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The effect of heating systems on dust, an indoor climate factor

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Abstract. As people stay approximately 90% of the days indoors, so they are affected by indoor environment. Indoor air quality for humans is even more important than outdoor air quality. The most important factors for shaping indoor climate, for example air temperature and air quality factors, such as various chemical and biological factors of air cleanliness – humidity and dust.

One of the working environment risks is dust which can be found everywhere in the air. Dust is a general name for solid particles with diameters smaller than 75 micrometres. Dust in homes, offices, and other human environments contains human skin cells, small amounts of plant pollen, human and animal hair, textile fibres, paper fibres, minerals from outdoor soil, and many other materials which may be found in the local environment. Dust may worsen asthma, hay fever, rhinitis, bronchitis, and allergy.

The aim of the research was to improve indoor climatology with different heating systems and to analyse, synthesise, and assess indoor climate parameters. The study methods were based on measurement of dust, temperature, relative humidity, and air velocity. Maximum dust concentration (11.39mg m^{-3}) in the air space was observed in conditions guaranteed by ground source heat pump, as the floor is warm and warm air moves upwards, spinning floor dust into the air. The lowest dust concentration (2.08mg m^{-3}) in the air space was observed in conditions guaranteed by remote heating system; none of the measurements exceeded the permissible limit. Air source heat pump provided for conditioning of the measured dust levels. The results were small (mean 6.1mg m^{-3}) and did not exceed the permissible limit in most cases. Dust content of all the heating systems was on the average score of 0.1m more than 3.4% higher than at 1.5m. Dust particles are divided into superfine particles, fine particles, and coarse particles. Most superfine particles occur in the average air measuring height (0.87m). Alternative heating systems, such as air source heat pump and ground source heat pump are becoming very popular nowadays, but we do not know yet their impact on indoor climate and our health.

Key words: indoor climate, dust, alternative heating systems, air source heat pump, ground source heat pump.

INSTRUCTION

Alternative heating systems, such as air and ground source heat pumps are becoming popular nowadays; more and more of these are being installed in private houses and enterprises. The use of renewable energy is a key to solving global energy problems, but as the technological solutions are rather novel, it is not known at present how these heating systems affect above all the indoor climate and through our health.

The selection of heating systems has an impact on room environment, air quality included. We spend time indoors approximately 90% of a twenty-four hour period and we are influenced by its room environment, which is important why the rooms need to have high-quality indoor climate: this will affect our health, working capacity, and how we feel. The most important parts of indoor climate are the thermal conditions, air temperature and draught in the room together with factors influencing air quality, such as various chemical and biological factors of air cleanliness, like air humidity, and dust (Seppänen & Seppänen 1998). Dust, the risk factor in living and working environment poses a problem both in industrial environment and home conditions. Dust is such a dispersion level of solids in which substance particles, i.e. dust particles float in the air for some time. The diameter of the solid particles is generally less than 75μm (Estonian Standard, 2006). The dust which floats in the room air space consists of particles of different sizes which settle more slowly the smaller they are. Most of the solid particles in the air are invisible to the human eye but their effect on human health is most hazardous. The floating dust in room air has come from the room itself and from outside air. Indoor dust is described as the dispersed distribution of solid material in indoor air. It may consist of both inorganic and organic particles as well as fibres of different sizes and can be very heterogeneous with regard to quantity and composition. Indoor sources include smoking and combustion processes, fibres from paper, wood and textiles, the occupants themselves, their pets, and activities taking place in the residence (Nilsson, 2004). Soft fitted carpets gather dirt that dries and turns into powder which is lifted up in the air as dust (Angelstok, 2006). The greatest health deterioration by dust is caused by means of respiratory organs. Dust passes through the nose, the pharynx and the larynx, moving via the trachea to the bronchi and finally to the pulmonary alveoli. The superfine dust particles are the most hazardous, causing cardiovascular and pulmonary diseases, e.g. asthma, bronchitis, allergy, or kaolinosis. The superfine dust particles (smaller than 1μm) form the majority of the overall dust amount and float in the air the longest. The health hazard of dust depends on its physico-chemical properties: solubility, particle size, form, solidity, electric charge, which is why it is essential to have science based information of the impact of novel heating systems on indoor climate, including dust, in order to achieve a comfortable, good, and healthy environment around us. The aim of the paper was to analyse, synthesise and assess correlation between dust measurement results and different heating systems in order to improve indoor climatology. To achieve the aim, the following tasks have been solved: classification of heating systems, selection of measuring method and equipment for indoor climate, selection of meters, dust measuring, data processing with software Microsoft Office Excel, and making a summary.

