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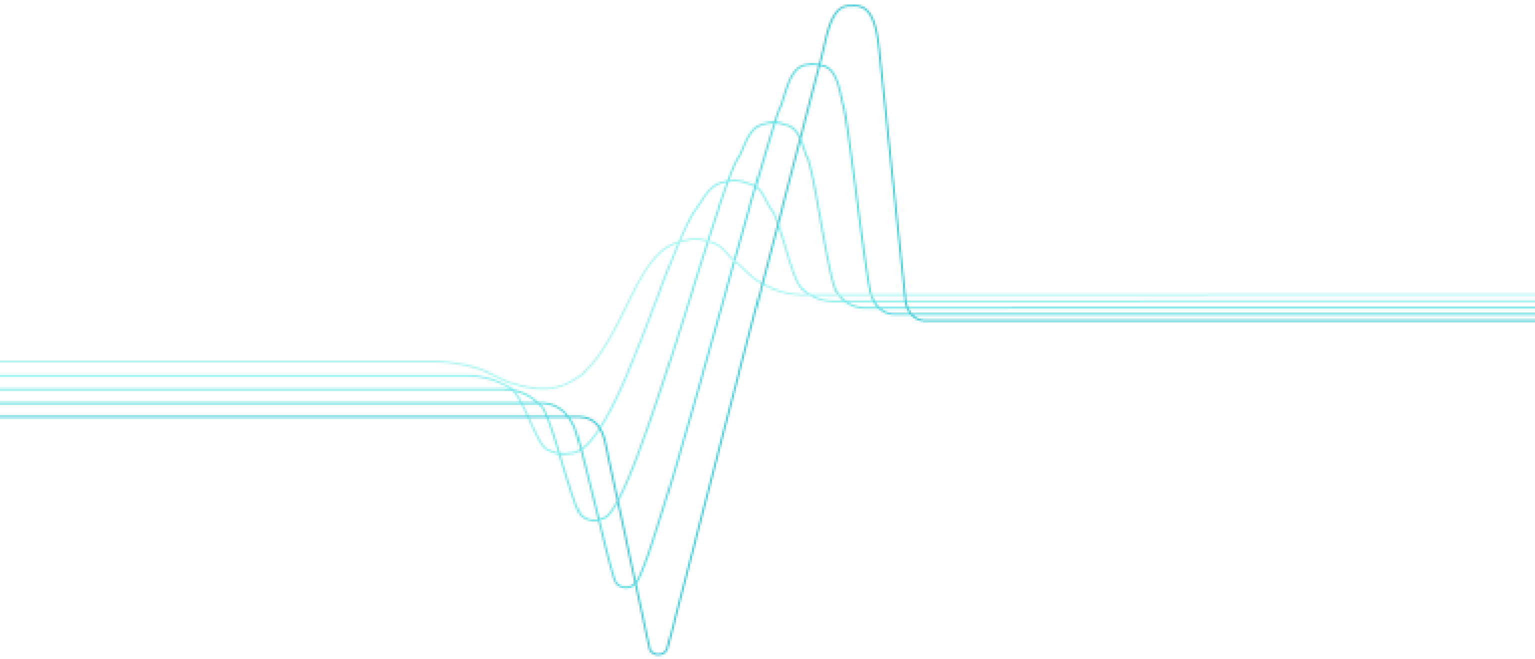

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Keywords demand side management, DSM, district heating systems, buildings, testing, test buildings, measurement, control devices, data collection, data analysis

Abstract

The main objective of the project was to show that lowering the cost of district heating (DH) is possible by using demand side management (DSM). The practical installation of DH DSM in a building is not expensive. Peak cut of 25–30 % is going to be achieved with exploiting the thermal mass of the building and by properly controlling the heating system. Indirect savings will also be evaluated. Hot tap water was not included in DSM.

There were three case study buildings, two in Jyväskylä Finland and one in Mannheim Germany, where the DSM demonstrations were carried out. A calculation tool for test buildings has been developed for quick evaluation of proper DSM possibilities. The characteristic model of buildings is described using thermal capacity-resistance description.

The research made in two Finnish case study buildings shows that the maximum heat load of a massive building (body of concrete) can be during 2–3 hours reduced as much as 20–25 % on the average because of the thermal capacity of radiator heating network. When the circulation water reaches the set DSM temperature level the heating load starts to increase up to the load level defined by any current DSM temperature setting. The loads of intake air heating are large but the thermal capacity of ventilation intake air heating is small compared to large room heating radiator systems. As the temperature change of ventilation can be felt immediately the DSM-control measures of ventilation must be very small and sensitive while the building is in a normal use. The only way to keep the heat demand of intake air heating low during the DH DSM operations is to slightly reduce the air flow temperatures by 1–2 °C.

Peak cut of 20 % in Jyväskylä means about 160 buildings of the volume 20 000 m^3. Based on simulations how to use energy production capacity in DSM, the total saving is evaluated 13 000 €/a in the Jyväskylä case. Thus a DSM investment of 845 € per consumer (5 %, 15 a) is aloud. If we assume to save an investment of 20 MW HOB (1,8 milj. EUR) because of DSM and we divide it to 20 years with 5 % interest, the additional saving will be 144 000 €/a and in addition maintenance and other fixed costs. It means an investment of about 10 000 € per consumer in the Jyväskylä case.

In the German Tower Block case in Mannheim the daily heat demand peak could be reduced by 4.1 %. This increases the efficiency of heat production at the power plant on the average by 3 %. This increased efficiency has been reached during peak demand time, which means during 1–2 hours per day. By simply closing the valve larger reductions would be possible during very short time periods. This is no option because the subsequent peak when reopening the valve would actually increase the daily maximum. It is not feasible to shift peaks in this way to times of low demand in the district heating network because the relevant time span (around three hours) is far too long.

The building is equipped with an air heating system and a computer based control system which tends to start the air conditioning system earlier when outdoor temperature is lower. It does so in order to insure the desired indoor temperature of 21.5 °C at 6:30 a. m. By doing so the computer system automatically flattens the daily heat demand when outdoor temperature is low. As a consequence it was not possible to achieve further peak reductions with DSM measures when the outdoor temperature is very low (<0 °C). The time constant of the air heated building is shorter than of buildings with radiator heating.

Two kinds of tariff structure is recommended. A fixed agreement, where supplier has the right to cut daily peak load of the consumer by remote control in agreed limits up to 25 % of connected capacity and for a maximum 3 hour per day in one or two periods. The consumer can have some discount in fixed annual payments. The post heating period should be 1.5–2 hours longer than cut period and the thermal effect should be returned linearly to avoid the remarkable post heating peak in the buildings. In other case the consumer can decide how he cuts his peak load. Hourly peak load a day will be measured and based on the maximum annual or monthly peak load he must pay a fix thermal power capacity payment a year.

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Abstrakt

Wichtigstes Ziel des Projekts war zu zeigen, dass es möglich ist, mit Hilfe von Maßnahmen auf der Nachfrageseite (Demand Side Management: DSM) die Wirtschaftlichkeit der Fernwärme zu verbessern. Die für DSM erforderlichen gebäudetechnischen Installationen sind nicht teuer. Mit einer geeigneten Regelungstechnik ist es möglich, unter Ausnutzung der Wärmekapazität des Gebäudes, Lastspitzen in der Wärmeversorgung um ca. 25–30 % zu senken. Sogenannte „indirekte Einsparungen“ werden ebenfalls bewertet. Anlagen zur Versorgung mit Warmwasser waren nicht in die hier untersuchten DSM Maßnahmen einbezogen.

In drei Fallstudien davon zwei Gebäude in Jyväskylä, Finnland, und eines in Mannheim, Deutschland, wurden DSM Maßnahmen durchgeführt. Ausserdem wurde ein Software Tool mit dessen Hilfe, basierend auf Messdaten, rasch der Erfolg von DSM Maßnahmen bewertet werden kann, implementiert. Die physikalischen Eigenschaften der Gebäude wurde anhand eines thermischen Speicher – Widerstand – Modells nachgebildet.

Die in den beiden finnischen Gebäuden durchgeführten Unteruchungen zeigen, dass das Heizwärme – Tagesmaximum während 2–3 h durchschnittlich zu 20–25 % gesenkt werden kann. Dieses Ergebnis gilt für massive aus Beton errichtete Gebäude, die mit einer Radiator Heizung ausgestattet sind. Die Heizlast steigt auf einen Wert, dessen Höhe von der eingestellten „DSM Temperatur“ des im Gebäude Heizungsnetz zirkulierenden Wassers abhängt. Die erforderliche Heizleistung zur Deckung des Lüftungswärmebedarfs ist zwar typischerweise groß, wohingegen die Wärmekapazität der aufgeheizten Luft klein ist im Vergleich zu einem großen statischen Heizungssystem mittels Radiatoren. Da Änderungen der Lufttemperatur sofort gespürt werden, können DSM-Maßnahmen an Luftheizungs-Systemen nur in geringem Umfang durchgeführt werden. Akzeptabel sind Senkungen der Zulufttemperatur von höchstens 1–2 °C.

Eine Senkung der Lastspitze von 20 % in Jyväskylä würde etwa 160 Gebäude mit einem umbauten Volumen von 20.000 m³ bedeuten. Basierend auf Simulationen der Wärmeerzeugung würde sich in Jyväskylä eine Einsparung von 13.000 €/a errechnen.

Diese Einsparung würde eine Investition in DSM-Technik von 845 € pro Verbraucher (5 %, 15a) rechtfertigen. Wenn mit DSM Investitionen in Kesselanlagen vermieden werden können - im untersuchten Fall würde eine Erzeugerleistung von etwa 20 MW (entsprechend 1,8 Mio. €) entfallen- könnten bei einer angenommenen Lebensdauer von 20 Jahren und einer Kapitalverzinsung von 5 % zusätzliche Einsparungen von 144.000 €/a erziehlt werden. Hinzu kommen kommen noch hier nicht quantifizierte Einsparungen für Wartung und Instandhaltung. Unter diesen Annahmen könnten DSM Investitionen von ca. 10.000 € pro Verbraucher durch Einsparungen bei der Wärmeerzeugung finanziert werden.

Durch die DSM – Maßnahmen in einem Verwaltungs-Hochhaus in Mannheim, Deutschland, konnte die Tages-Lastspitze der Wärmeleistung um 4,1 % gesenkt werden. Dadurch würde die Effizienz auf der Erzeugerseite um durchschnittlich 3 % erhöht werden. Diese Effizienzsteigerung würde während 1–2 Stunden täglich, in denen die DSM –Maßnahmen wirksam sind, erzielt. Es ist möglich, während sehr kurzer Zeiträume, durch „schließen des Ventils“ größere Lastspitzen Reduzierungen zu erreichen. Durchgeführte Untersuchungen zeigen jedoch, dass dadurch die dann sehr ausgeprägte Lastspitze beim Wiederöffnen des Ventils, das Tagesmaximum sogar erhöht würde. Da die Lastspitze im Fernwärmenetz sehr lang ist (ca. drei Stunden pro Tag), war es beim untersuchten Gebäude nicht möglich die Lastspitze auf diese Weise in Schwachlastzeiten zu verschieben.

Das Gebäude ist mit einer Luftheizung und einem mittels Computer gesteuerten Leitsystem ausgestattet. Abhängig von der Aussentemperatur startet das Leitsystem die Luftheizung aus Gründen der Wärmekosteneinsparung so spät wie möglich, aber doch so, dass um 6:30 eine Inneraumtemperatur von 21,5 °C garantiert ist. Je kälter die Aussentemperatur um so früher wird die Heizung gestartet. Auf diese Weise wird schon vor Einführung von DSM bei kalten Aussentemperaturen Wärmeleistung in Schwachlastzeiten verschoben und der Lastgang geglättet. Daher war es nicht möglich an kalten Tagen (< 0 °C) mittels DSM weitere Lastspitzen Reduktionen zu erreichen.

Zwei Tarifmodelle sind im Zusammenhang mit DSM zu empfehlen:

Erstens, eine Vereinbarung, in der dem Versorger das Recht eingeräumt wird, innerhalb festgelegter Grenzen, die Lastspitze um bis zu 25 % über maximal 3 h während einer oder zwei Perioden pro Tag ferngesteuert zu reduzieren. Dem Verbraucher würde ein vertraglich bestimmter Abschlag in der Fernwärmerechnung gewährt. Die der Kappung folgende Aufheizphase sollte 1,5–2 länger sein als die Zeit, in der die Kappung aktiv ist. Die Wärmeleistung sollte langsam erhöht werden um die typische Lastspitze am Ende der Kappung zu vermeiden.

Zweitens, ein Tarif in dem stündlich die Wärmeleistung gemessen und entsprechend der höchsten monatlichen oder jährlichen Wärmeleistung ein Leistungspreis in Rechnung gestellt wird. In diesem Modell bliebe es dem Kunden überlassen auf welche technische Art und Weise er die Lastspitze reduziert.

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Tiivistelmä

Projektin tavoitteena oli osoittaa, että kaukolämpöjärjestelmässä suoritettavalla kulutuksen ohjauksella voidaan alentaa kustannuksia. Rakennusten massaa ja automaatiojärjestelmää hyödyntämällä voidaan saavuttaa 25–30 %:n tehonleikkaus. Projektissa arvioidaan myös epäsuoria säästötoimenpiteitä. Lämmin käyttövesi ei kuulu ohjauksen piiriin.

Kulutuksen ohjausta kokeiltiin kolmessa rakennuksessa, joista kaksi oli Jyväskylässä ja yksi Mannheimissa. Kulutuksen ohjauksen vaikutuksen ennakkoarviointiin kehitettiin yksinkertainen laskentamalli, jossa kuvataan rakennuksen päämitat ja materiaalit. Laskentaperiaate perustuu materiaalien lämpökapasitanssi – resistanssiominaisuuksien laskentaan.

Kokeellinen tutkimus osoitti, että kahdessa suomalaisessa rakennuksessa (betonirunko) tehoa voitiin leikata 2–3 tunnin jaksolla keskimäärin 20–25 % hyödyntämällä rakennusten massaa ja vesikeskuslämmitystä. Kun vesilämmityksen veden lämpötila saavuttaa DSM-toiminnon asetusarvon, automatiikka säätää lämpötilan asetettuun DSM-lämpötilaan. Ilmalämmityksellä lämmitetty rakennus voi ottaa suuren tehon ilman liikkuessa, mutta ilman lämpökapasiteetti on pieni verrattuna vesilämmitysjärjestelmään. Ilman lämpötilan alentuminen aiheuttaa lähes välittömästi korjauksen säätöjärjestelmän kautta. Ainoa tapa estää ilmastoinnin välitön korjaus sisälämpötilan perusteella, on säätää ilman lämpötilan asetusarvo 1–2 °C normaalia alemmaksi.

Jyväskylän kaukolämpöjärjestelmässä 20 % huipputehon leikkaukseen tarvitaan noin 160 rakennusta, joiden jokaisen lämmitetty tilavuus on 20 000 m^3. Simulointilaskelmien perusteella tuotantokapasiteetin käytössä voidaan saavuttaa noin 13 000 € säästöt vuodessa. Säästön perusteella DSM-laitteisiin voidaan sijoittaa 845 € kuluttajaa kohden (5 %, 15 v.). Jos DSM:n avulla voidaan välttää yhden 20 MW:n (1,8 milj. EUR) huippukattilan rakentaminen, niin 20 vuoden pitoajalla ja 5 %:n korkovaatimuksella se merkitsee 144 000 € lisäsäästöä ja lisäksi säästetään huolto ja muut kiinteät kulut. Se merkitsee Jyväskylän tapauksessa jo 10 000 € investointimahdollisuutta kuluttajaa kohden.

Saksalaisen MVV:n toimistotornin huipputehoa Mannheimissa voidaan leikata noin 4,1 %. Lämmitystehon säästöllä voidaan parantaa CHP-laitoksen kokonaishyötysuhdetta keskimäärin 3 %. Parantunut hyötysuhde saavutetaan lämmön huippukulutuksessa 1–2 tunnin aikana päivittäin. Sulkemalla kiinteistön lämmityskierron venttiilit voidaan saavuttaa suurempiakin lyhytaikaisia tehon leikkauksia. Venttiilien sulkeminen aiheuttaa kuitenkin sen, että leikkausjakson jälkeiselle jaksolle voi tulla vuorokauden huippukulutustehot ja toivottu vuorokauden huipputehon pieneneminen menetetään. Toimistotorni on ilmalämmitteinen ja 3 tunnin tehon leikkausjakso on ilmalämmitetylle rakennukselle liian pitkä.

Ilmalämmitteisen toimistotornin lämmitysjärjestelmä on tietokoneen ohjauksessa ja lämmitysjärjestelmä aloittaa sisälämpötilan noston aamulla, kun ulkolämpötila on vielä kylmä. Varmistaakseen oikean sisälämpötilan 21,5 °C viimeistään klo 6.30, lämpötilan nosto aloitetaan riittävän ajoissa ja siten jo tasoitetaan vuorokauden lämmitystehon vaihtelua. Mittauksilla todettiin, että ulkolämpötilan ollessa alle 0 °C mitään tehon säästöä ei enää saavuteta. Ilmalämmitteisen rakennuksen aikavakio on lyhyempi kuin vesikiertolämmitteisen.

