BUILDING MASS USED AS SHORT TERM HEAT STORAGE

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ABSTRACT
Daily variations of the heat demand in a district heating system increase the heat generation cost due to the marginal use of more expensive fuels. The use of building masses as short term heat storage has been investigated by Göteborg Energi. The possible heat storage and the prevailing conditions have been estimated. Field measurements have been performed for verification. The preliminary results show that the daily load variations at system level can be eliminated with building masses as active short term heat storage.

GÖTEBORG DISTRICT HEATING SYSTEM
The Göteborg district heating system reaches over three municipalities; Göteborg, Partille, Ale, and is also hydraulically connected to the Mölndal district heating system. The trench length is 1056 km long (Mölndal not included) and has a water volume of 66650 m^3. The heat is delivered in 17860 substations, of which 11250 are installed in single family houses.

There are about 15 different heat production plants with a maximum heat generation capacity of over 1900 MW in the system. Three of the production plants are combined heat and power plants.

Daily variations in heat demand
The daily variations of the heat demand in Göteborg district heating system have been illustrated in Andersson, Werner (2006a). Fig. 1 describes the daily variations for each month relative to the annual average heat load and fig. 2 describes the daily variations relative to the average monthly heat load.

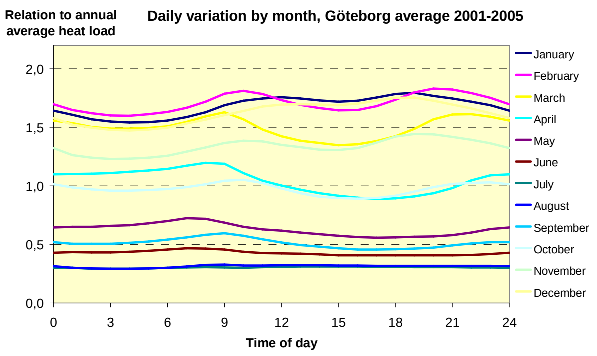

Fig.1. Monthly average daily variations of heat load in Göteborg compared to the annual average heat load.

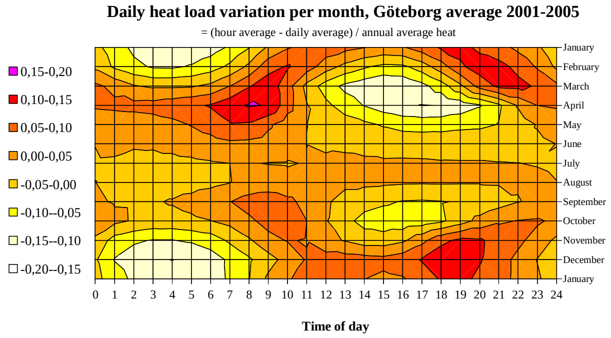

Fig.2. Daily variations of heat load in Göteborg, 2001-2005. (Amplitudes and month versus time of day.)

Fig.1 and 2 show that during the years 2001-2005, the difference between maximum and minimum daily heat load is substantial during the heating season. The social behavior of the residents causes peaks in heat load in the morning and in the evening. The variations are largest in the spring months March and April when the difference between night and day outdoor temperatures is large. During the summer months, when the hot water load dominates, the difference between maximum and minimum daily heat load is very low.

In March and April, the largest difference between maximum and minimum heat load is about +-0,15 times the annual average heat load which together is 30% of 430 MW = 130 MW. Since there are no hot water accumulators in the Göteborg district heating system, starting and stopping heat generation plants is necessary several times a day as well as using the water mass in the piping system as energy storage by varying the supply temperature.

HEAT STORAGE
A district heating system consists not only of the piping system, production plants and substations, but also of the buildings with their radiator and hot water systems and also the building masses. Using building masses (including the energy storage in the radiator piping system) as short term energy storage is an opportunity that seems promising and possibly more cost efficient than constructing large separate hot water accumulators.

Short term heat storage could be of great use in reducing daily variations in heat generation and also in case of failure in a heat plant. If there is building mass heat storage with accumulated heat available, it might be possible to reduce the hours of auxiliary heat production.

Demand side management (DSM) has been investigated by (Wigbels, Bøhm & Sipilae, 2005). Both calculations and measurements were made in the district heating system of Jyväskylä. The maximum possible reduction of total heat load in the district heating system was estimated to 25% when DSM was applied in all of the buildings simultaneously.