METHODS

The research objects were the applied heating systems and the indoor climate together with dust, its component at the Heat Pump and Indoor Climate Laboratory in the building of Institute of Technology at Estonian University of Life Sciences. The surface area of the laboratory is 32.49m², height 3.23m and volume 104.94m³. In the middle of the room there are workplaces for 10 students and teachers for conducting lectures. Two of the six windows in the room can be opened; the windows are covered with lamella curtains and can be opened in two ways: by tilting and turning. To measure dust content in the air, the GRIMM dust monitor model 1.108 has been used which measures 15 different dust fractions 0.3…20μm (mean dust particle length being 4.8μm) and mass of dust 0.1…100,000μg m^{-3} (Tragbare Staubmessegeräte, 2005). In order to get reliable results according to the theory of experiment planning (Мельников et al., 1980), a confidence probability of $\alpha = 0.95$ was chosen. To achieve the established level, the following was taken into account: technical data of measuring equipment, sensor measurement error and acceptable error for electronic measuring equipment $\varepsilon = 0.4\ \sigma$, where σ is Root Mean Squared Error deviation, considering also the meter's accuracy class. Measurement of dust content in room occurred in four points of measurement at three heights: 0.1m, 1.0m, and 1.5m; the obtained values were compared to the reference values of dust content 10mg m^{-3} (Estonian Government Regulation, 2001). Altogether 20 measuring operations were performed in the conditions of laboratory indoor climate, guaranteed by different heating systems. During each measuring operation, dust was measured in four points of measurement, where the meter recorded each point of measurement at each measuring height (0.1m, 1.0m, 1.5m; mean measuring height 0.87m) and at least 50 measurement results with a 6 second interval. The measurements were carried out in cold season (a season with mean daily outdoor temperature +10 ºC and below), when outdoor temperature was within 0…-14.4 ºC, relative outdoor humidity 68…98%. Numerical values of room microclimate parameters were measured as a reference basis: air temperature ϑ_S, air velocity v_S and relative humidity $W s_S$, as these indices are related to dust (Table 1). Resulting from work specification by physical load based on general human energy expenditure, the study carried out at the lab can be qualified as light physical work, the energy expenditure of which amounting to 500kJ h^{-1} (category Ia). According to operational category Ia, the optimum room temperature in cold season is 20…24 ºC, which is a basis for the choice of temperature mode of heating systems. The optimum relative humidity of air is 40…60% and the optimum air velocity is 0.1m s^{-1} (Estonian Government Regulation, 1995). The two doors and windows were closed during the measuring. In between the measuring, the room was aerated and all windows that could be opened and all doors were kept open at least 10 minutes. Dust content in the air was measured during the operation of different heating systems, but only one heating system or its special mode was operating at a time. Two heating systems were alternative and novel. These were the ground source heat pump (floor and radiator heating) and the air source heat pump. The third one, district heating, was used separately as a reference basis. The ground source heat pump as an alternative heating system harvests energy from the ground; in summer the sun heats the ground surface and in winter the solar energy stored in the ground is pumped with the help of ground source heat pump into the room heating technology (Straube, 2009). The ground source heat pump Booster SP could be used in two variants as it operates on floor and radiator mode. In case of floor heating of the ground source heat pump, heat transmission into the room occurs through heating pipes installed into the floor structure; as for radiator heating, there was a finned tin radiator in the middle of the wall under the window.

Table 1. Measurement time and conditions.

	Conditions					
Measuringtime	**Heating mode**	**No. of people**	**Room aeration**	**Aeration length** min	**Micro-climate** ϑ_s, v_s, Wss °C, m s^{-1}, %	**Outdoor climate** ϑ_v, v_v, Wsv °C, m s^{-1}, %
1	2	3	4	5	6	7
04.02.2009	Floor heating (ground source heat pump)	2	Unaerated	-	24.8 0.13 28	-13.2 1.1 84
04.02.2009		3	Aerated	10	24.9 0.14 29	-13.2 1.1 84
05.02.2009		8	Aerated	15	23 0.14 29	-7.8 2.97 86
06.02.2009	Radiator heating (ground source heat pump)	10	Aerated	15	20.5 0.14 28	-5.5 1.2 90
09.02.2009		3	Unaerated	-	23 0.14 37	0.0 1.4 100
09.02.2009		6	Aerated	15	23 0.14 37	0.0 1.4 100
11.02.2009	Air source heat pump 24 °C	2	Aerated	10	23.8 0.14 26	-7.8 1.1 97
11.02.2009		2	Unaerated	-	22.9 0.15 26	-6.7 1.6 98
13.02.2009	Air source heat pump 24 °C	7	Aerated	15	23.3 0.15 29	-0.4 1.4 98
20.02.2009	Air source heat pump 22 °C	11	Aerated	15	22 0.16 29	-5.6 3.5 84
22.02.2009	Air source heat pump 22 °C	1	Unaerated	-	22.7 0.17 26	-4.3 3.2 68

Table 1 to be continued.