Tutkijaryhmä suositteli kahta DSM-toimintaa tukevaa tariffivaihtoehtoa. Kiinteän vuosimaksun pienentämiseen perustuva tariffi, jossa lämmön toimittajalla on oikeus leikata kuluttajan huipputehoa maksimissaan 25 % liittymistehosta ja maksimissaan 3 tuntia päivässä yhdessä jaksossa tai jaettuna kahteen jaksoon. Tehon leikkausta seuraava jälkijakson tai kahden jälkijakson pituus voi olla 1,5–2 tuntia leikkausjaksoa pidempi ja teho palautetaan lineaarisesti takaisin ulkolämpötilaa vastaavalle tehotasolle. Toisessa vaihtoehdossa kuluttaja voi valita, miten ja milloin tehon leikkaus suoritetaan. Päivittäinen tehohuippu mitataan ja vuoden tai kuukauden maksimi tehohuipun mukaan asiakas maksaa kiinteän maksun vuosittain tai kuukausittain.

Preface

Demand Side Management in District Heating Systems (DH DSM) is a research project, which has been started on the first of November, 2000 and finished November 31, 2003. It was a cooperation project between MVV Energie, VTT Processes, Electrowatt-Ekono, Jyväskylän Tilapalvelu and Jyväskylän Energia. Jyväskylän Tilapalvelu has also the subpartner Atmostech Oy, which is represented by Hitcon Ky in Jyväskylä.

In addition to EU support the project has been financed also by Finenergy (Energia-alan keskusliitto ry), Finnish Technology Agency (TEKES) and Jyväskylän Energia Oy.

The project was coordinated by VTT Processes. MVV Energie, Jyväskylän Tilapalvelu and Jyväskylän Energia were responsible for measurements, measurement equipment and software installations for DSM. VTT Processes, Electrowatt-Ekono and MVV were responsible for measurement analysis and building tool, which could preanalyse DSM impacts to case study buildings. This report text is a co-operation work of all partners, VTT Processes being responsible for editing the text.

Contents

1. Introduction

The main objective of the project was to show that lowering the cost of district heating (DH) is possible by using demand side management (DSM). The practical installation of DH DSM in a building is not expensive. Peak cut of 40 % is going to be achieved with exploiting the thermal mass of the building and by properly controlling the heating system. The optimum control strategies was developed. Indirect savings was also be evaluated. Computer models of test buildings was created for quick evaluation of proper DSM strategies.

Based on test buildings in Finland and Germany the project was also evaluate the effects of large-scale use of DSM in many key buildings of the district heating systems tested. The ways to share the benefit resulting from the use of DSM equally between the DH Company and the end-customers was developed. Tariffs favouring the DSM and marketing ideas was also created.

Test sites (buildings) in Finland and Germany as well as each district heating (DH) system was established. The extra equipment installed consists of meters, controlling devices and data connections. The equipment was tested, adjusted and comparative data of normal building behaviour was recorded.

2. Methods in DSM control

DSM Control is most convenient to realise by using multiple temperature control curve applications, where different curves are activated by demand. The curves added to room heating control for DSM application have the same shape as the normal (existing) curve but the slopes or the vertical position of curves are different. DSM –curves are located below the normal curve but for the preheating and heating up procedures there is a curve above the normal level.

2.1 Radiator system

DSM measures cause extra stress cycles on heating system. The stress caused by temperature transients can be reduced by making the temperature changes as slow as possible (a change of 1 °C per 5 minutes is an acceptable rate in a large pipe system). Temperature transient when cutting all heating off by DSM action is at maximum 30°C (a radiator network dimensioned for temperatures 70 °C/40 °C). When cutting some 20 % of the heating load during the peak load condition the drop of temperature is 8 °C. Because of these large temperature changes it is reason to use several steps when making the changes between DSM mode and normal heating mode. Instead of stepwise operation sophisticated controls can have floating temperature control, which follows the temperature difference between the return and flow side. Floating control enables relatively simple DSM control as the number of step-by-step operations is reduced.

The load reduction is estimated by using a radiator heat transfer calculation model in constant flow condition. In actual heating networks with thermostatic valves and poor lining up the flow rate at radiators is not all constant. This causes higher heat transfer at radiators where the thermostat valves are opening due the lowering room temperatures.

When setting the temperatures for DSM control in a specific building one should note that the temperature differences between supply and return are very seldom as high as dimensioned. The flow rate in some parts of the heating network can be much higher than the designed rate. To define the peak heating up load after DSM actions the flow rate and the thermal capacity of heating system must be checked by the analysis of temperature transient tests.

The decrease of loads is largest at the beginning of DSM control measures because of the thermal capacity of heating network it takes time before the network is cooled down to the set DSM flow temperature level. When the circulation water reaches the set DSM temperature level the heating load starts to grow up to the load level defined by any current DSM temperature setting. In a radiator network with a normal thermal capacity it takes at least one hour before the heating load starts to grow after the flow temperature reduction measures.

2.2 Ventilation air

The loads of intake air heating are large but the thermal capacity of ventilation intake air heating is small compared with large room heating radiator systems. As the temperature change of ventilation can be felt immediately the DSM-control measures of ventilation must be very small and sensitive while the building is in a normal use. When the building ventilation is running the only way to keep the heat demand of intake air heating low during the DH DSM operations is to slightly reduce the air flow temperatures (by 1–2 °C).

2.3 Air heating system

The major part (around 70 %) of "MVV Tower Block" buildings heat demand is met by the air conditioning system as shown in Figure 1. Each side of the building is equipped with a separate two pipe water distribution system and pipes for preheated air. The temperature and flow of the preheated air remains almost constant during the whole year (16 °C and 90 000 m^3/h). Dependent on the climate conditions the water within the mentioned distribution system can be switched to cold water to cover cooling demand.

All floors of the building are equipped with decentralised air injectors. Each injector is equipped with a hot water/air heat exchanger, which is connected to the distribution system. The indoor temperature is separately measured at each side of the building (average of values measured in four floors). The control of the indoor temperatures is done by adjustments of the temperature of the water circulating through the heat exchangers. This adjustment can be done separately for each side of the building.

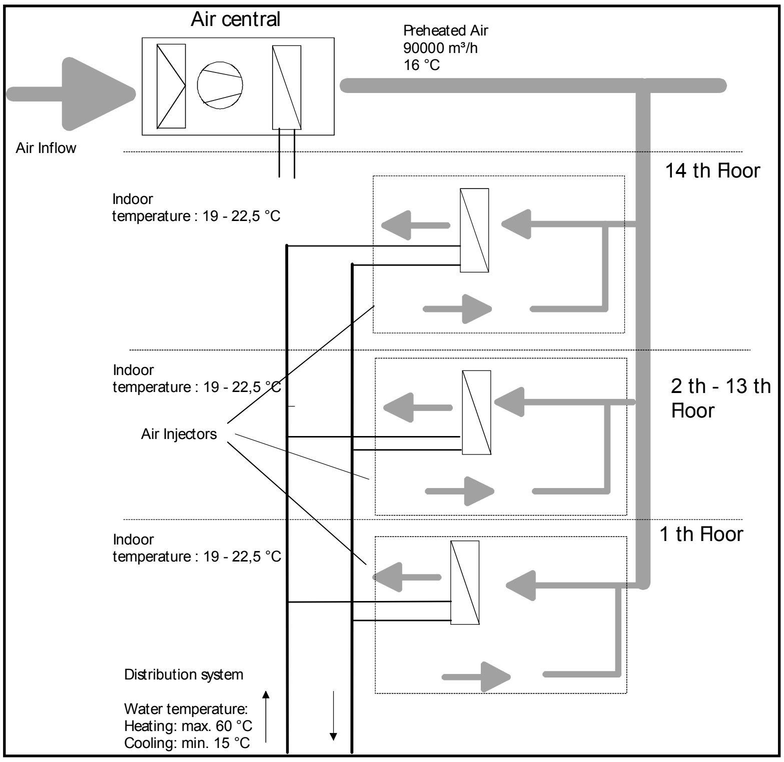


Figure 1. Tower Block Air Conditioning System.

A minor part of the building's heat demand is necessary to operate radiators and some smaller decentralised air heating systems. There is also a certain heat demand for hot tap water generation.

The system operates in the way described above during work hours between 6:30 a. m. and 19:00 p. m. During night-time, Sundays and holidays the system operates in an “economy-mode”. This means that the air central is switched off and the heat exchangers in the air injectors work like radiators. During the “economy-mode” the indoor temperature set point is decreased to 19 °C. Hot water temperature in the distribution system must be increased to around 60 °C to make an operation of the heat exchangers as radiators possible. During the “comfort-mode” between 6:30 a. m. and 19:00 p. m. the indoor temperature set point is different for each of the four heat loops within a range of 22–22,5 °C.

The typical course of the daily heat demand is presented in figure 2. As it can be seen heat demand peaks in the early morning between 4:00 h a. m. and 8:30 h a. m. when the air central starts and the operation of the system is switched from the above mentioned “economy-mode” to the normal “comfort-mode”.

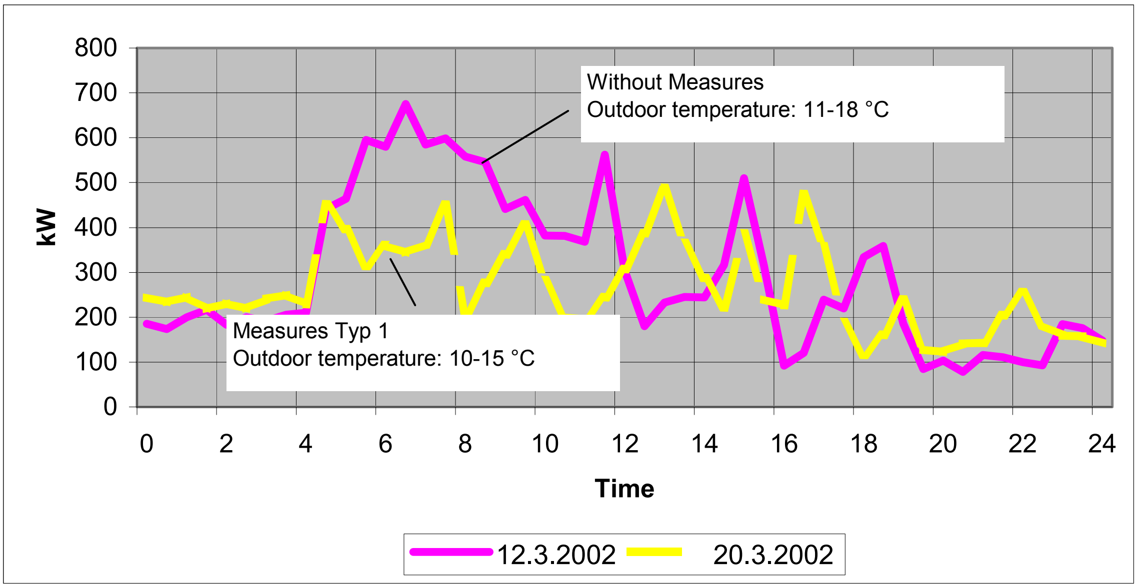


Figure 2. MVV Tower Block's Heat Demand.

The exact start time of the air central is determined by the software such that an indoor temperature of at least 21,5 °C is guaranteed at 6:30 a. m. The software aims to minimise energy consumption and therefore starts operation as late as possible. The unintended consequence of this strategy is the observed load peak.

2.4 Hot tap water

The changes of hot tap water consumption are so rapid that it is not advisable to take any direct tap water dependent load control, which changes the flow temperatures of room, floor or other heating networks. The temperature changes would be too large and fast for constant flow heating systems.

3. An evaluation tool for building energy systems

A calculation tool for test buildings has been developed for quick evaluation of proper DSM possibilities. The last version of the tool is created in table calculation form.

3.1 Description of the calculation tool

The characteristic model of buildings is described using thermal capacity-resistance model as shown in figure 3. The model calculates also mass of the buildings divided into external walls, roof, bottom, internal walls, and internal ceilings

Convection heat cells include heat power from heating or cooling, electrical equipment, lighting, people, solar, etc. and radiation heat cells include radiation power from the same cells.

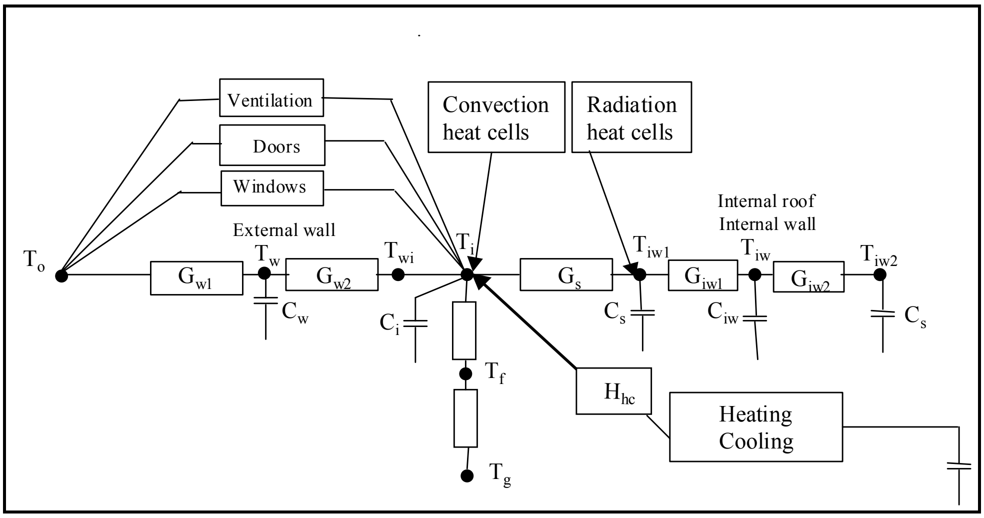


Figure 3. Capacity-resistance model for adjacent rooms of the building, Temperatures: T_0 = outdoor, T_i = internal, T_w = coat wall, T_{iw} = internal wall or ceiling, T_{wi} = medium temperature of internal surfaces, T_f = floor, T_g = ground.

Heat balance of the nodes can be described.

Convection

$$C_i \frac{dT_i}{dt} = P_c + P_{vent} - G_w(T_i - T_0) - G_{win}(T_i - T_0) - G_s(T_i - T_s)\,, \tag{1}$$

where $C_x = hA\rho c_p$ is thermal capacity of X; h is hight or thickness (m), A is area (m^2), ρ is density of material (kg/m^3) and c_p is specific heat capacity of the material (kJ/kg, K).

The thermal conductance is G = UA; U is thermal transmission factor (W/m^2, K)

Radiation

$$C_s \frac{dT_s}{dt} = P_r + P_{sol} + G_w(T_s - T_i) - G_{w1}(T_s - T_{iw}) \tag{2}$$

$$C_{iw} \frac{dT_{iw}}{dt} = G_{iw2}(T_i - T_{iw}) + G_{iw1}(T_{i2} - T_{iw}), \tag{3}$$

If T_i is equal to T_{i2} and G_{iw2} equal to G_{iw1}, the equation (3) can be written

$$C_{iw} \frac{dT_{iw}}{dt} = 2G_{iw}(T_i - T_{iw}) \tag{3'}$$

$$C_w \frac{dT_w}{dt} = G_{w2}(T_{wi} - T_w) - G_{w1}(T_w - T_0) \tag{4}$$

Thermal power of solar radiation is

$$P_{sol} = \psi_{sc} \alpha_w q_{sol} A_w, \tag{5}$$

where ψ_{sc} is a shadow factor for the building and α is a factor for technical properties of the window. q_{sol} is solar radiation to the surface.

P_r is radiation power of occupation (lighting, electrical machines, etc.) and P_c is convection power of occupation (lighting, electrical machines, warm tap water, etc.).

Heating capacity for ventilation is

$$P_{vent} = q_a c_{pa} \rho_a (T_0 - T_i) \cdot (1 - \eta_{hrs}), \tag{6}$$

where index a is a property of the air, q is air flow, c_p thermal capacity, ρ density and η is the efficiency of the heat recovery system.

When we operate with temperature control in buildings for DSM operation, the thermal response of the building must be known. When we know the material, which the building is made of, we can evaluate the thermal response of the building.

$$\rho V c \frac{d\theta}{dt} = G\theta, \tag{7}$$

where ρ is material density, V is material volume, c is specific thermal capacity of materials, G is conductance of the building and θ (=T-T_{out}) is temperature compared to reference temperature. G is also ϕ/θ, where ϕ is thermal loss through conductance of the building. Then we have

$$\theta = \theta_0 e^{-\frac{G}{\rho Vc}t}, \tag{8}$$

where 1/τ = G/ρVc ==> is the time constant of the building. The active part of the building capacity consists of 10 % of the materials inside the building and takes part of the inside temperature control.

When the heating is cut off, the building starts cooling (cut period) and when the heating is turned on, the building starts warming (lift period).