BUILDINGS AS SHORT TERM HEAT STORAGE

The potential of using building masses as short term energy storage in Göteborg district heating system has been theoretically investigated in (Andersson & Werner, 2006b). The conditions for the calculations were:

- Total annual heat load of 3500 GWh/year
- 3037 degree days in Göteborg
- 25% of the heat load is available as heat storage
- 25% of the heat load is used for hot water preparation

For these conditions, the available heat power is 9-54 MW as shown in fig.3, when the induced change of the outdoor temperature is between 1 and 6 ℃.

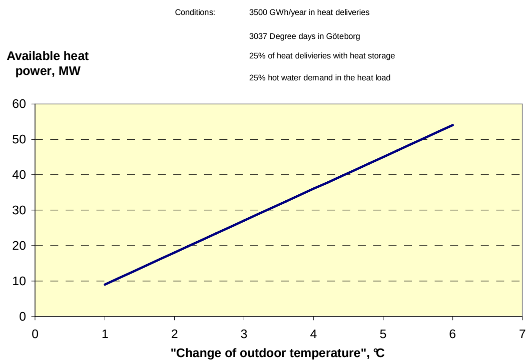

Fig.3. Available heat generation for induced changes in the outdoor temperature (heat power versus change of outdoor temperature). (Andersson & Werner, 2006b)

The maximum time for the heat storage in operation is determined by the permitted change in the indoor temperature in the apartments. With different reduction limits in room temperature, the heat storage can be active during the time illustrated in fig 4. The time constant is assumed to be 100 hours. Longer time constants will give longer active storage times. The actual heat storage potential is described in fig. 5.

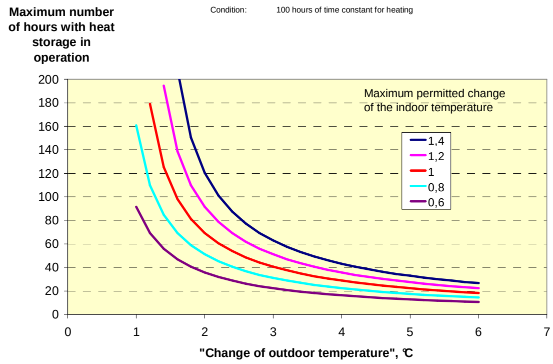

Fig.4. Maximum time for heat storage discharge for different permitted changes in indoor temperature and different induced changes of the outdoor temperature. The time constant is 100 hours. (Andersson & Werner, 2006b)

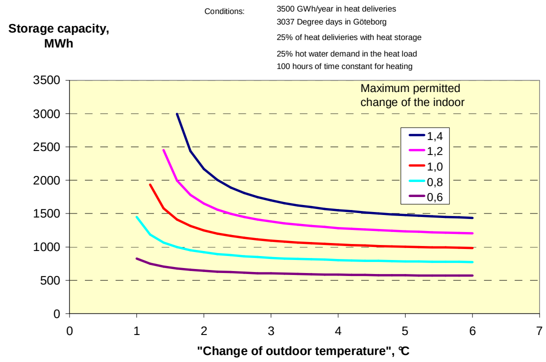

Fig.5. Size of heat storage for different changes in indoor temperature and different changes of outdoor temperature. The time constant is 100 hours. (Andersson & Werner, 2006b)

The calculations presented in fig. 3-5 give indications of large heat storage potentials without causing any substantial decrease in residential comfort. The daily variations in March and April of +-0.15 times the annual average heat load (+-65 MW) can be eliminated by shifting the outdoor sensor with approximately 7.5°C (extrapolating the results in fig. 3). This heat storage can be active about 10 hours and still not reduce the indoor temperature with more than 1℃ (extrapolating the results in fig 4). To reduce the morning heat load peak in April – this building mass heat storage is of sufficient size – and the building mass heat storage can be recharged during the afternoon.

MEASUREMENTS

In order to investigate the real influence of building mass heat storage on the indoor temperature and determine the actual time constant, field measurements have been performed in some typical residential buildings:

- wooden building of three floors with stone foundation (“landshövdingehus”), (R-road 1B, 5, 9, 9A)
- large stone buildings of 4-5 floors (J-street 9C, R-street 15)

- towerblock buildings of 8 floors (Q-street 2, 4 ,6 ,8)
- newly built towerblock, residential building: 72 apartments in 14 floors, 8000 m^2 (OD-road 12) (2006)
- old brick office building (G-street) (renovated 2000, 10000 m^2)

All of the buildings have district heating as heating source. The heat load for domestic hot water was not changed during the tests.