1	2	3	4	5	6	7
22.02.2009	Air source heat pump 22 °C	1	Aerated	10	22.7 0.17 26	-4.3 3.2 68
17.02.2010	Floor heating (ground source heat pump)	2	Unaerated	-	22.5 0.14 17	-14.4 2.6 80
17.02.2010	Floor heating (ground source heat pump)	2	Aerated	10	22.2 0.14 21	-14.4 2.6 80
26.02.2010	Radiator heating (ground source heat pump)	2	Unaerated	-	21.2 0.06 21	-2.4 2.8 87
26.02.2010	Radiator heating (ground source heat pump)	2	Aerated	10	21.2 0.06 21	-2.4 2.8 87
08.03.2010	Air source heat pump 22 °C	1	Unaerated	-	21.8 0.06 20	-5.1 2.1 72%
08.03.2010	Air source heat pump 22 °C	1	Aerated	10	21.3 0.05 21	-5.1 2.1 72
16.03.2010	District heating	2	Unaerated	-	22.4 0.05 20	-6.2 1.5 71
16.03.2010	District heating	2	Aerated	10	21.4 0.04 21	-6.2 1.5 71%

The air-to-air source heat pump ASYA09LCC used in room utilises outdoor air as energy source; outdoor air is cooled down with the help of compressor and refrigerant in an outdoor device (Daghigh et al., 2010). During the operation of air source heat pump its temperature modes at 22 °C and 24 °C were used to guarantee conditions complying with work category Ia in the room. District heating system consists of a heating plant, pipelines, fittings, and heating elements or cast iron radiators which have been placed under the window into niches close to longitudinal walls of the room. On ground source and air source heat pump modes, dust content in the air was measured also during study work.

RESULTS

Heating system structures influence the movement of air in the room which is directly connected with the movement of dust in the room. With the help of a ventilator in the wall panel of air source heating system's air source heat pump the air is being moved the most; thus, the air is moving actively in the room and due to this stirs up dust from different surfaces, as air velocity increases. As a result, dust content in the room air may increase. The structure of the ground source heat pump's radiator is finned with air moving upwards along the fins; from the radiator surface, contact with higher temperature generates air convection upwards. Without hitting the bottom surface of the window sill, dust content in the room air may increase. The floor heating system of the ground source heat pump heats the floor surface. The room floor is warm and warm air moves up, lifting dust upwards from the floor and equipment and bringing dust into the zone of human respiratory organs. The cast iron radiators of the district heating system had a different structure than that of the radiator used with the ground source heat pump. In a cast iron radiator, heat moves between the fins both horizontally and out of the ends and fins and straight upwards. Air velocity is slower, which is why dust will not volatilize, and secondly, when it moves upwards, it will hit the bottom surface of the window sill, causing part of the dust to land back on the radiator and floor surface. It is also noteworthy that the position of the cast iron radiators (in niches under the windows) differs from that of the tin radiator, which is why air movement in the room may be completely different.