3.2 Simplifying the building

The building is simplified for calculation as shown in figure 4. Every floor is described with two rows of rooms: rooms adjacent to the external wall and internal rooms including corridors and stairs. The first floor has a floor against ground and top floor has a roof above.

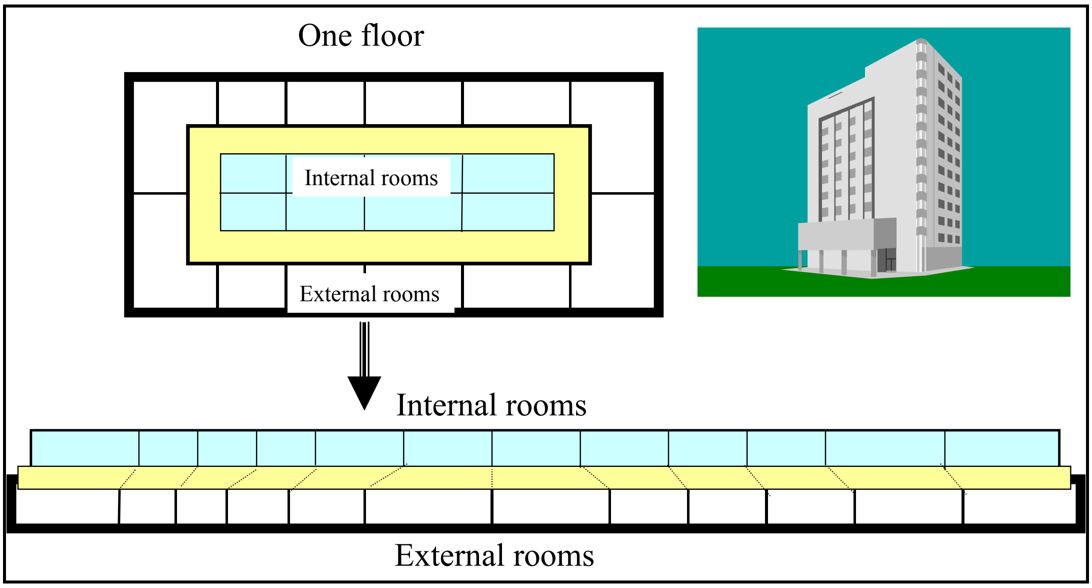


Figure 4. Simplified building for thermal property calculation.

3.3 Case studies

3.3.1 Governmental Centre in Jyväskylä

Description of the building

The office building is a governmental centre in Jyväskylä. The building has 6 floors and total floor area is 5 940 m^2. The building has concrete body covered with brick and the total volume is 19 380 m^3. The window area is about 30 % and the door area about 0,5 % of the wall area. The roofing is tar blanket and covered with small stones. The building top has 300 mm of insulation, the walls 150 mm and the bottom 100 mm. The total heat consumption (corrected by degree days) was 713,1 MWh in 2000 and 867,8 MWh in 2001. A connected heating capacity of the building is 580 kW.

Sharing of the building mass is shown in figure 5. We see that half of the total mass of 4515 tons consists of ceilings. The bottom and outer walls are 35 % of the total mass.

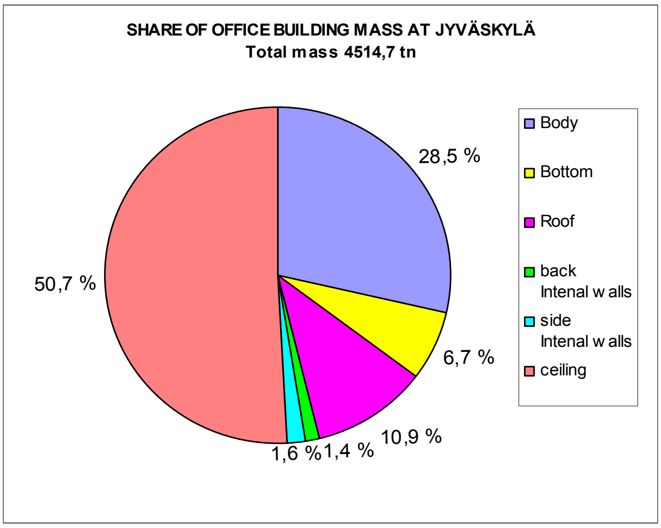


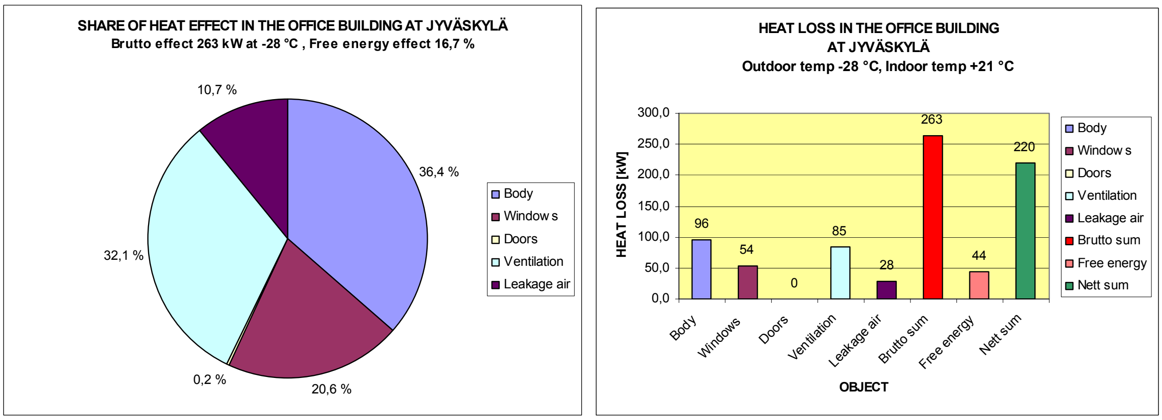
Figure 5. Share of the building mass.

Energy balance of the governmental centre building

The energy balance of the building is calculated at –28 °C of outdoor temperature and +21 °C of indoor temperature. Share of the heat losses is shown in figure 6.

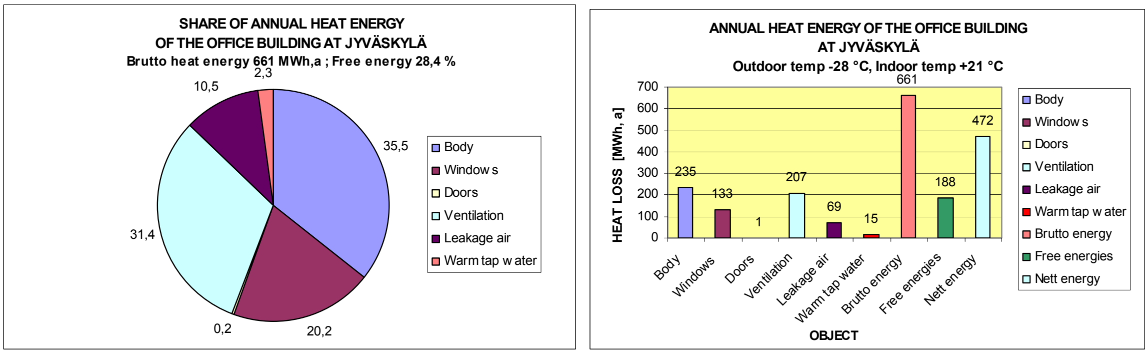
The total heating power is 263 kW, from which 44 kW is covered by free energy cells like people, solar radiation, electric devices, etc. Heat recovery rate of ventilation is 40 %, which is supposed to be carried out by a plate heat exchanger in ventilation canal.

The annual heating energy demand of the building is 661 MWh and hot tap water energy demand is about 15 MWh. Free energy is about 188 MWh per year, so net annual heating energy demand is 472 MWh. The share of annual heat energy demand is shown in figure 7. The building body and windows spend more than half of the annual energy, and ventilation 31 %.



a) b)

Figure 6. Share of heat losses in the building.



a) b)

Figure 7. Share of annual heat demand of the building.

Time constant of the governmental centre

The lift period takes about the same time as cut period as shown in figure 8. The indoor temperature becomes 2 °C (21 ==> 19 °C) lower during 4 hours, if ventilation is on and outdoor temperature is –28 °C. If ventilation is shut off, it takes 5:50 hours to reach 2 °C lower indoor temperature. The time constant τ of the building is 135 hours, when ventilation is shut off and 92 hours when the ventilation is on.

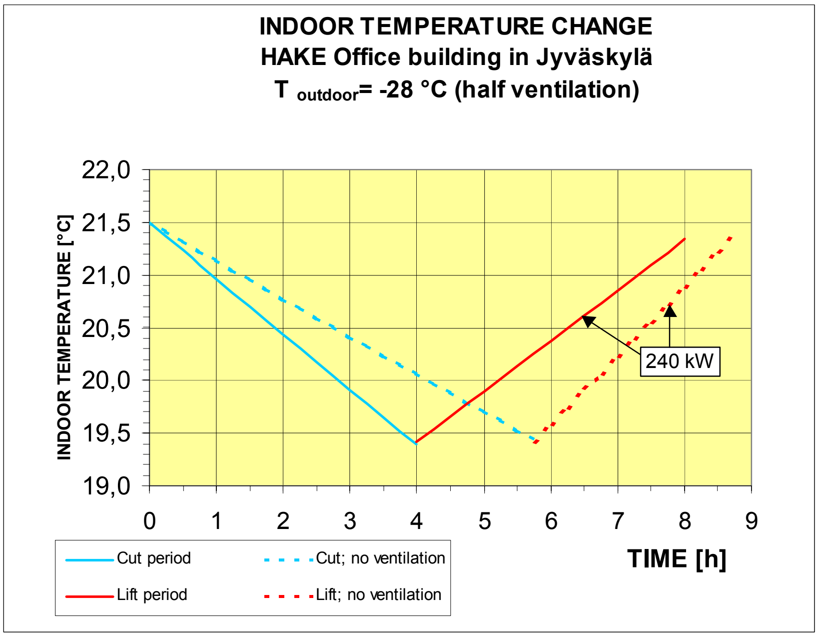


Figure 8. Response of the Governmental Centre building for DSM in Jyväskylä, when ventilation is on or off.

3.3.2 Kortepohja Senior Citisens' Day Centre in Jyväskylä

Description of the building

The dwelling building is pensioners' service building in Jyväskylä. The building has 2 floors and total floor area is 2150 m^2. The building has concrete body covered by brick and the total volume is 7100 m^3. The window area is about 13 % and the door area about 2,2 % of the wall area. The building is covered by a tin roof. The building top has 250 mm of insulation, the walls 150 mm and the bottom 100 mm. The total heat consumption (corrected by degree days) was 308,0 MWh in 2000 and 292,8 MWh in 2001. A connected heat capacity of the building is 290 kW.

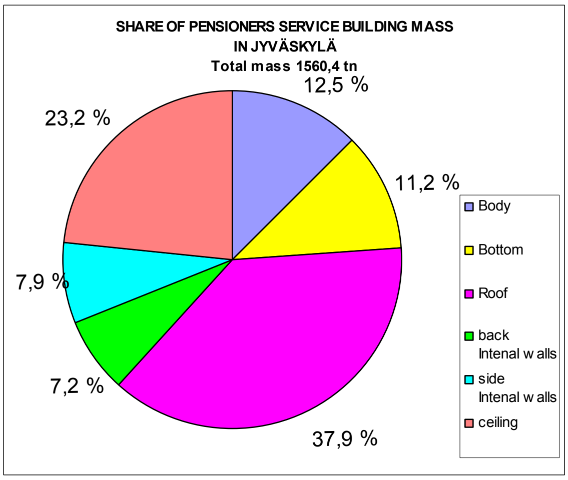
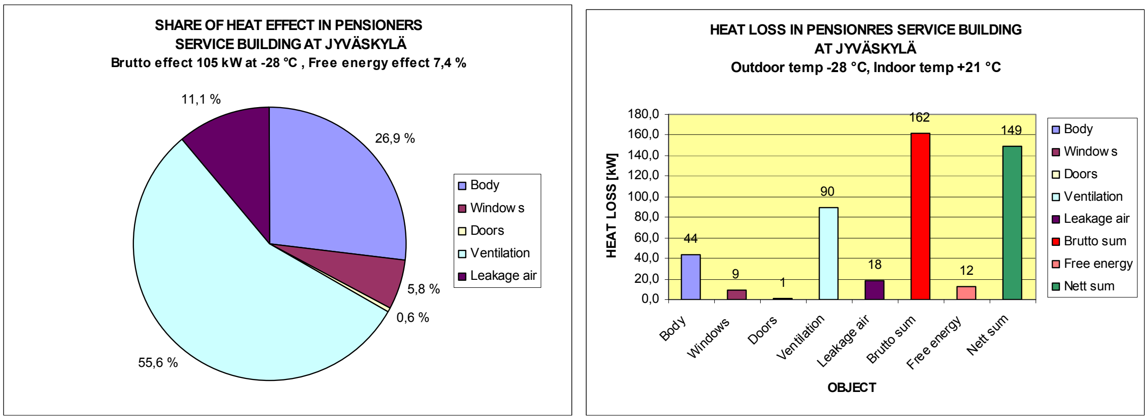


Figure 9. Share of the building mass.

Share of the building mass is shown in figure 9. We see that 37,9 % of the total mass of 1560 tons consists of the roof. The bottom and outer walls are 23,7 % and ceiling 23,2 % of the total mass.

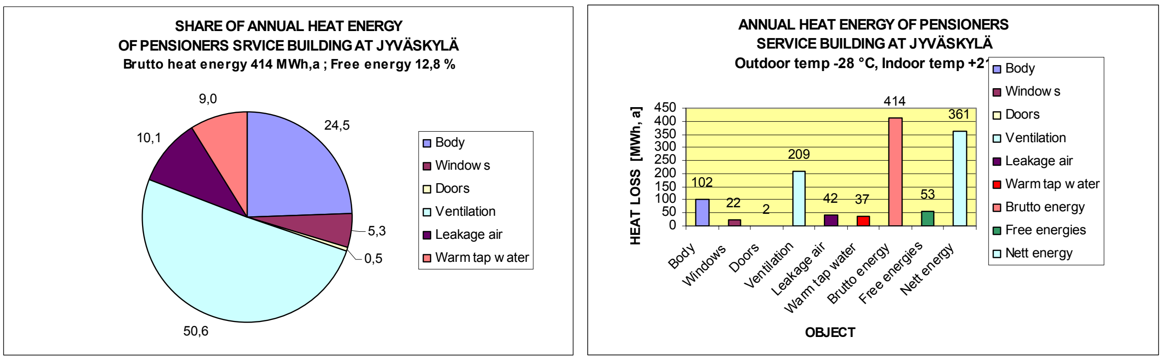
Energy balance of the pensioners' service building



a) b)

Figure 10. Share of heat losses in the pensioners service building.

The energy balance of the building is calculated at –28 °C of outdoor temperature and +21 °C of indoor temperature. Share of the heat losses is shown in figures 10.



a) b)

Figure 11. Share of annual heat demand of the pensioners service building.

The total heat effect is 162 kW, from which 12 kW is covered by free energy cells like people, solar radiation, electric devices, etc. A heat recovery system is only in tending rooms and recovery rate of ventilation is 10 %, which is supposed to be carried out by a plate heat exchanger in ventilation canal.

The annual heating energy demand of the building is 414 MWh and hot tap water energy demand is about 37 MWh. Free energy is about 53 MWh per year, so net annual heating energy demand is 361 MWh. The share of annual heat energy demand is shown in figure 11. The building body and windows spend about 30 % of the annual energy, and ventilation 50 %.

Time constant of the pensioners service building

The lift period is about one hour longer than cut period as shown in figure 12. The indoor temperature becomes 2 °C (21 ==> 19 °C) lower during 6 hours, if ventilation is on and outdoor temperature is –26 °C. If ventilation is shut off, it takes almost 14 hours to reach 2 °C lower indoor temperature. The time constant τ of the building is 73 hours, when the ventilation is shut off and 45 hours when the ventilation is on.

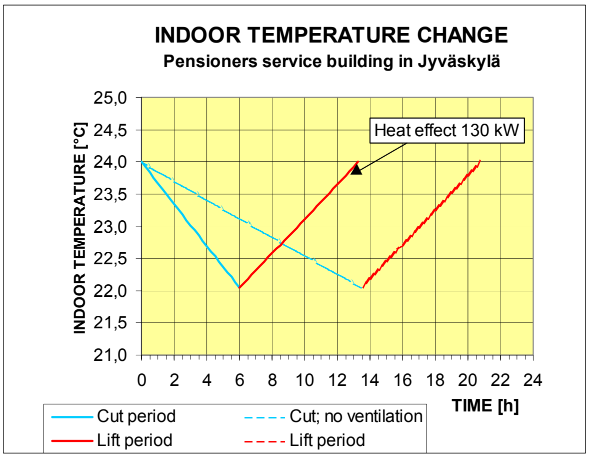


Figure 12. Response of the senior citizens' service hause for DSM control.