The indoor temperatures were measured in 1-2 rooms of 3-5 apartments in every staircase. The temperatures were registered with small temperature loggers (Intab) every five minutes, and the measurements were conducted during approximately five days. Since the initial room temperatures in the apartments were not known, the measuring period started, in some of the test objects, with a day of increasing the room temperature followed by reduction of delivered heat to the building. The time constants of the buildings were evaluated for that day. The reduction of delivered heat was followed by a day with recharging the room temperature at a higher heat power than normal. All heat deliveries were normal during day five.

The selection of apartments, in which the indoor temperatures were measured, were made by operating technicians, with knowledge of which of the residents were available for contacts regarding the temperature loggers.

The heat load was changed by shifting the radiator supply temperature curve in appropriate magnitudes. The shifting was done manually by an operating technician and differed between the measured periods and measured objects. The time constants were estimated with actual changes in the control system.

Heat loads and outdoor temperatures were registered every hour.

Wooden building

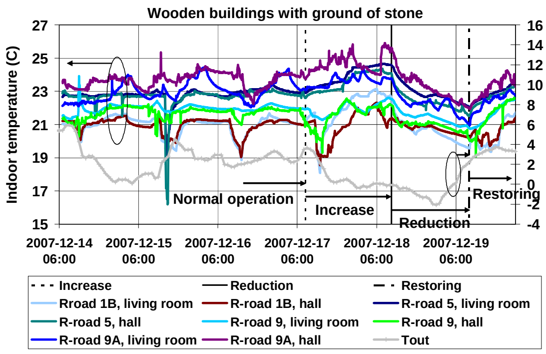

Fig. 6. Indoor temperature at R-road.

Fig. 6 illustrates that the indoor temperature was originally unevenly distributed within the building. The residents in the apartment at R-road 1B, had about 3℃ lower normal temperature than the residents in the apartment at R-road 9A. The variations in indoor temperature, within one apartment, were in the magnitude of 2-3℃. The short term reductions in in door temperature during normal operation period, is believed to be caused by open windows. The uneven distribution in indoor temperature, both between apartments and in time, indicates that thermostatic valves were not active.

During the reduction period the indoor temperature declined with an average of 2.4℃.

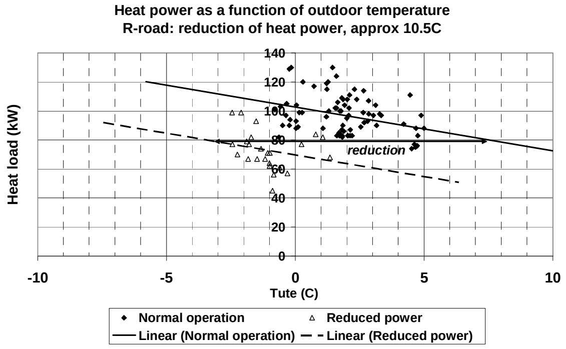

Fig. 7. Reduction of heat power during the reduction period.

During the testing period, the delivered heat power was reduced according to fig. 7. The average of the time constant of the building was estimated to 102 hours.

All of the addresses at R-road are connected to the same district heating substation.

Stone buildings

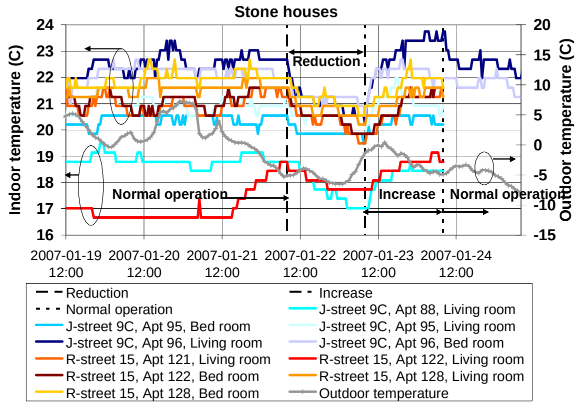

Fig. 8. Indoor temperature at J-street and R-street.

