh/a to 3.9 MWh/a depending on the room air setting of the heat pump (Fig. 11). The renewable energy proportion of the heat pump covers about 34 – 43 % of the total space heating demand of the building.

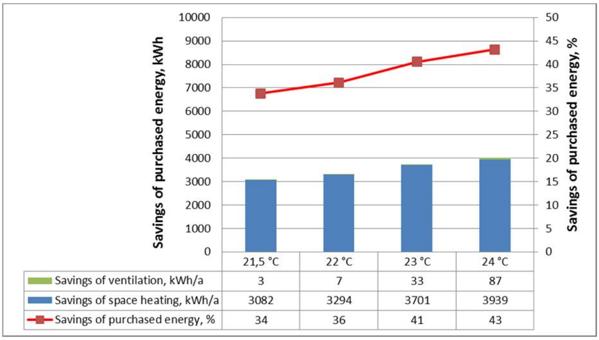

Fig. 11 Savings of purchased energy (= renewable energy use) with different room air temperature setting of the air-to-air heat pump.

The seasonal coefficient of performance (SCOP) is presented without and with the total emission efficiency of the heat pump (Fig. 12). The values with the efficiency are calculated by multiplying the SCOP values with the total emission efficiency (Fig. 10).

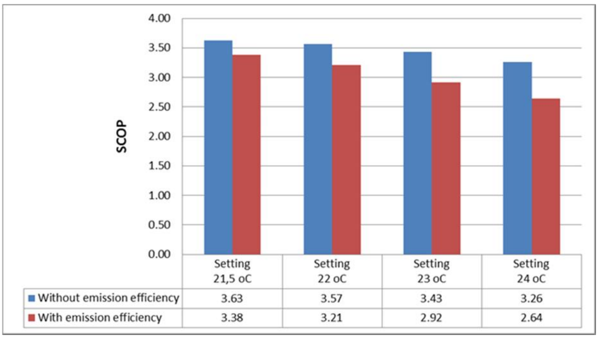

Fig. 12 Seasonal coefficient of performance without and with total emission efficiency. Results are shown with different room air setting of the heat pump.

The heat pump can cover practically all of the heat demand of the living room where it has been installed. The doors to the stairway and to the bedrooms are kept open during the simulations and thus the heat pump can cover reasonable proportion of the heat demand also in those rooms (Fig. 13). The doors of the bathroom as well as the other doors are kept closed during the simulation which affect to the heat diffusion.

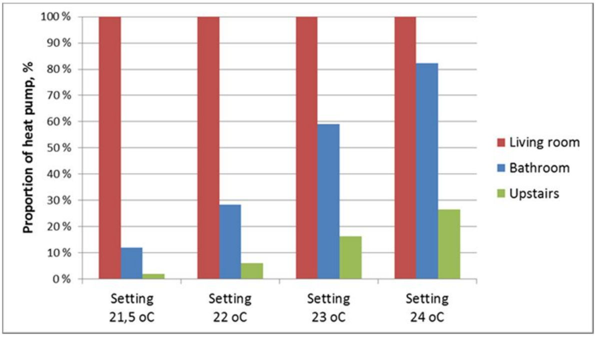

Fig. 13. The fractions of the heat pump of the space heating consumption in different rooms. The results are shown for different room air temperature settings of the heat pump.

4. Simple Method for Determination of Net Production and SCOP

The annual net saving ($Q_{net\ saving}$) of an air-to-air heat pump is defined as a function of the annual net heat production ($Q_{net\ production}$) and the seasonal efficiency factor (SCOR)

$$Q_{net\ saving} = Q_{net\ production} * (1- 1/SCOR). \tag{5}$$

The annual electricity consumption ($Q_{electricity}$) of the air-to-air heat pump is calculated as the proportion of the annual net heat production to the seasonal efficiency factor

$$Q_{electricity} = Q_{net\ production} / SCOR. \tag{6}$$

The annual net heat production of the air-to-air heat pump is a correlation of the specific space heating demand of the building ($q_{building}$) and the coverage area of the heat pump. The coverage area is the floor area of the space where the heat pump is installed bounded by the internal doors ($A_{heat\ pump}$) plus a proportion (b) of the other spaces on the same floor level as the heat pump or the spaces of the floors above (A_{other})

$$Q_{net\ production} = (A_{heat\ pump} + b * A_{other}) * q_{building}\,. \tag{7}$$