3.3.3 Tower Block at Mannheim

There are two different approaches to model the dynamics of a building. The first approach uses the available knowledge about the physical properties of the materials used and construction. This information is used to determine the parameters of the resistance-capacity-model by VTT. This approach had been followed by VTT based on the available data and design of the MVV Tower Block (see in chap. 4).

The alternative approach is to determine the mentioned parameters from the large database, which has been created within the project. This methodology starts with the above mentioned resistance-capacity-model. The next step is to determine the parameters C (thermal capacity) and G (inverted thermal resistance).

Figure 13 shows the resistance-capacity-model used. The indoor-Temperature T_{indoor} depends directly on the heating power. Parameter of the model is the thermal capacity C, which describes the building's ability to store heat, and the inverted thermal resistance G, which describes the building insulation. Additionally there are heat losses associated with the natural and artificial ventilation.

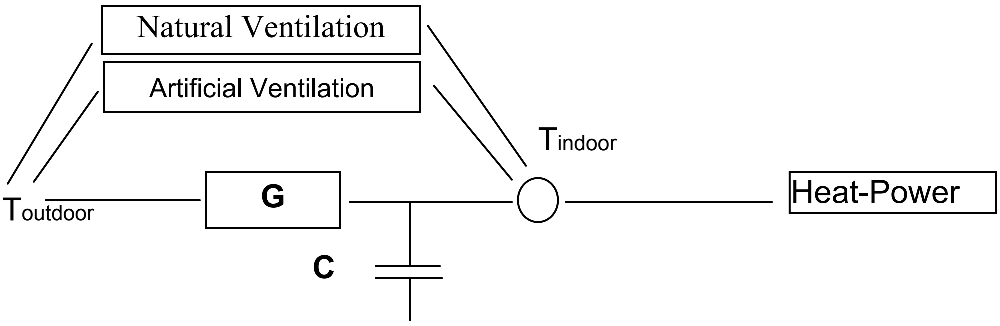


Figure 13. Simple Resistance-Capacity-Model.

The model in figure 13 may be represented as equation (9). The algorithm calculates the new T_{indoor} as an increment to the old value. The time delay Δt between two values has been set equal to the sampling period of the data measurement (1800 s). As can be seen in equation (9) the increment depends on the heating power P_H, the ventilation loss P_V and the difference between indoor and outdoor temperature $T_i - T_{out}$.

$$T_{i_{new}} = T_{i_{old}} + \frac{\Delta t}{C}\left(P_{H_{old}} - P_{V_{old}} - G\left(T_{i_{old}} - T_{out_{old}}\right)\right) \tag{9}$$

$$P_V = P_{V_{natural}} + P_{V_{artificial}} \tag{10}$$

We modelled ventilation losses (P_V in equation (10)) as the sum of natural ventilation - which has been estimated as 30.000 m³/h - and artificial ventilation by the existing air conditioning system. Operation of the air-conditioning system is well known (see chapter 4.2). It is therefore possible to calculate the impact of artificial ventilation.

Based on data measured during December 2001 the values of the parameters *G* and *C* were determined using regression analysis.

As can be seen in figure 14 the model catches quite well the daily fluctuations in the indoor temperature. Also the major indoor temperature reductions during weekends and holidays are reflected in the model. The modelled indoor temperature remains approximately 2 K below the measured value if the outdoor temperature is high (around 10 °C). It is around 2 K higher when an outdoor temperature below 0 °C.

In Fig. 15 the model was tested using data samples which had not been used for parameter identification. Again it must be noted, that the indoor temperature calculated by the model varies according to the outdoor temperature. It is higher than the measured value as long as the outdoor temperature is below 0 °C and vice versa.

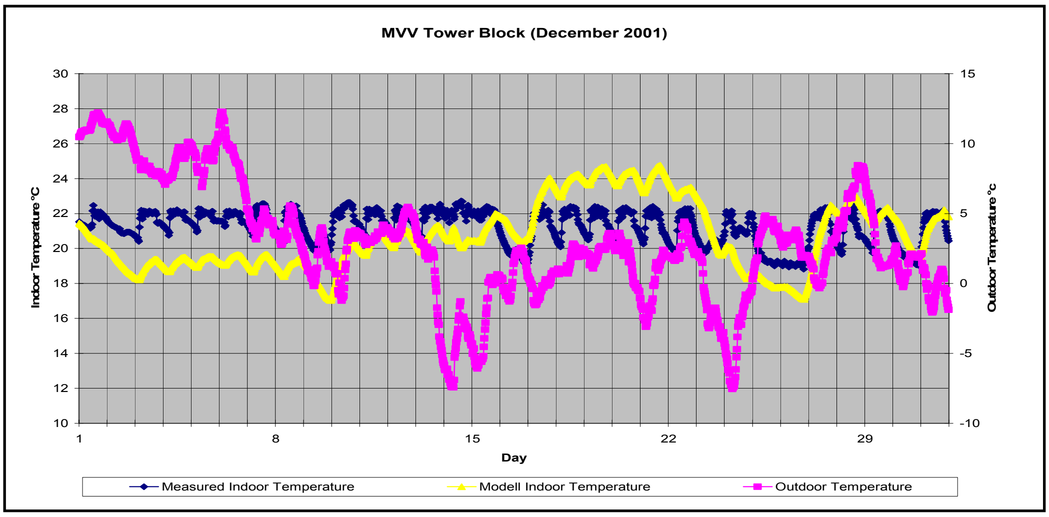


Figure 14. Modelled and measured indoor temperature.

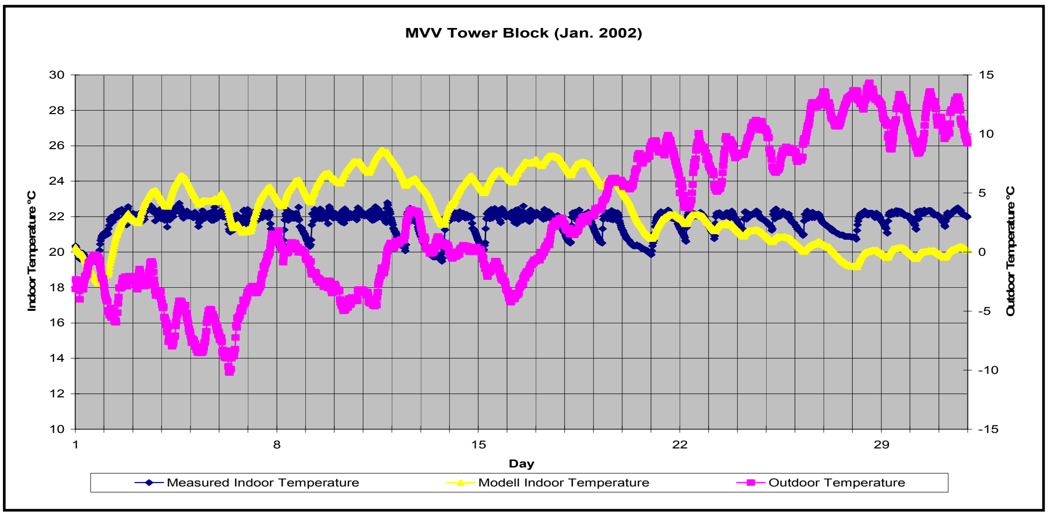


Figure 15. Model-test with data which had not been used for parameter identification.

The differences between the measured and the calculated indoor temperature may be explained by simplifications made during the modelling process. First, the dynamics of the building should be described by a more sophisticated model than the first order difference equation (9) presented above. This will be done in the next steps. Second, there remains some doubts about the efficiency of the recuperation system which enters the model via equation (10). Detailed analysis of the air flow temperature before and after the recuperation system will hopefully clarify this issue (current estimation 50 % recuperation).

Table 1. Comparison of modelling approaches.

	Unit	**VTT**	**MVV**
Static Heat Loss G	kW/K	28	30
Thermal Capacity C	MJ/K	11.793	9.785
Cut Time*	h	5,7	5,5

* Time of a 2 K decrease after heat supply has been stopped without considering ventilation (outdoor temperature: –12 °C)

Main purpose of the data based modelling described above, is to check the plausibility of results derived from the alternative approach followed by VTT, which has been described above. As one would expect, the comparison in Tab. 1 shows that the two approaches lead to very similar results.

3.4 Analysing of measured data and comparing to building model

3.4.1 Governmental Centre in Jyväskylä

Temperatures of the outgoing (= incoming to the consumer) and return (= outcoming from the consumer) DH-pipeline at the Governmental Centre are presented as a function of outdoor temperature in figure 16 based on measurements January to May in 2002. The function is approximated by a polynomial of 3. degree. Because of the more than 10 °C deviation in outdoor temperatures the correlation of the return temperature is not as good as that of the outgoing temperature.

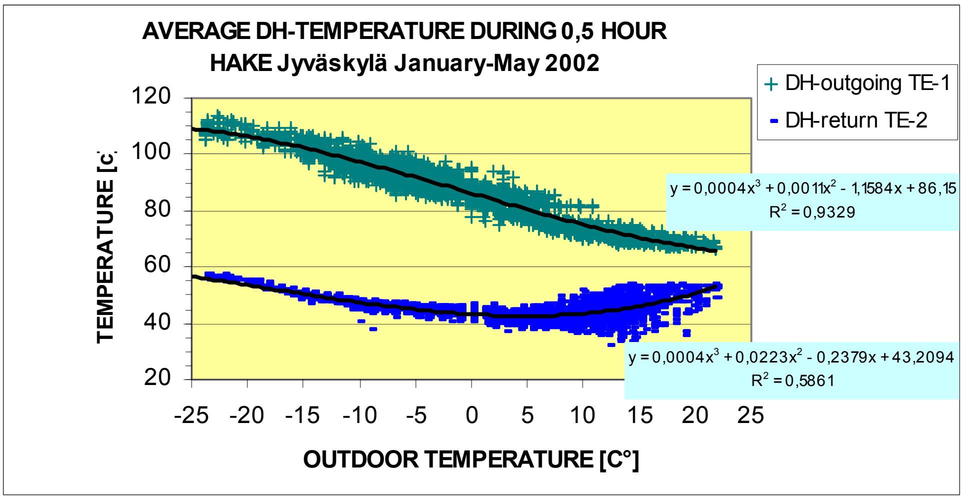


Figure 16. Outgoing and return temperature of the DH pipeline at the consumer as a function of outdoor temperature.

Water flow and heat demand at Governmental Centre divided in radiator heating circuit and HVAC heating is presented in figures 17 and 18. The functions are approximated by a polynomial of 4. degree. The functions work to +17 °C of outdoor temperature, when the heating will be cut off and hot domestic water demand will remain.

Heat power at Governmental Centre is presented in four ways as a function of outdoor temperature in figure 19. The building model calculates the first curve. The second curve is based on the fitted function in figure 18. The third curve is measured heat power through heat meter at the consumer. The fourth heat power is calculated based on outgoing and return temperatures in figure 14 and water flow in figure 17. The best response to measured heat power data exists in the building model.

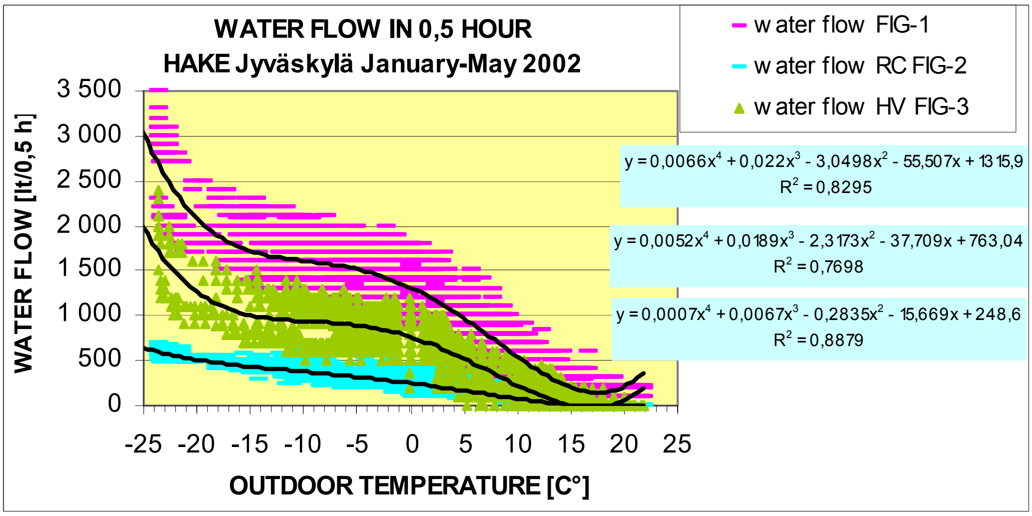


Figure 17. Water flow at Governmental Centre as a function of outdoor temperature.

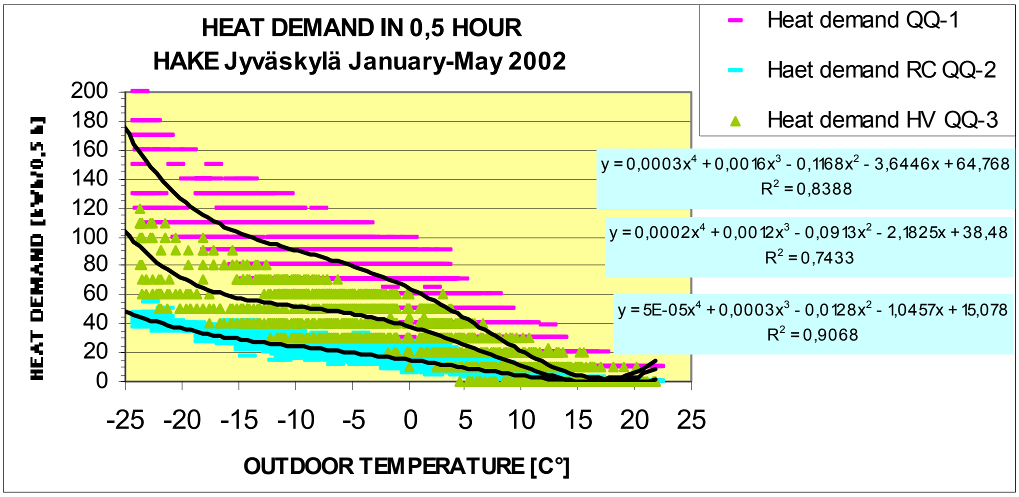


Figure 18. Heat demand at the consumer as a function of the outdoor temperature.

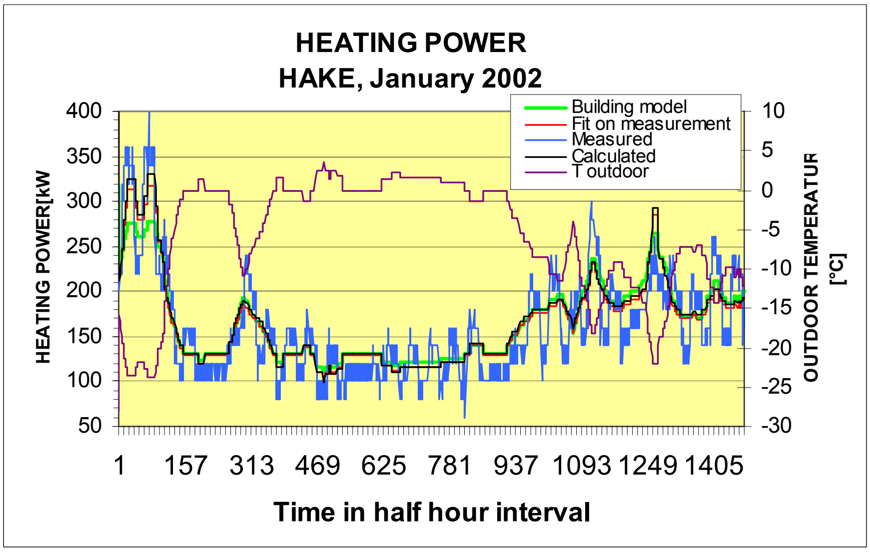


Figure 19. Heat power response in 4 ways as a function of time (outdoor temperature) in Governmental Centre, January, 2002.

3.4.2 Kortepohja Senior Citizens Day Centre in Jyväskylä

Correspondingly to Governmental Centre in figure 19 heat power in Senior Citizens Day Centre is presented in four ways as a function of outdoor temperature in figure 20. The building model calculates the first curve. The second curve is based on the fitted function based on measurements of the total and radiator heating power. The third curve is measured heat power through heat meter at the consumer. The fourth heat power is calculated based on DH outgoing and return temperature and water flow. The best response to measured heat power data exists in the building model.