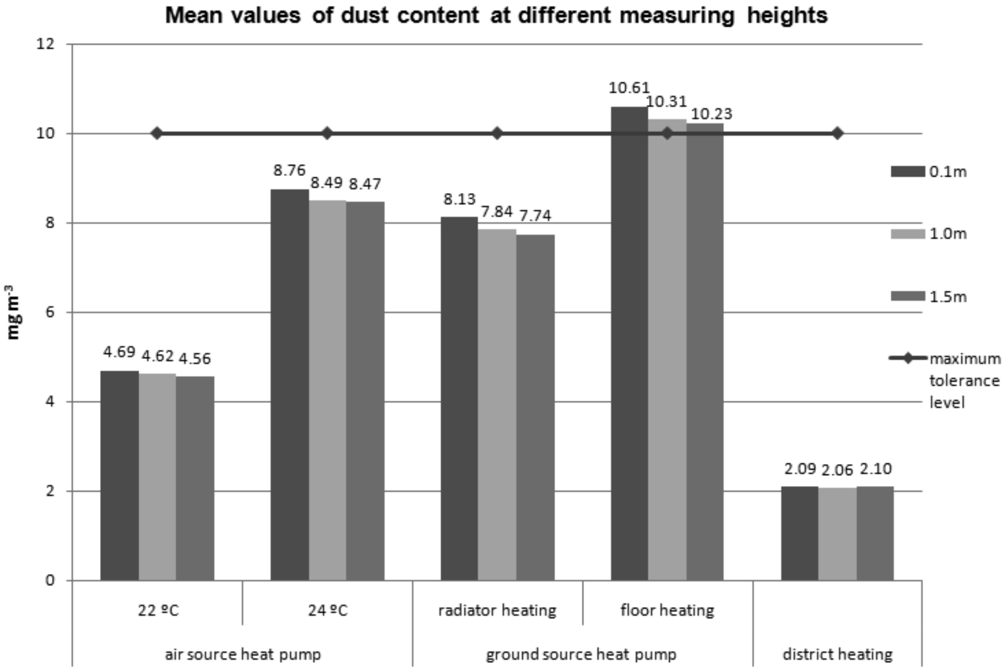

Figure 1. Mean values of dust content at measuring heights 0.1m, 1.0m and 1.5m in case of different heating systems.

The mean results of dust content per all heating systems were 3.4% higher at 0.1m height than at 1.5m height (Fig. 1). Dust content was higher at floor level than in the respiratory zone. The greatest height difference could be noted at the radiator heating mode of the ground source heat pump with mean dust content at 0.1m height 4.8% higher than at 1.5m height and at floor heating mode where dust content in the air at 0.1m height was 3.6% higher than at 1.5m height. The slightest height difference in dust content could be noted in case of district heating system (1.9%). The maximum mean dust content at 0.1m height was 68.6 % of the standard and the minimum at 1.5m height was 66.2% of the standard. Higher indoor air concentrations of sedimented dust in rooms with coal burning and open fireplace are more than in homes with district heating system (Moriske et al., 1996).

As for dust content, district heating proved to be the best heating system, guaranteeing indoor climate conditions with the lowest dust content in the air (Fig. 2). In indoor climate conditions guaranteed by district heating, the mean dust content was 2.08mg m^{-3}, making 20.8% of the standard, without the measurement result surpassing the maximum tolerance level in none of the cases. The highest dust content (11.39mg m^{-3}) in the room air could be noted in conditions guaranteed by floor heating of the ground source heat pump, as the floor is warm and warm air moves upwards, stirring up dust from the floor and equipment. In conditions guaranteed by floor heating had high dust mite numbers, indicating that this type of heating system is compatible with a thriving dust mite population (de Boer R, 2003). As for dust, the most dangerous alternative heating system for human health is to guarantee indoor climate with floor heating of the ground source heat pump, as out of the measured results only 40% met the standard; furthermore, the general dust content in the room air was very high. During the working modes of alternative heating systems, the lowest measured dust content could be noted in indoor climate conditions guaranteed by air source heat pump where the measured dust content results were below the permitted level (average 6.1mg m^{-3}) in most cases. In conditions guaranteed by the air source heat pump, dust content is highest while people are in the lab and during study work. With their activities, people make the dust move; furthermore, the air source heat pump in its turn moves the hovering particles and stirs them up from different surfaces. In indoor, conditions guaranteed by the air source heat pump (air temperature 20…24 °C), the measured dust content stayed within the standard in 87.5% cases.

Consequently, the air source heat pump is a more acceptable heating system in relation to dust as during its operating mode, the dust content in the air is low. In indoor conditions guaranteed by radiator heating of the ground source heat pump, measurement results indicate that due to people, dust content in the air increases by 33.9%. In indoor conditions guaranteed by the air source heat pump at temperature modes 22 ºC and 24 °C dust content measurement results indicate that dust content in the air increases by 28.9% due to people.

In conditions guaranteed by radiator heating of the ground source heat pump it is not useful to aerate the room as each measurement proved that dust content measured after room aeration was higher than that of dust content in an unaerated room. Room aeration did not give positive results due to the fact that dust from nearby highway (~100m) flew into the lab through the window and draught stirred up dust from the lab equipment, raising dust concentration in the room by almost 50%.