The indoor temperature differs between the apartments at both J-street 9C (red nuances): 17ºC to 22ºC and R-street 15 (blue nuances): 19ºC to 24ºC. This measurement was performed with temperature loggers of low resolution, why the details of normal variations of the room temperature, was difficult to analyze. However, the resolution was enough to evaluate the time constants.

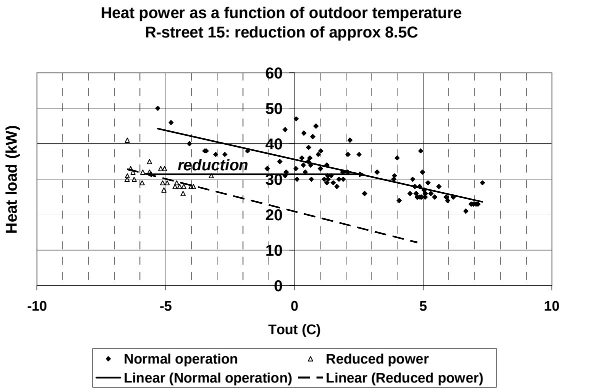

Fig. 9. R-street 15. Reduction of heat power during the reduction period.

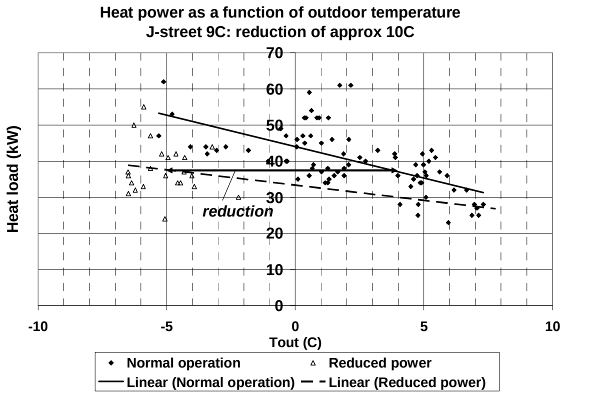

Fig. 10. J-street 9C. Reduction of heat power during the reduction period.

The input outdoor temperature for the control system was increased with 10ºC at both J-street and R-street. The average time constants of R-street 15 and J-street 9C were both estimated to 155 hours.

Towerblocks

The towerblocks at Q-street 2-8 were tested during two periods. The first time, there was no measurable difference in indoor temperature in the day when the heat power was reduced in the substation. Therefore the measurements were repeated, but the heat power reduction now lasted for two days (fig.11). During this period, the values of exhaust air temperature was also noted for comparison (fig.12).

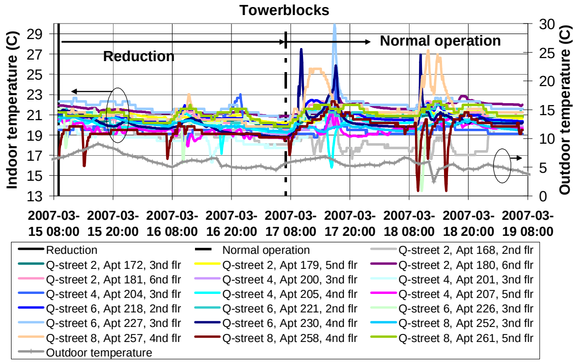

Fig. 11. Indoor temperature at Q-street 2-8.

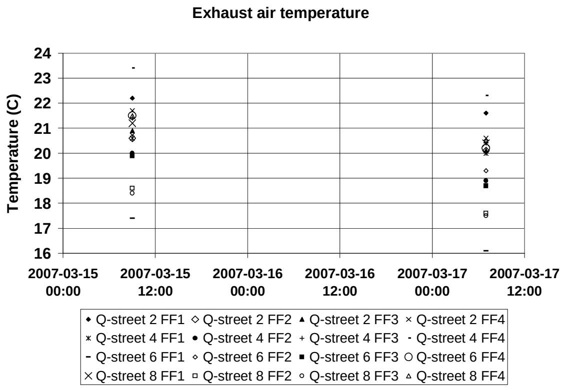

Fig. 12. Exhaust air temperature at Q-street 2-8.