However the net heat production of the heat pump can't be higher than the maximum heat production (Q_{max}) calculated from the energy label data. The label includes seasonal coefficient of performance (SCOP) and the annual electricity consumption per year ($Q_{consumption}$). For Finland only values for the northern climate are valid.

$$Q_{net\ production} \leq Q_{max} = SCOP * Q_{consumption} \tag{8}$$

The seasonal efficiency factor (SCOR) includes the seasonal coefficient of performance (SCOP) but also a parameter that takes into account the noise limit of the indoor unit of the heat pump (c) and the total emission efficiency ($\eta_{emission}$)

$$SCOR = (SCOP - c) * \eta_{total} \tag{9}$$

The noise caused by the indoor air unit of the heat pump in a new house can't be higher than our national regulation [5] allows. The sound pressure level has been limited as maximum of 28 (dB). This means that the fan setting of the indoor unit must be limited in most units to the middle setting. This will affect the characteristics of the heat pump which in this simple method is taken into account only in the seasonal efficiency factor.

The seasonal coefficient of performance (SCOP) of the energy label data is valid when the net production is lower than the maximum heat production. In principle the SCOP value varies depending from the net heat production: in nearly zero energy house with low space heating demand the SCOP is high and the net heat production is low whereas in an old building with high space heating demand the net heat production is high but the SCOP is low. This phenomenon is based on the fact that under part load conditions the COP is much better than at full load conditions. For the Finnish climate only the SCOP values of the northern climate can be used.

5. Conclusions

The paper presents net heat production of the air-to-air heat pumps in relation to heating energy demand of the building and corresponding SCOP values and renewable energy use with different settings of the heat pump (+21.5 - +24 °C). The results show also how the heat spreads around the building by convection.

The main result of the study is the proposal for the defining of the energy savings of the air-to-air heat pumps in regulations. The proposed method is simple and doesn't require deep understanding of the behavior of the air-to-air heat pump. The basis of the method is the information given in the energy label and the calculated net energy production of the heat pump according to the relevant room area.

The seasonal coefficient of performance (SCOP) depends clearly on the characteristics of the air-to-air heat pump but also on the part load conditions. This means that in buildings with lower heating demand the SCOP is better than in buildings with high heating demand with the same heat pump which is due to differing part load conditions. The net heat production is not sensitive on the heating power characteristics of the heat pump in the new and nearly zero energy buildings. In the old building with high annual heating demand the low heating capacity of the heat pump may limit the net heat production during the lowest outdoor air temperature.

One phenomenon is that the air-to-air heat pump can cover relatively bigger part of the space heating demand of the building in low energy houses. This can be explained by the fact that the heating power of the heat pump transferred to rooms are not affected by the heating demand of the building but only temperature differences between the rooms. In this perspective it is clear that the same transferring heating power can cover bigger proportion of the heat demand when the demand is low.

It was find out that the air-to-air heat pump model of the IDA-ICE is a bit tricky to adjust for specific heat pump because of so many parameters to be tuned. Also the lack of measured data (heating power and COP) especially at part load conditions, which is often the main operation range, complicates the tuning of the model and increases the margin of error of the results.

Acknowledgment

The work was financed by the Ministry of the Environment, the Finnish Heat Pump Association and VTT.

References

[1] 2010/31/EU, article 5
[2] EN 15316-2-1:2007. Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies - Part 2-1: Space heating emission systems
[3] http://www.scanoffice.fi/
[4] http://www.energimyndigheten.se
[5]Suomen rakentamismääräyskokoelma. C1Ääneneristys ja meluntorjunta rakennuksessa. Määräykset ja ohjeet. 1998.