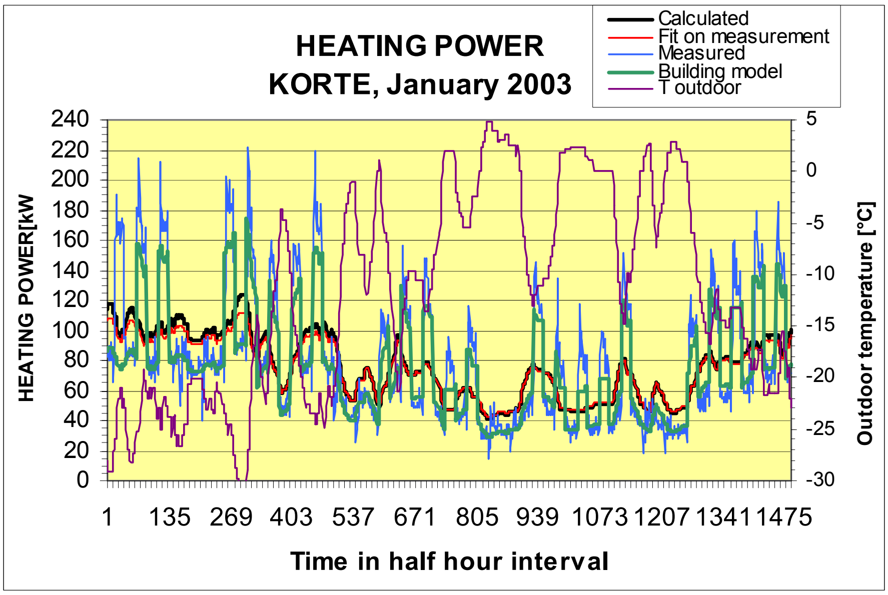


Figure 20. Heat power response in 4 ways as a function of time (outdoor temperature) in Senior Citizens Day Centre, January, 2002.

4. DH DSM test buildings

4.1 Description of the test buildings

4.1.1 Governmental Centre in Jyväskylä

The government office building (shown in Fig. 21) located in Central Finland has 6 floors and total floor area is 5 940 m^2, where the heated floor area is 5140 m^2. The building has concrete body covered by brick and the total volume is 19 380 m^3. The window area is about 30 % and the door area about 0,5 % of the wall area. The roofing is tar blanket and covered with small stones. The total heat consumption (corrected by degree days) was 713,1 MWh in 2000 and 867,8 MWh in 2001. A heat exchanger capacity consists of three parts (arrangement 1 in Appendix 1): heating 465 kW, air conditioning 1280 kW and domestic hot water 580 kW.

Figure 21. Governmental Centre in Jyväskylä.

4.1.2 Kortepohja Senior Citizens' Day Centre in Jyväskylä

The dwelling building (shown in Fig. 22) is senior citizens' Day Centre in Jyväskylä, in Central Finland. The building has 2 floors and total floor area is 2150 m^2, where the heated floor area is 2010 m^2. The building has concrete body covered by brick and the total volume is 7100 m^3. The window area is about 13 % and the door area about 2,2 % of the wall area. The building is covered by a tin roof. The total heat consumption (corrected by degree days) was 308,0 MWh in 2000 and 292,8 MWh in 2001. A heat exchanger capacity of the building is divided into two units (arrangement 2 in app. 1): heating and air conditioning together 290 kW and domestic hot water 270 kW.

Figure 22. Senior Citizens' Day Centre in Jyväskylä.

4.1.3 Tower Block in Mannheim

MVV participates in the DH DSM Project with administrative and industrial buildings (see Tab.2). All buildings are already connected to the DH System. Heating and air conditioning are controlled by an existing central building automation system.

Building 1 "MVV Tower Block" (see also Fig. 23) is a typical administrative building. It has been constructed in the late sixties and recently renovated. The major part of the building's heat demand is met by the air conditioning system.

Table 2. Participating facilities in Mannheim.

No.	Building	Heated Area	Heat Consumption in 2000
1	MVV Tower Block	25.661 m²	2529,9 MWh/a
2	MVV Technical Administration	34.758 m²	3163,0 MWh/a
3	Streetcar Maintenance	18.592 m²	3606,2 MWh/a
4	Bus Maintenance	n. a.	1137,8 MWh/a

There is also a certain heat demand for hot tap water generation. Radiators meet a minor part of the heat demand.

Figure 23. MVV administration building.

4.1.4 MVV Technical Administration and vehicle maintenance buildings in Mannheim

Building 2 “MVV Technical Administration” (see Fig. 23) consists of several buildings of different age (from the fifties to the late eighties). The major part of the buildings' heat demand is met by a centralised air conditioning system. Nevertheless, static heating by radiators is still significant. Tap hot water demand can be neglected. The building is mainly used for offices and workshops.

Buildings 3 and 4, “Streetcar Maintenance” and “Bus Maintenance” (Fig. 24), are typical industrial facilities. They principally consist of large halls, which are heated by decentralised blowers. There is also a significant hot water demand, which can be separately measured. The hydraulic systems of the blowers are equipped with temperature sensors and control valves so that it is possible to control the return flow temperature of each blower. These buildings have recently been built and can be considered as typical industrial facilities.

All test buildings are connected to a high standard building automation system. This system allows to implement different kinds of strategies for peak load shifting.

Figure 24. Streetcar maintenance and bus maintenance.

4.2 Design and installations in DSM test buildings

4.2.1 DSM installations and measurements in Jyväskylä

These case buildings have sophisticated house control systems, which give a possibility to realise the above mentioned multiple temperature control curve application by editing the control software. The system is equipped with temperature measurements at all needed points, also in return pipes which are needed for floating flow temperature control in the heating up mode. Figures 25–28 illustrate what happens during 24 hours in the heating system of Kortepohja day-centre and governmental building at Jyväskylä.

The aim of DSM tests in the selected case buildings is to find out the maximum load control measures which can be done without interfering the normal use of these buildings. All loads except the hot tap water are taken into consideration. If for example the ventilation with air intake heating is left outside the DSM control measures the temperature control of intake air will effectively compensate the reduced heating by radiators and floor heating. The temperature compensation by intake air heating is avoided by using lower (2 °C below the normal) temperature line of compensation during the DSM measures.

Preset time program is an easy and convenient way to control the preheating and load reduction sequences when the effect of load control is kept low – as no disturbance in indoor temperature comfort is allowed. Preset time program is widely used in the control of night- time reduction of the heating and this same function can be simply utilised when the lowering of heating is programmed to happen during the peak load hours.

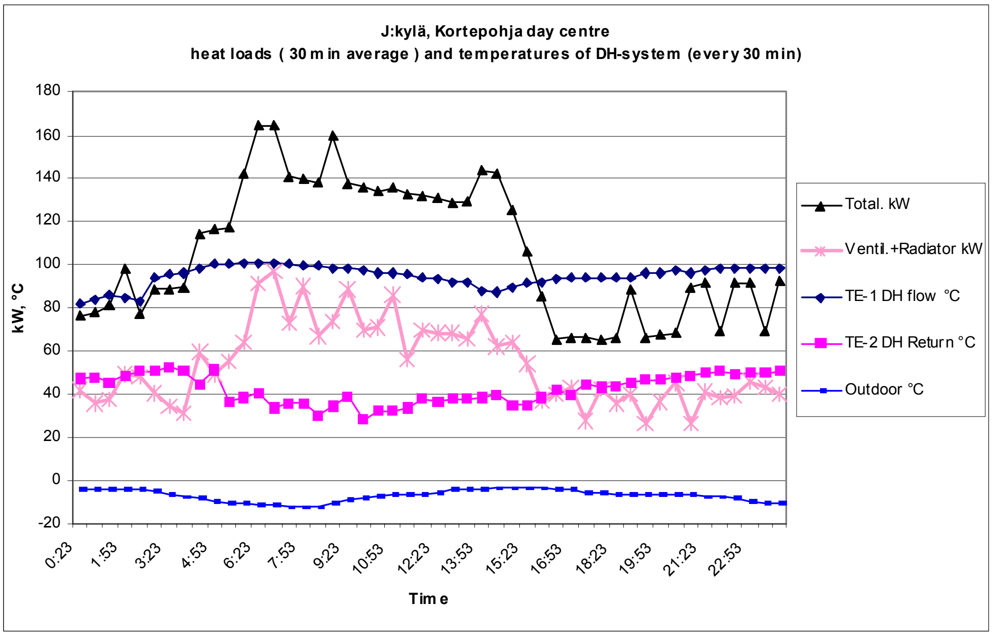


Figure 25. Loads of Kortepohja Day Centre during a period of 24 hours during a weekday with outdoor temperatures between –12 °C...–4 °C.

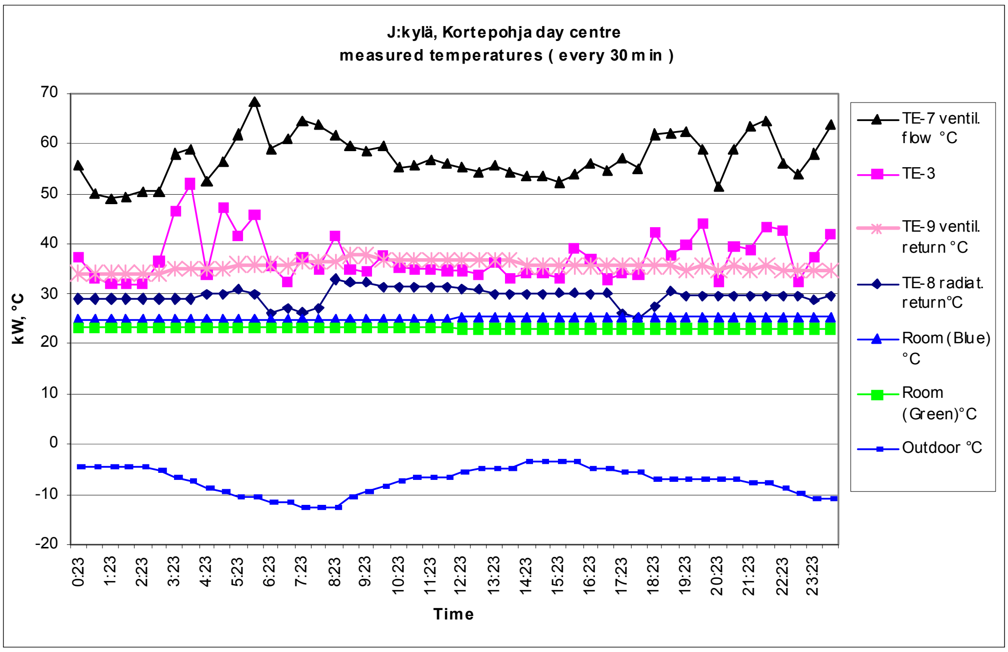


Figure 26. Temperature measurements of heating system and rooms in Day Centre during a period of 24 hours in a weekday with outdoor temperatures –12 °C...–4 °C.

The control system is at this moment programmed to realise the DSM operations according to a daily set time schedule. The timing and other settings of the program are easy to modify as the tests give more information of the effect of DSM actions.

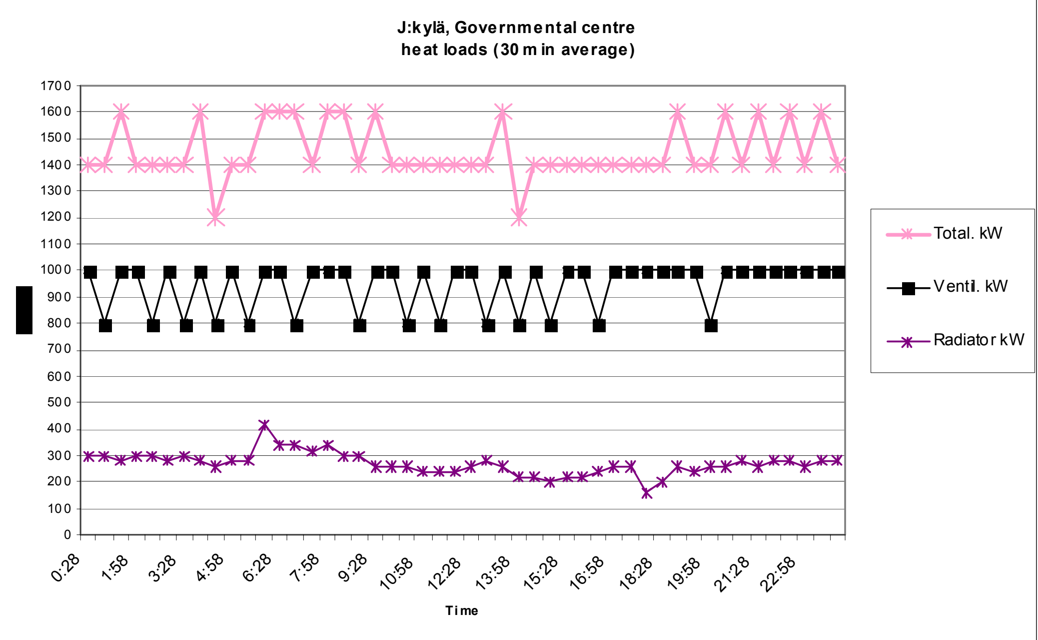


Figure 27. Loads of Governmental Centre during a period of 24 hoursduring a weekday with outdoor temperatures between –12 °C…–3 °C.

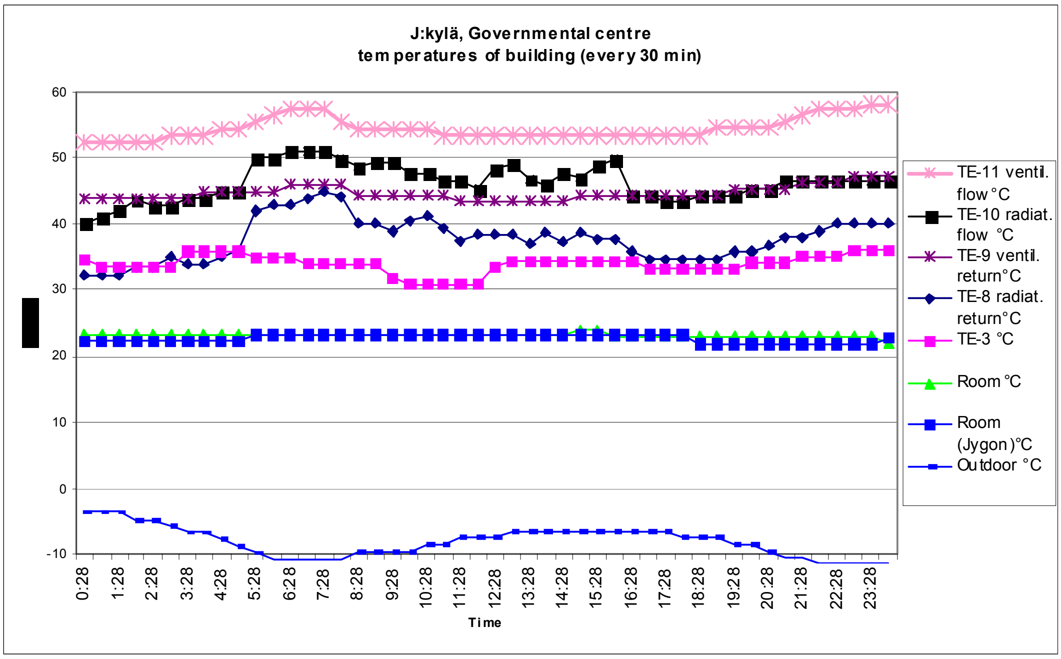


Figure 28. Temperature measurements of heating system and rooms in the Governmental Centre during a period of 24 hours during a weekday with outdoor temperatures between –12 °C…–3 °C .

Two metering arrangements were designed for the test buildings in Finland. The following data (tables 1–7) were specified to be measured and to be recorded with both arrangements.

Table 3. Minimum requirement for DSM-metering in arrangement 1.

Code	**Measured and recorded values (name)**	**Unit**	**Measurement frequency**	**Explanation**
TE1	Temperature 1	°C	Every 30 min	DH flow temperature
TE2	Temperature 2	°C	Every 30 min	DH return temperature
TE3	Temperature 3	°C	Every 30 min	DH return temperature after HE heat exchanger
TE4	Temperature 4	°C	Every 30 min	Outside temperature
TE5	Temperature 5	°C	Every 30 min	Room temperature 1
TE6	Temperature 6	°C	Every 30 min	DH return temperature after AC heat exchanger
FIQ1	Water flow 1	l/s (kg/s)	Every 30 min	Total DH water flow
FIQ2	Water flow 2	l/s (kg/s)	Every 30 min	DH water flow after HE heat exchanger
FIQ3	Water flow 3	l/s (kg/s)	Every 30 min	DH water flow after AC heat exchanger
Code	**Calculated values (name)**	**Unit**	**Required data**	**Explanation**
QQ1	Total load	kW	TE1, TE2, FIQ1	Total HE + AC + DHW effect
QQ2	Heating load	kW	TE1, TE3, FIQ2	Total HE effect
QQ3	Heating load	kW	TE1, TE6, FIQ3	Total AC effect
	Domestic Hot Water (DHW) load	kW	QQ1, QQ2, QQ3	Total DHW

Table 4. Optional measurements in arrangement 1.