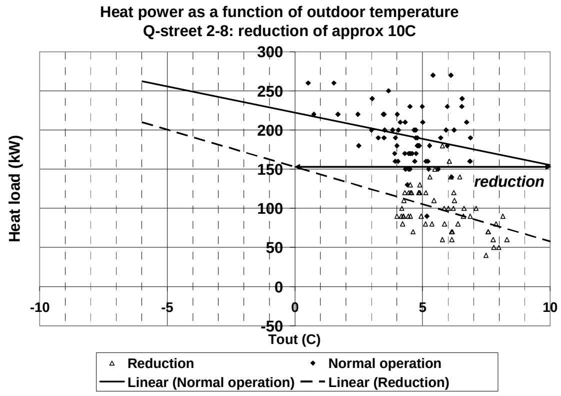

Fig. 13. Q-street 2-8. Reduction of heat power during the reduction period.

The input outdoor temperature for the control system was increased with 10ºC. The two day reduction period gave a total average time constant of 330 hours measured with the temperature loggers. For exhaust air sensors, the temperature differences are somewhat lower, which gives higher time constants: total average time constant based on exhaust air sensors was 486. These values are so high that a suspicion of internal heat sources arises. The ventilation system supply air was meant to be unaffected by the reduction of heat power delivered to the substation. It should not increase the heat delivered by the ventilation system during the testing period. The measured reduction in heat power delivered to the substation was of expected size, which indicates that there were no extra heat deliveries with the ventilation system unless the ventilation system was connected to another heat source than district heating. No such evidence has yet been found.

Measurements have also been made in a newly built towerblock (built in 2006). The apartments have individual metering of energy for hot water, heating and electricity. Since the building is new, the thermostatic valves should be more active and functional. Fig.14. illustrates the indoor and outdoor temperatures and fig. 15 illustrates the changes in heat power levels.

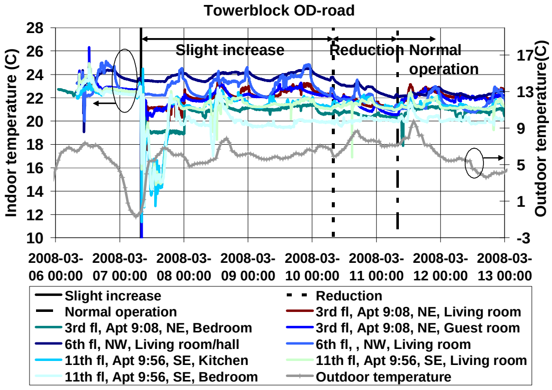

Fig. 14. Indoor temperature at OD-road.

At the same time as the heat power was increased, the outdoor temperature increased rapidly. Especially in the apartments in the east, the room temperature decreased in a very short time. This rapid change in room temperature was probably the result of closing thermostatic valves and/or open windows, due to influence of the rising sun. The low indoor temperatures were proceeded by a small but rapid increase in indoor temperature.

The change in indoor temperature at the 11th floor was so small that the average time constant of 11th floor became infinite. The measured temperatures at 11th floor were therefore omitted in calculation of the building average time constant.

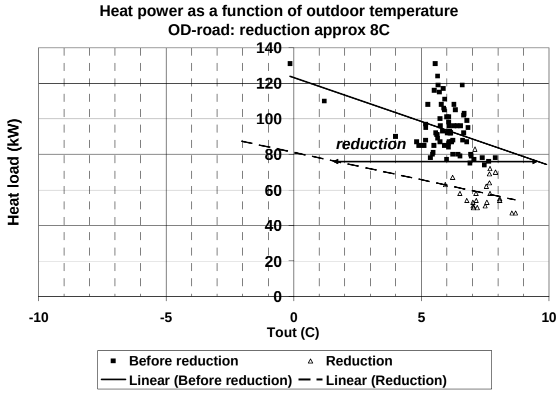

Fig. 15. OD-road. Reduction of heat power during the reduction period.

The input outdoor temperature for the control system was increased with 10ºC. The average total estimated time constant was 218 hours (11th floor excluded).

Old brick building

In the area of G-street, there were several old brick buildings that once were used for shipbuilding, now rebuilt and used for offices. One important difference between the operation of a residential building and an office building is the forced ventilation in the office building. During the test, illustrated in fig. 16, the ventilation was turned off, when the heat power to the radiator circuit was reduced. When the heat power was increased again, the set point value for the supply air was increased over normal set point value to get a quick reheating of the building. At normal operation, both radiator circuit and ventilation system was back at normal set point values.