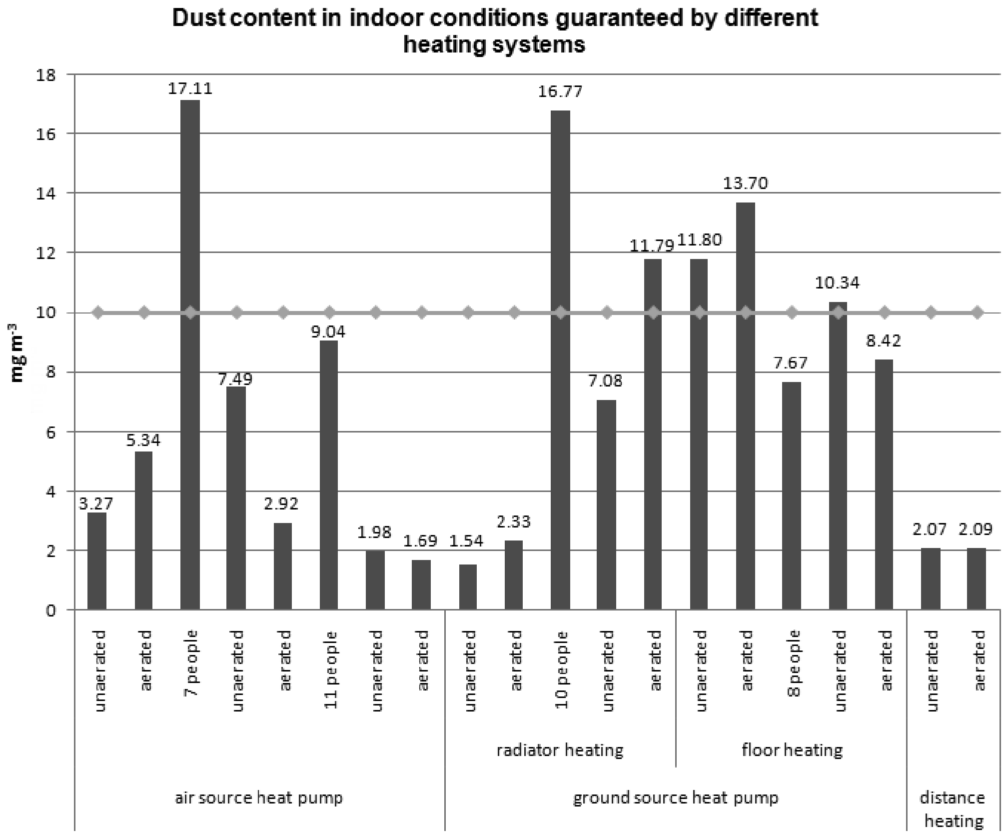

Figure 2. Mean dust content at average height in indoor conditions guaranteed by different heating systems.

Superfine particles are dust particles, the size of which is less than 1µm; their order of magnitude can be divided into five measurement groups: 0.3µm, 0.4µm, 0.5µm, 0.65µm, and 0.8µm (Fig. 3). These kinds of particles easily find their way into the lungs, causing health problems for people. Superfine dust particles of the size below 1µm can mostly be found in cases when there are people in the room whose activities cause air to move, lifting thus dust particles. Fine particles can be divided into three measurement groups with order of magnitude 1.0µm, 1.6µm, and 2.0µm. Fine particles stop in human bronchi and bronchioles and may cause various respiratory diseases. Course particles are dust particles of the size 3.0µm, 4.0µm, 5.0µm, 7.5µm, 10.0µm, 15.0µm, 20µm and bigger.

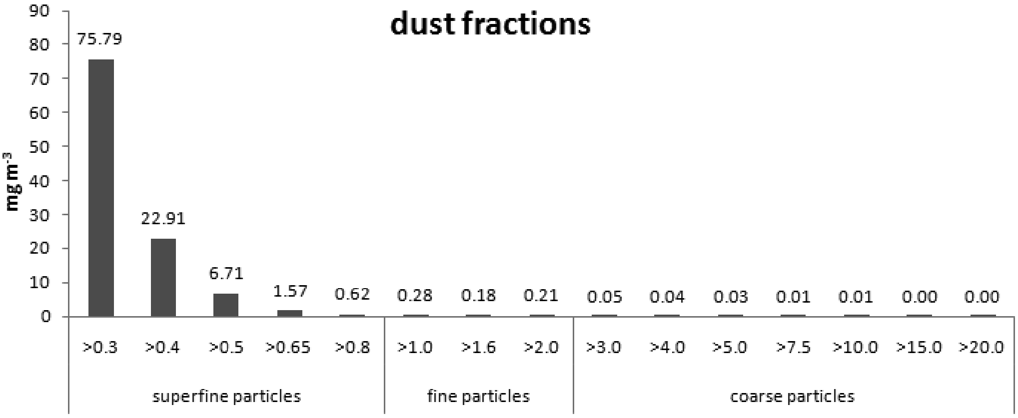

Figure 3. Mean dust content by fractions at average measuring height 0.87m in indoor conditions guaranteed by all heating systems together.