Code	**Measured and recorded values (name)**	**Unit**	**Measurement frequency**	**Explanation**
TE8	Temperature 8	°C	Every 30 min	Secondary HE circuit, return temperature after radiators
TE9	Temperature 9	°C	Every 30 min	Secondary AC circuit, return temperature after AC equipment
TE10	Temperature 10	°C	Every 30 min	Secondary HE circuit, flow temperature
TE11	Temperature 11	°C	Every 30 min	Secondary AC circuit, flow temperature
TE12	Temperature 12	°C	Every 30 min	Room temperature 2, (AC inlet temp.)

Arrangement 1 (Appendix 1)

This connection scheme is applied for DH consumers with three heat exchangers; Heating (HE), Air-conditioning (AC) and Domestic Hot Water (DHW), for example in Governmental centre. Both radiator network and Air-conditioning (AC) units have separate secondary heating circuits.

Table 5. Minimum requirement for DSM-metering in arrangement 2.

Code	**Measured and recorded values (name)**	**Unit**	**Measurement frequency**	**Explanation**
TE1	Temperature 1	°C	Every 30 min	DH flow temperature
TE2	Temperature 2	°C	Every 30 min	DH return temperature
TE3	Temperature 3	°C	Every 30 min	DH return temperature after HE+AC heat exchanger
TE4	Temperature 4	°C	Every 30 min	Outside temperature
TE5	Temperature 5	°C	Every 30 min	Room temperature 1
FIQ1	Water flow 1	l/s (kg/s)	Every 30 min	Total DH water flow
FIQ2	Water flow 2	l/s (kg/s)	Every 30 min	DH water flow after HE+AC heat exchanger
Code	**Calculated values (name)**	**Unit**	**Required data**	**Explanation**
QQ1	Total load	kW	TE1, TE2, FIQ1	Total HE + AC + DHW effect
QQ2	Heating load	kW	TE1, TE3, FIQ2	Total HE + AC effect
	DHW load	kW	QQ1, QQ2	Total DHW

Table 6. Optional measurements in arrangement 2.

Code	**Measured and recorded values (name)**	**Unit**	**Measurement frequency**	**Explanation**
TE7	Temperature 7	°C	Every 30 min	Secondary HE+AC circuit, flow temp.
TE8	Temperature 8	°C	Every 30 min	Secondary HE circuit, return temperature after radiators
TE9	Temperature 9	°C	Every 30 min	Secondary AC circuit, return temperature after AC equipment
TE12	Temperature 12	°C	Every 30 min	Room temperature 2, (AC inlet temp.)

Arrangement 2 (Appendix 1)

This connection scheme is applied for DH consumers with two heat exchangers; Heating (HE) and Domestic Hot Water (DHW), for example in Kortepohja day centre. Radiator network and Air Conditioning (AC) units are connected to the same secondary heating circuit.

Measurement accuracy

Table 7. Required measurement accuracy.

Type of measurement	Accuracy	Other remarks
Temperature	+/– 0.5 °C	For example Pt100
Water flow	+/–2 %	According to DH association's recommendation

Installations

All the required (for minimum and optional measurements) new equipment and instrumentation are installed to the substations of the two test buildings. The following table 8 comprises the need for new equipment.

Table 8. Installed new equipment.

	Building 1 Arrangement 1	**Building 2** Arrangement 2
Name	Kortepohja day centre / old-age home	Governmental centre
New heat meters (pcs)	1	2
Measurement sensors (pcs)	5	11
Sensor pockets (pcs)	5	11
Additional piping (m)	2	5

4.2.1.1 Radiator heating network

Full DSM load reduction means that the setting of heating flow temperature is dropped to the level of normal room temperature, which cuts off the whole load of the radiator network until the room temperature falls below the normal room temperature.

As the temperature decreases the thermostat valves of radiators go to fully open and the flow rate of network increases up to the maximum rated value. As flow increases and the pressure difference drops it must be verified that there is enough flow in all critical points such as entry wind boxes and other places of high freezing risk.

A partial DSM load reduction is made by reducing the heating flow temperature to the level, which leads to the desired reduction of load (see the temperature curves in figures 29–30 and tables 9–10). The curves with thick lines are in order from top to bottom:

+20 % load for preheating and heating up, normal operation and curves for load reduction by –20 %, –40 %, –60 % load cut out.

In the governmental building there is in use a specific night time and weekend economy-mode setting, which is 5 °C below the normal flow temperature control curve (Table 9). A morning peak just after 6 o'clock (on Mondays the heating starts at 1:00 am after long period of economy-mode operation during the weekends) is resulted because of the recovery heating before the working time starts.

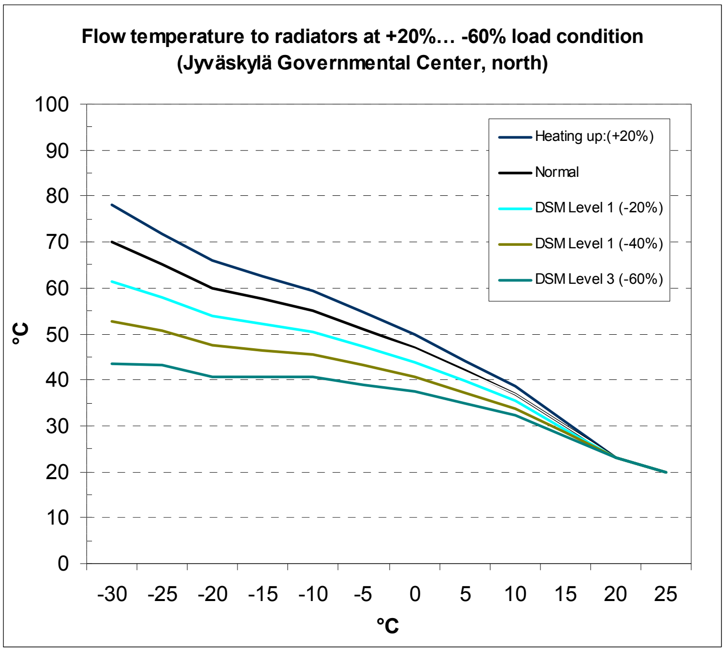


Figure 29. Inlet temperature of the radiator circuit as a function of outdoor temperature in the governmental center at Jyväskylä.

In the Kortepohja day-centre economy-mode operation follows the same time setting in all days of week (Table 10). In the radiator network the temperature reduction is only 1 °C (22:00–05:00 and in the floor-heating network reduction is 2 °C 23:00–04:00). Also this small night time set downs increases the morning peak but the peak is shorter than in case of set down of many degrees centigrade. The peak load in the morning are caused mostly by ventilation heaters.

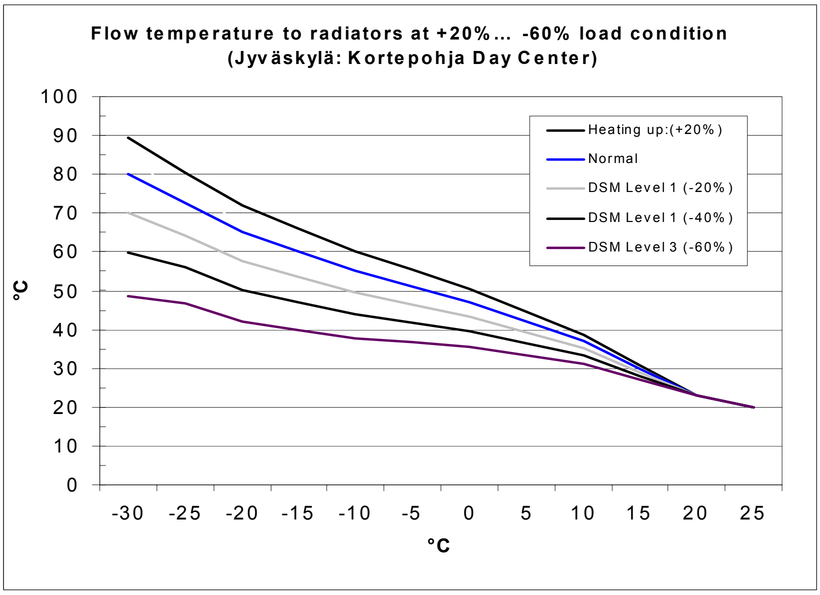


Figure 30. Inlet temperature of the radiator circuit as a function ofoutdoor temperature in Kortepohja daycentre at Jyväskylä.

The load reduction is estimated by using a radiator heat transfer calculation model in constant flow condition. In actual heating networks with thermostatic valves and poor lining up the flow rate at radiators is not all constant. This causes higher heat transfer at radiators where the thermostat valves are opening due the lowering room temperatures. The night time set down decreases the thermal capacity of building available for DSM load shifting. When DSM load shifting is scheduled the night time set down period of heating is bypassed and some of period is replaced with DSM preheating.

Table 9. The flow temperatures of radiators in the Governmental building during the normal heating mode and during the different DSM modes.

Administrative building (HAKE) Radiators										
Outdoor °C	Heating system flow temperature °C									
	Normal heating		DSM Heating +20 % load		DSM control –20 % load		DSM control –40 % load		DSM control –60 % load	
	N	S	N	S	N	S	N	S	N	S
–30	70	70	78	78	62	62	53	53	43	43
–20	60	60	66	66	54	54	47	47	41	41
–10	55	55	59	59	50	50	46	46	40	40
0	47	45	50	48	44	42	41	39	37	35
10	37	30	38	31	35	28	34	27	32	25
20	23	23	23	23	23	23	23	23	23	23
25	20	20	20	20	20	20	20	20	20	20
Night and weekend set down –5 °C			No night time or weekend set-down while DSM actions is scheduled							
Period										
Mo	01:00–20:00									
TueFri	06:00–18:00									
Su	12:00–20:00									

Table 10. The flow temperatures of radiators in the Kortepohja daycenter during the normal heating mode and during the different DSM modes.

Kortepohja daycenter (KOPA) Radiators					
Outdoor °C	Heating system flow temperature °C				
	Normal heating	DSM Heating +20 % load	DSM control –20 % load	DSM control –40 % load	DSM control –60 % load
–30	80	90	70	60	49
–20	65	72	58	50	42
–10	55	60	50	44	38
0	47	50	43	40	36
10	37	39	35	33	31
20	23	23	23	23	23
25	20	20	20	20	20
Night time set down –1 °C		No night time set down while DSM action is scheduled			
Period					
Mo–Su	05:00–22:00				

After the DSM reduction is turned off, the return to normal heating is made by increasing the setting of temperature curve gradually to the level of preheating curve for 2(3) hours and then setting back to the normal curve as the whole building is heated back to normal temperature.

4.2.1.2 DSM control in floor heating

The full load cut off in floor heating can be made by reducing temperature of the hot water supply flow down to level of return temperature of the floor circuits as shown in table 11. Floor heating circuits have their own room thermostats controlling magnetic valves of each room circuit and all valves will be opened during a long DSM period but while the fresh water intake is at low temperature (about 30 °C) no heat is transferred to the floors. The flow through the floor circuits is in the Kortepohja Day Centre connected to the same heat exchanger with radiators and the total secondary flow is increased also by this amount.

Table 11. The flow temperature of floor heating in the Kortepohja Day Centre during the normal heating mode and during the different DSM modes.

Kortepohja daycenter (KOPA) Floor heating temperature control				
	Floor heating flow temperature °C			
Outdoor °C	Normal heating	DSM control –20 % load	DSM control –40 % load	DSM control –60 % load
–30	50	~30	~30	~30
–20	45	~30	~30	~30
–10	40	~30	~30	~30
0	37	~30	~30	~30
10	35	~30	~30	~30
20	30	~30	~30	~30
25	25			
Night time set down –2 °C		No night time set down while DSM action is scheduled		
Set period				
Mo–Su	04:00–23:00			

Preheating by heating up the floors would here take settings from separate room thermostat, therefore floor heating is not used for preheating.

The return to normal operation of floor heating follows the upward going temperature of the radiator network.

4.2.1.3 DSM control of intake air heating

By controlling the heating of intake air it is possible to compensate the effect of fast changing external and internal heat gains. In the Kortepohja Day Centre and in the Governmental building there is temperature compensation in the ventilation system, which controls the temperature of outgoing air or the room temperature and sets the temperature of in-blast air as shown in table 12. The load demand of air heating is at highest at the start up of ventilation, which takes place during the morning peak time (06:00–08:00 hours).

In Kortepohja the ventilation of dwelling rooms is in constant operation at constant flow rate and the compensation is made by outgoing air. In other rooms the ventilation is by time switch or manually operated.

In the Governmental building the ventilation is operating also constantly and the temperature compensation is made at separate heating coils in every room.

Table 12. The flow temperature of ventilation in the Kortepohja day centre and in the Governmental building. Normal heating mode and DSM mode (all).

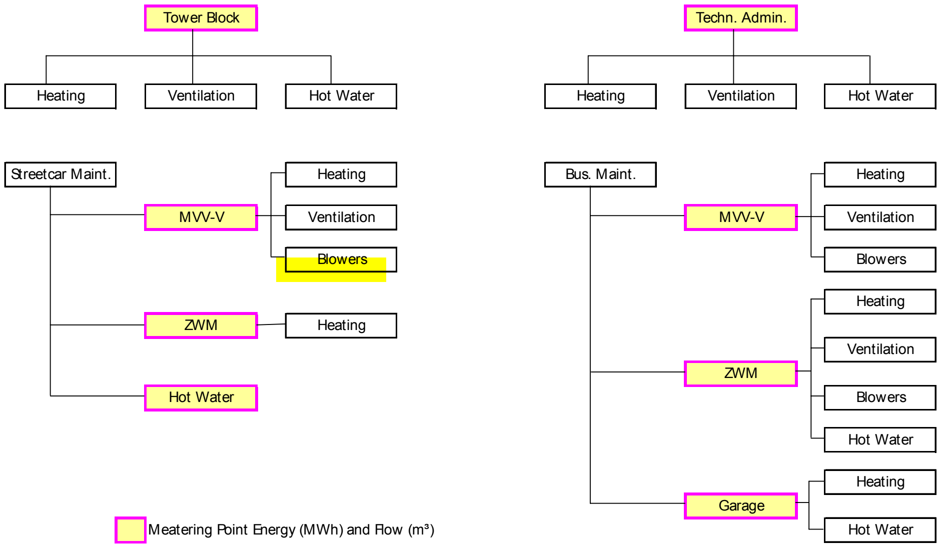
Kortepohja: (KOPA) all systems Governmental building: TF5				Governmental building: (HAKE) TF2 , TF3		
Outgoing air/ room temp. °C	Normal In-blow air °C	*DSM In-blow air °C*		Outgoing air/ room temp. °C	Normal In-blow air °C	*DSM In-blow air °C*
16	24	*22*		16	24	*22*
18	22	*20*		18	22	*20*
20	20	*18*		20	21	*19*
22	18	*16*		22	19	*17*
24	16	*14*		24	18	*16*
In line correction quantity:	-	DSM: –2 °C		In line correction quantity:	2.0 °C	DSM: 0 °C

In-line correction factor in the temperature compensation is an appropriate parameter to make DSM actions in ventilation systems, which must be constantly running at the nominal flow rate. By reducing or by using a negative correction factor the temperature compensation can be cut and the total heat demand of ventilation reduced, until the room temperature has fallen down by the set amount (<–2 °C) of the correction factor.

The return to normal operation is done by setting the correction factor back to the normal value.

4.2.2 DSM installation and measurements in Mannheim

The current structure of the metering system is presented in figure 31. There has been installed additional metering devices to measure the heat demand of the Tower Block's hot water preparation separately.



Metering point; energy (MWh) and flow (m^3)

Figure 31. Structure of the metering system.

First the Tower Block's hot water consumption was considered as very small compared to the overall heat demand. After the installation of temporary measuring devices during December and January 2001 we had to revise our assumption. It turned out that the share of the hot water preparation of the buildings heat demand cannot be neglected (see example in Fig. 32). We therefore decided to install metering devices analogous to the existing ones (see Fig. 31).

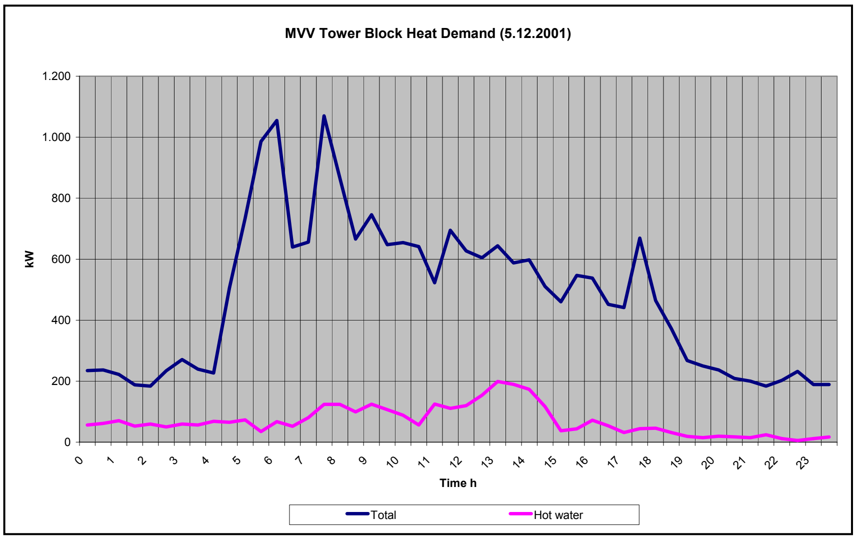


Figure 32. Heat Demand MVV Tower Block.