In order to be able to turn off the ventilation system, the test was performed during a week-end to reduce the discomfort for the office employees.

The room temperature was normally individually controlled by the employees in each room.

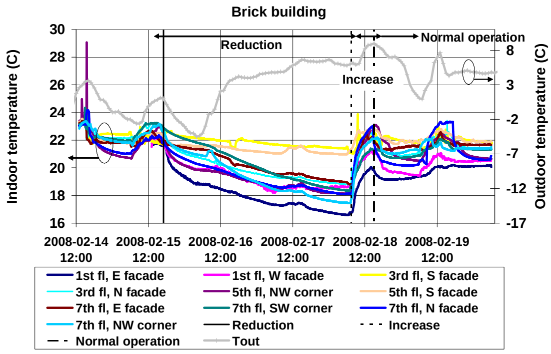

Fig. 16. Indoor temperature at G-street.

In this test, the influence of present working people was very clear, especially after the reduction in heat power. The influence of direction of the building façade was also very clear – both rooms at the south façade had essentially lower reduction in room temperature during the test than the other direction.

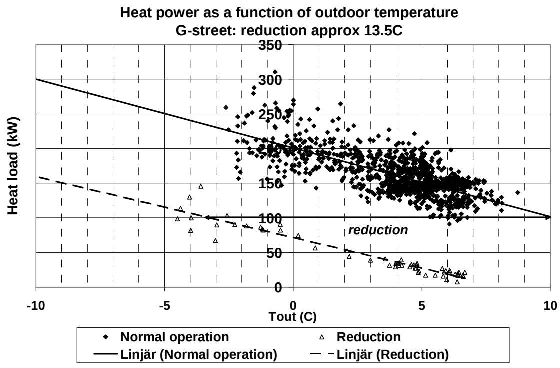

Fig. 17. G-street. Reduction of heat power during the reduction period.

The input outdoor temperature for the control system was increased with 20°C and the average total estimated time constant of the building was 504 hours. If the measurements at the south façade were excluded, the average total estimated time constant was 341 hours.

RESULTS

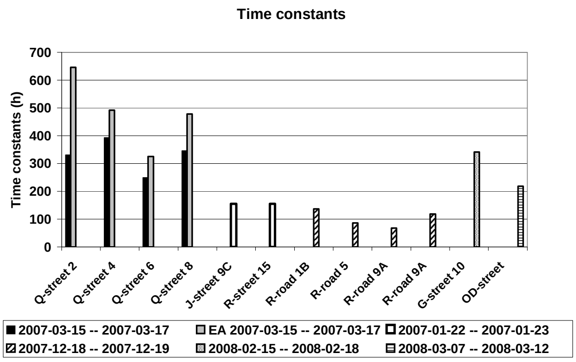

Fig.18. Estimated time constants.

The estimated time constants were often well above the assumed 100 hours (fig.18). Even the wooden buildings have time constants with an average of 102 hours. It should be noted that no effort has been taken to find the most exposed apartment with the lowest initial indoor temperature.

These tests have been conducted with induced increased outdoor temperatures of 10-20℃ during a day or more. This was more than the required increase to eliminate the maximum daily variations in April and March in the Göteborg district heating system. Since the time necessary for eliminating the daily variations is much shorter then a day, the change in indoor temperature will be much lower than the actual changes in the performed tests.

The possible heat storage magnitudes in building masses, illustrated in fig. 3-5, are, most likely, not overestimated.

Building masses and radiator circuit piping systems as active heat storage can have a large potential, especially if the thermostatic valves are not operating ideally. With new and active thermostatic valves, the thermostatic valves are counterworking the discharge and recharging of the heat storage, since the change in indoor temperature should be limited to the dead zone of the thermostatic valves – often 0.5℃.

ACKNOWLEDGEMENTS

The studies of the indoor temperature and the time constants have been performed in cooperation with Bostads AB Poseidon, Familjebostäder i Göteborg AB, Göteborgs Stads Bostadsaktiebolag (Bostadsbolaget), and Älvstranden Utveckling AB. The staff of the companies that has taken part in setting up and performing the measurements, the residents and the employees in the buildings, where the heat deliveries have been reduced, are all gratefully acknowledged.

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