The order of magnitude of course particles can be divided into seven measurement groups. Very few or almost no course particles can be found in the air of the room. Course particles may be visible in the air of the room. As the mean mass of course particles has been transformed into mg m^{-3}. Fig. 3 does not display dust particles of 15µm and 20µm length. The sizes of dust particles in indoor conditions guaranteed by all heating systems showed that the smaller the dust particle sizes, the more they can be found in the air of the room. Course particles with the greatest number of measurement groups can be found the least in the air of the room.

CONCLUSION

Dust content measured in indoor conditions guaranteed by district heating, air source heat pump, and radiator heating of ground source heat pump stays within the standard, which is why it is practical to use these heating systems in buildings. Floor heating of ground source heat pump should be excluded as dust content is greatest in indoor conditions guaranteed by floor heating (113.9% of the standard). If one has the ground source heat pump installed and wishes to use floor heating, it would be wise to use it in moist rooms where people do not stay long, such as bathroom, garage, sauna, and toilet. Mean results of dust content per all heating systems at 0.1m height were 3.4% higher than at 1.5m height. Superfine dust particles (with sizes 0.3µm. 0.4µm. 0.5µm. 0.65µm. and0.8µm) can be found the most in the air of the room (at average measuring height 0.87m) and these are most dangerous for human health as they penetrate deep into the lungs, causing health problems. It does not always give positive results to aerate the room in order to avoid dust content in the air of the room. In this case, dust flew into the room from the window which opened towards the street or highway; in addition, draught stirred up dust from the equipment of the room, causing dust concentration to increase almost by 50%. In order to decrease dust content in the air of the room, various collective technical protective equipment should be used at dust source, e.g. to implement adequate cleaning according to hygiene requirements.

One solution could be the use of humidifiers (e.g. hydro-air ioniser), as increase in air humidity can decrease dust content in the air to some degree. If technical measures for avoiding dust are not adequate, personal protective equipment must be applied.

REFERENCES

Seppänen, O., Seppänen, M. 1998. Hoone sisekliima kujundamine. Tln. Koolibri. – 270 (in Estonian).

Õhu kvaliteet. Üldosa: sõnastik. 2006. Eesti Standard. EVS-ISO 4225:2006 Eesti Standardikeskus. – 18 (in Estonian).

Nilsson, A. 2004. Novel Technique for Analysing Volatile Compounds in Indoor Dust. Linköping University. – 65.

Angelstok, F. Ventilatsiooni alused. 2006. Sisekaitseakadeemia. Available: http://riksweb.sisekaitse.ee/index.asp?action=127&id=260 (in Estonian).

Grimm Aerosoltechnik. Tragbare Staubmessegeräte. Deutschland 2005.–71.

Мельников, С. В., Алешкин, В. Р., Рощин, П. М. 1980. Планирования эксперимента в исследованиях с/х процессов. Л.: Колос. 168 с.

Töökeskkonna keemiliste ohutegurite piirnormid. Määrus. Vastu võetud 18.09.2001 (RT I 2001. 77. 460) (in Estonian).

Tööruumide mikrokliima tervisekaitsenormid ja –eeskirjad TKNE-5/1995. Määrus. Vastu võetud 28.12.1995 (RTL 1996. 13. 98) (in Estonian).

Straube, J. 2009. Ground Source Heat Pumps (‘Geothermal’) for Residential Heating and Cooling: Carbon Emissions and Efficiency. *Building Science Digest* 1–11.

Daghigh, R., Ruslam, M. H., Zaharim, A. and Sopian. K. 2010. Air Source Heat Pump System for Drying Application. *System Science and Simulation in Engineering* **9** (63). 404–409.

Moriske, H. -J., Drews, M., Ebert, G., Menk, G., Scheller, C., Schöndube, M. and Konieczny, L. 1996. Indoor air pollution by different heating systems: coal burning, open fireplace and central heating. *Toxicology Letters* **88** (1–3). 349–354.

de Boer, R. 2003. The effect of sub-floor heating on house-dust-mite populations on floors and in furnituure. *Experimental and Applied Acarology*, **29**, (3–4). 315–330(16).