Data is recorded systematically since March 1, 2001. There is time synchronous recording of energy consumption, flow and temperatures (table 13). Starting on November 1 some selected indoor temperatures will also be recorded.

Table 13. Data format.

Datum / Uhrzeit	Aussentemperatur	Vorlauftemperatur	Rücklauftemperatur	Zählerstand	Wärmeverbrauch in MWh	Zählerstand	Durchflussmenge in m^3
Date / Time	Outdoor Temp.	Inflow Temp.	Return Flow Temp.	Counter	Energy Consumption	Counter	Flow
8.2.2001 17:00	14,55	67,20	46,10	4		194	
8.2.2001 17:30	14,62	67,10	44,95	4	0	197	0,3
8.2.2001 18:00	15,10	67,60	45,60	5	0,1	200	0,3
8.2.2001 18:30	15,02	67,65	46,20	5	0	203	0,3

The typical course of the daily heat demand is presented in figure 33. As it can be seen heat demand peaks in the early morning between 4:00 h a. m. and 8:30 h a. m. when the air central starts and the operation of the system is switched from the above mentioned "economy-mode" to the normal "comfort-mode".

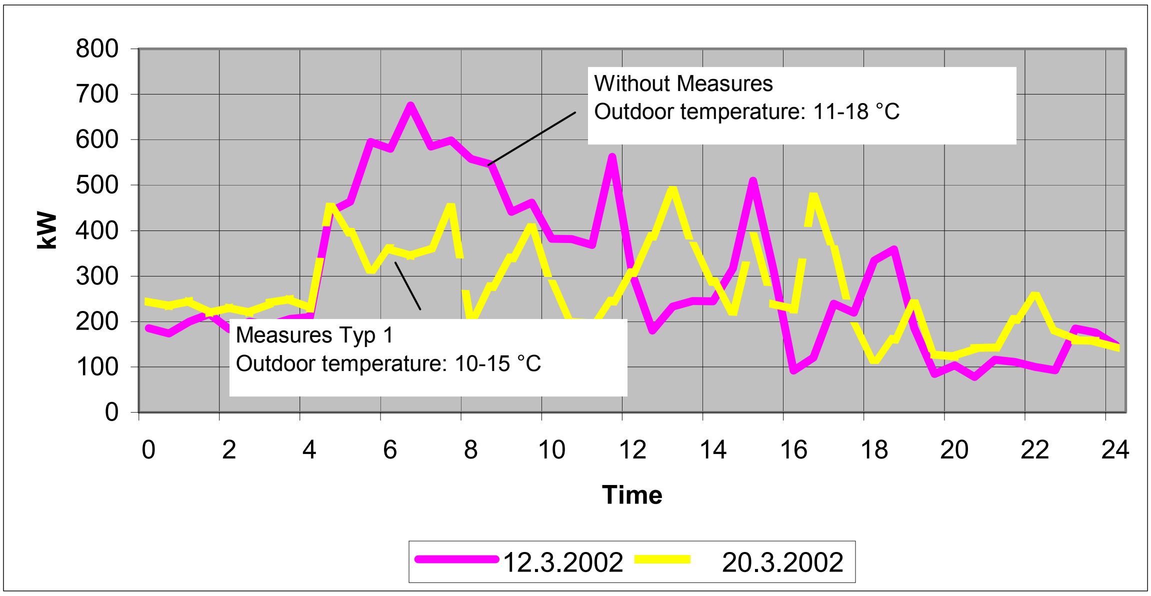


Figure 33. MVV Tower Block's Heat Demand.

The exact start time of the air central is determined by the software such that an indoor temperature of at least 21,5 °C is guaranteed at 6:30 a. m. The software wants to minimise energy consumption and therefore starts operation as late as possible. The unintended consequence of this strategy is the observed load peak.

To reduce the above mentioned load peak in the early morning hours we tried the following approaches:

1. Step by Step increase of the indoor temperature set point during the above mentioned "economy-mode" from 19 °C to 21 °C at 3:00 a. m. and 21,5 °C at 4:00 a.m. From this follows that the heat demand to increase the indoor temperature to the required 21,5 °C is shifted to night-times when the air central doesn't work. We called this way of operation "Measures Type 1"
2. As has been explained currently the exact start time of the air central is determined by optimisation software. In the second approach we replaced this software routine by a fixed schedule:

   4:00 a. m.: start of operation of the air central
   4:30 a. m.: increase of the indoor temperature set point to 22,2 °C at the north side
   5:00 a. m.: increase of the indoor temperature set point to 22,5 °C at the western side
   5:30 a. m.: Increase of the indoor temperature set point to 22,0 °C at the south side
   6:00 a. m.: increase of the indoor temperature set point to 22,0 °C at the eastern side
   We called this second way of operation "Measures Type 2"

Both measures had been realised and tested during one week (Measures Type 1: March 18. to 22. 2002, Measures Type 2: April 1 to 5. 2002). Daily courses of heat demand are presented in figure 33 (Measures Type 1). As can be seen the peak load has been substantially reduced through Measure 1. We employed regression calculations to assess the effect of the measures over the entire period of data collection but we did not get a clear cut result. There is some evidence that Measures Type 1 may be an effective way to reduce heat demand peaks.

5. DSM measurements and analyses in the test buildings

5.1 Governmental Centre in Jyväskylä

The office building of Governmental Centre was a good case building for DSM tests as its heating load pattern is that of a typical office with high daytime load and morning peak load. The thermal capacity of this concrete building is high which enables effective DSM cuts. The cut off made by reducing the heating supply temperature for a period of about three hours did not cause any uncomfortable indoor temperatures even during the extreme cold winter period in January 2003. In the beginning of January the outdoor temperature in Jyväskylä was about –30 °C which did mean some 27 °C reduction in the heating supply temperature. During the transient test in December 2002 (in Fig. 34) it was not so cold weather (–8 °C) but as the cut off period of heating and ventilation (during night-time) was seven hours long then the greatest drop of indoor temperature was 3 °C and the drop of average indoor temperature of eight measurements around the building was 2 °C. The smallest temperature drop measured during the transient test was only 0,5 °C. The location for the temperature measurement of DSM reset function must be carefully selected to secure the indoor comfort when preset DSM cut period is long lasting.

DSM cut off was tested already before the transient test by using the two lower DSM control curves (–20 and –40 %) programmed in the controller unit. As the effects of these reductions were too modest and as the transient test with several temperature control measurements show that the thermal capacity in all parts of the building is high enough the lowest pre-programmed control curve (–60 %) was taken into use.

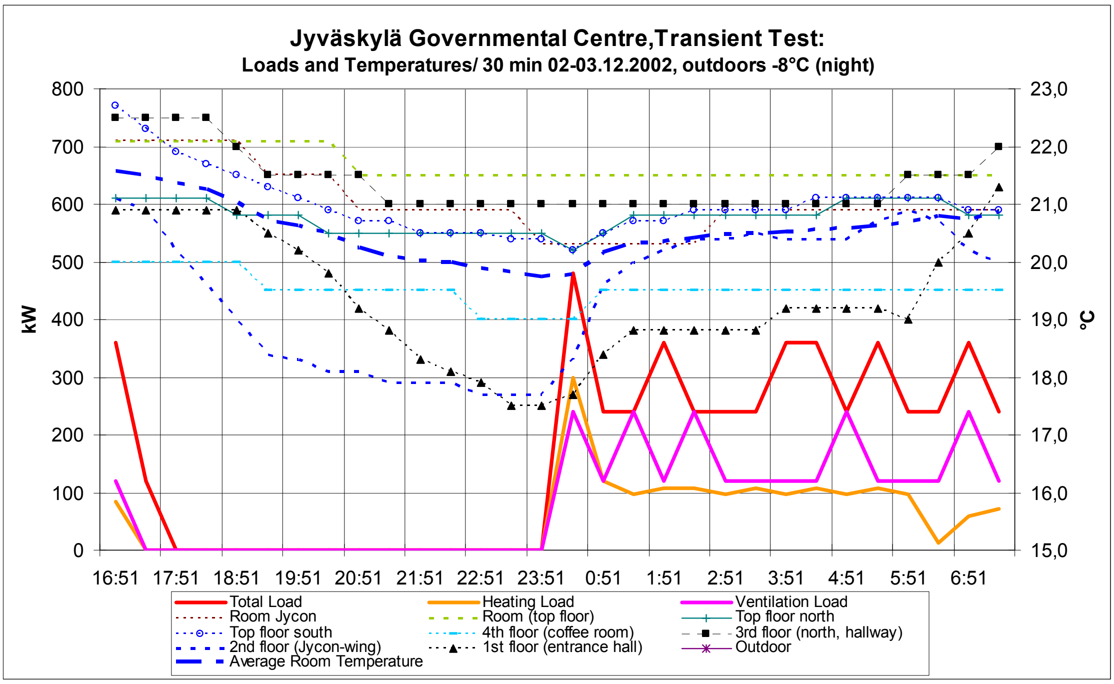


Figure 34. Transient test in December 2002.

As the flow temperature is reduced during the DSM (shown in Fig. 35) cut the heat demand of heating system drops a lot at the beginning of DSM period, until the thermal capacity of secondary network is fully utilised. As the flow temperature is low compared to present heat demand the flow rate increases rapidly as all radiator thermostatic valves are opening to fully open position. The level of return temperature follows rapidly the drop of the flow side temperature.

In the ventilation intake air heating the temperature remains almost untouched as the temperature compensation of ventilation air is reduced by 2 °C for the DSM period.

The period of maximum cut off period is some 30 minutes and after one hour the heat demand reaches the balanced level. This same time constant is valid when the preheating is applied. The effect of preheating is much reduced as the thermostatic valves are closing very soon and the flow rate of network gets small and the average temperature of the radiator network stays low. By increasing the flow temperature to reach 20 % higher heating capacity such high increase of heating is effective only for a short period (< 1 hour) and for the rest of preheating period (3 hours) there is only +5 % higher heating load than the normal load because of thermostatic valves. It can be seen that has not very important part in the scale of the whole building. Locally the preheating is important in rooms where the risk of freezing is high like in entry wind boxes. The radiators of entry wind boxes are normally without thermostatic valves. There the preheating of building materials is effective during early morning hours when the doors stay closed.

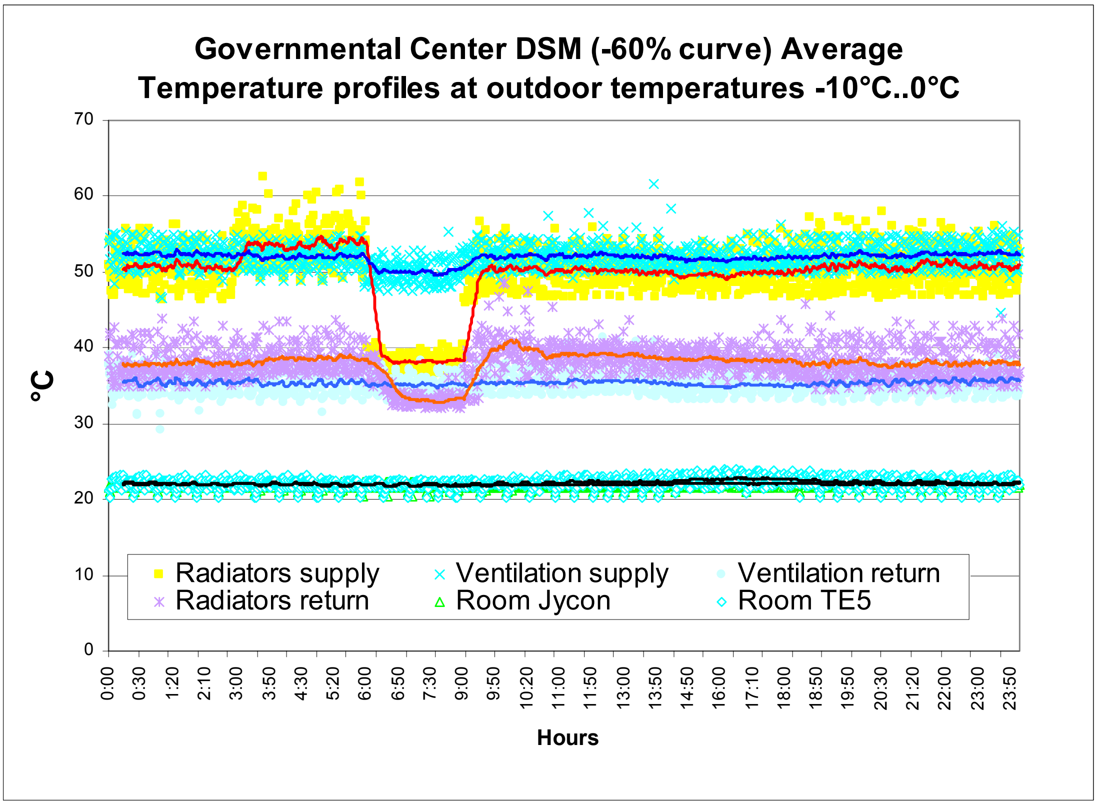


Figure 35. The flow and return temperatures of ventilation andradiator circuit during preheating and DSM periods.

The maximum temperature reduction at DSM cut off was limited to secure enough heating capacity to the critical points of radiator network and to maintain the top temperature of radiators at high enough level to give impression of heating in such situation. When the top temperature of radiators stays above 40 °C it still reduces the draft at the windows and maintains the comfortable feeling even when the radiator is touched by hand. The maximum DSM load reduction level at supply temperature was limited to –60 % of the normal load level (in Fig. 36). At the beginning of the DSM period this temperature reduction leads to maximum load reduction of –80 % for a period of 30 minutes and after following 30 minutes the load reduction recovers to level –30 % to –20 % of the normal heating load. Because of increased flow during the DSM actions in the secondary network is the actual reduction of heating capacity less than a half of the figures calculated by using constant flow condition.

The increase of heat consumption because of DSM is caused by the preheating period as the temperature of radiator network is high compared to the normal case when some night time set down of flow temperature is applied. The heat consumption of this case building has increased (about 50 %) during the test period, but the ventilation system with intake air heating is replaced (the capacity is higher than before test period) since the beginning of tests it is not possible to tell what is the effect of DSM. It is evaluated that the share of total increase is 40 % to additional ventilation capacity and 10 % to DSM. The results in outdoor temperature –10 to –20 °C and –20 to –30 °C are presented in appendix 2. The influence of DSM cannot be told exactly as the heat consumption has been rising because of increased ventilation (because of problems with high humidity). The outdoor temperature corrected consumption does not take into account the effects of the sun and the wind.

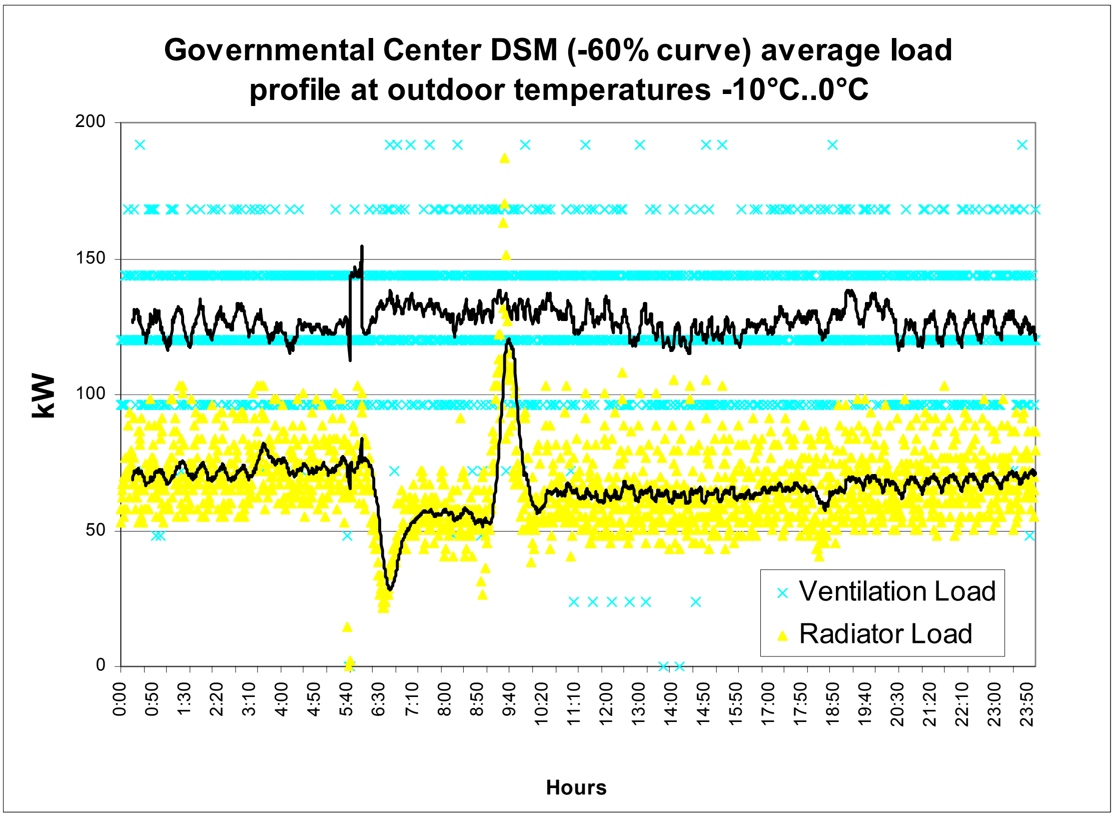


Figure 36. Loads of ventilation and radiator heating during DSM operation in winter 2003.

The ventilation system does not start to compensate the reduced heating as the DSM period is short enough compared to the preset temperature reduction of in-blowing air (–2 °C of the normal).

The analysis of the temperature and load measurements of the Governmental Center gives reason to reduce the length of preheating period to maximise the network temperature just before the DSM cut off. When normal night time set down of flow temperature is used just before the short preheating the flow rate in the whole radiator network stays high during the preheating and maximum heat can be accumulated in a short accumulation period. The flow rate at the entry wind boxes must be measured or secured by temperature measurements during the DSM cut off period if the preheating is minimized.

Here was in use a computer based centralised control system where all kinds of changes are possible to be implemented by modifying the program. When making the DSM and preheating curves it was noted that the system is still somewhat too complicated and hard to be adjusted to meet all the needs of this demonstration project. The peak after DSM period is the most visible result of simplified control measures. This high after-peak would not exist if some floating or other slow control measures were used in the control of flow temperature. The controls of flow temperature were somewhat unstable already before DSM was applied and the fast changing temperatures and flows made the system even more unstable when the DSM preheating and cut off was used. The control was stabilized a lot by changing the control parameters to slow down the controller.

The idea to use the original shaped control curves was created to be easily applied with the all existing controllers by using an external device to adjust the preheating and DSM curves with the proprietary down and upward slopes. Here it might be a better solution to use a same kind of change of temperature level as it was used with the compensation of ventilation air controller.

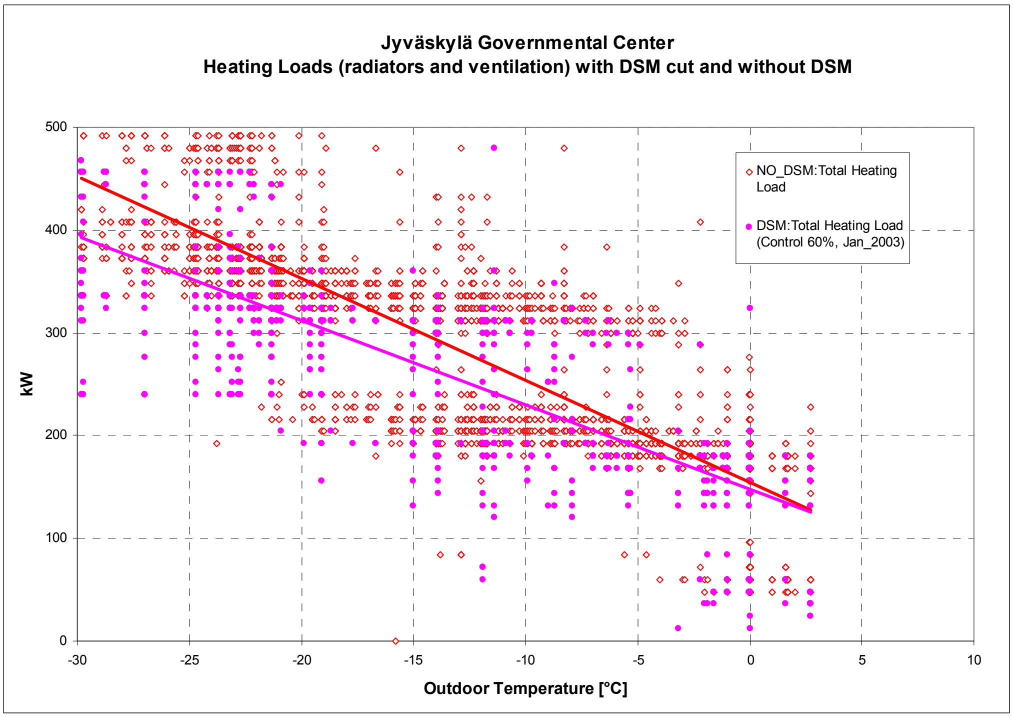


Figure 37. Impact of DSM in Governmental Centre to thermal power compared to periods without DSM as a function of outdoor temperature.

The impact of DSM to thermal power in Governmental Centre is presented in figure 37. The half an hour thermal power marks are printed as a function of outdoor temperature when DSM is used or not used. Regression lines represent the DSM tendency as a function of outdoor temperature. DSM cuts thermal power about 15 % at maximum and there are no DSM when outdoor temperature is more than +3 °C.

5.2 Kortepohja Citizens Day Centre in Jyväskylä

The building of Kortepohja Day Center was not an easy case building for DSM tests as its heating load pattern is very much changing during daytime and the peak loads exist all day. The building is occupied by old people and nurses also during the night-time. Thus constant ventilation and stable temperature condition are needed. The thermal capacity of this building is high enough to enable effective DSM cuts. The cut off period of three hours by using reduction curve of –60 % (31,5 °C reduction in heating supply temperature) did not alone cause any uncomfortable indoor temperatures even during the mentioned extreme cold winter period in January 2003. It was found that the heating capacity of entrance hall with high windows is too low even without the DSM. As the people were used to this cold region of the building also before the test the low temperature did not cause any complaints.

At the beginning of DSM demonstration in September 2002 that there were noted the unstable supply temperatures of both radiator and ventilation. This problem could not able to be solved by changing the parameters of controller program. As the ventilation was connected in series with the radiator loop, the temperature reduction of radiator circuit was reflected directly to the heat supply of ventilation. This series connection was not documented in the PI drawings and therefore it was not noted before the DSM operations were applied with major supply temperature reduction. The capacity of the heat supply was not enough to serve both the radiator and ventilation heating. The supply temperatures were unstable in the both circuits. The control parameters were updated to make the control more stable but as the flow capacity was not large enough, the result was that the piping of heating networks was separated right after the heat exchanger.

As this building is continuously occupied it was difficult to arrange the transient test. The ventilation must be on all the time and as the connection of heating water system of ventilation was originally connected in series with the radiator network it was not possible to stop heating without disturbing the ventilation. As the connection of heating networks and ventilation was finally changed in parallel connection, a partial transient test was possible.

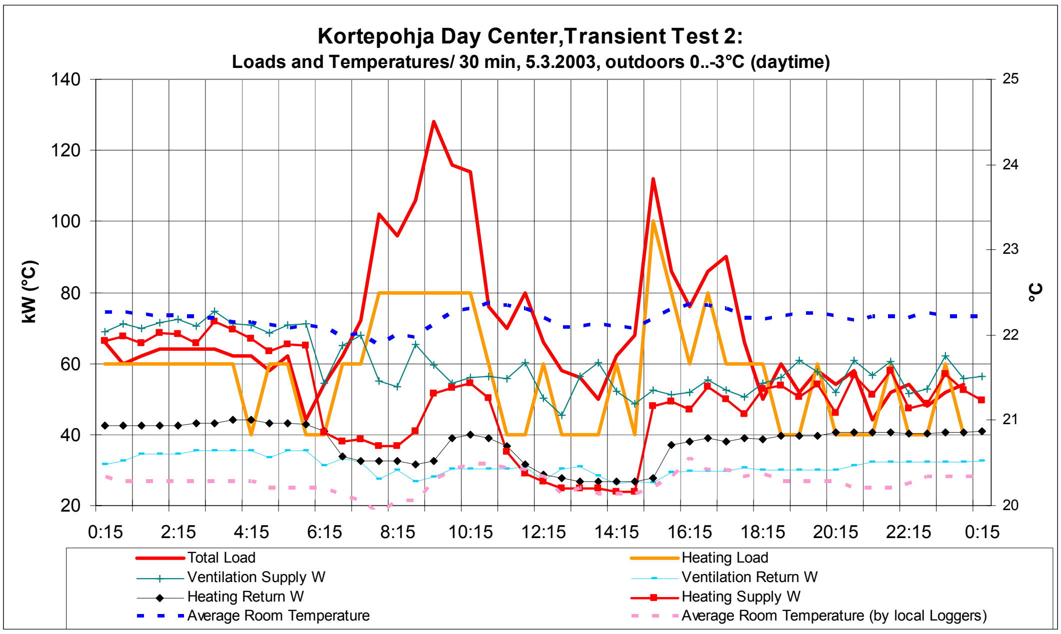


Figure 38. Transient test in the March 2003.

During the transient test in March 2003 the outdoor temperature was (–3C…0 °C) and the cut off period of heating was five hours at maximum and the largest measured drop of indoor temperature was 0,8 °C as shown in Fig. 38. The average temperature did not change more than 0,2 °C. Some room temperatures did even increase during the test so this calculated temperature drop cannot be used to present the thermal capacity of this building.

As the flow temperature is reduced during the DSM cut the heat demand of heating system drops at the beginning of DSM period, until the thermal capacity of secondary network is fully utilised (see Fig. 39). When the flow temperature is low compared to present heat demand the flow rate increases rapidly while all radiator thermostatic valves are opening to fully open position. The level of return temperature follows rapidly the drop of the flow side temperature. The demand of heat increases also during the DSM period as there is increase in heating of therapy rooms and also the heating of ventilation is connected to the radiator network.

The temperature compensation of ventilation air is reduced by 2 °C for the DSM period but it is obvious that the demand of ventilation increases in the morning during the DSM period and thus the heating load increases.

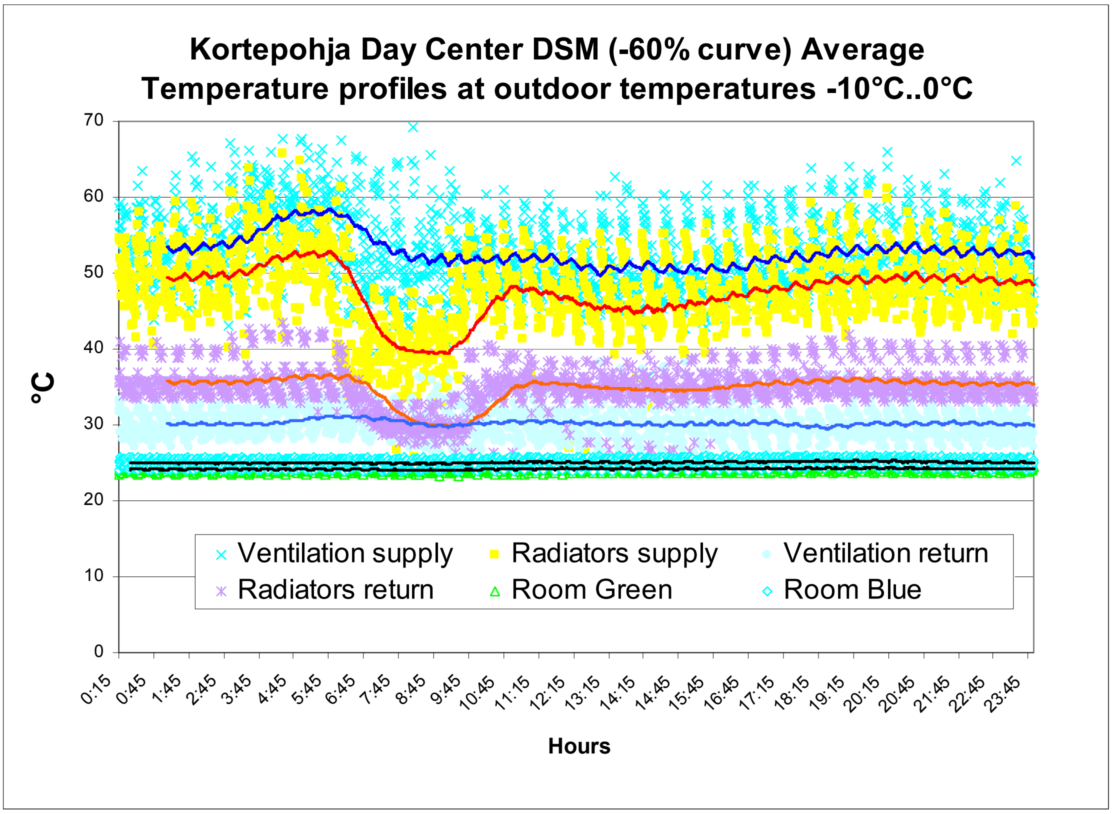


Figure 39. The flow and return temperatures of ventilation and radiator networks during the preheating and the DSM periods.

Maximum cut off period is some 30 to 60 minutes and after one hour the heat demand reaches the balanced level (in Fig. 40). This same time constant is valid when the preheating is applied. The effect of preheating is much reduced as the thermostatic valves are closing very soon and the flow rate of network gets small and the average temperature of the radiator network stays low. By increasing the flow the temperature reaches 20 % higher heating capacity. This high increase of heating capacity is effective only for a short period (< 1 hour) and for the rest of preheating period (3 hours) there is only 5 to 10 % higher heating load than the normal load because of thermostatic valves. Locally the preheating is important in rooms where the risk of freezing is high like in the large entry hall with wide glass wall. The radiators of entry wind boxes are without thermostatic valves and the main entrance is equipped with a heating coil unit.

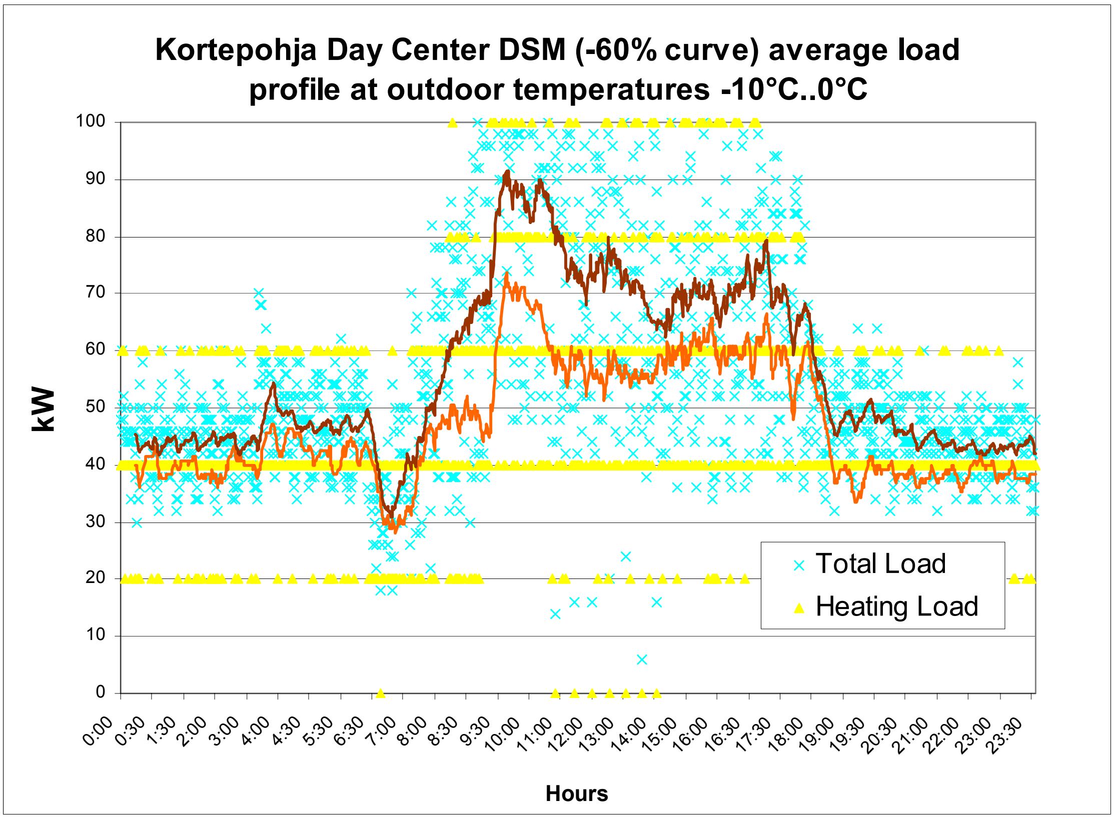


Figure 40. Loads of ventilation and radiator heating during DSM operation in winter 2003.

The maximum temperature reduction at DSM cut off was limited, such as it was done also in Governmental Centre, to secure enough heating capacity to the critical points of radiator network. There were no complaints during the DSM tests while the temperature of radiators was kept above 40 °C. It was enough to prevent the draft at the windows and to maintain the hand comfortable heat of radiators.

The maximum DSM load reduction level at supply temperature was limited to –60 % of the normal load level. At the beginning of the DSM period this temperature reduction leads to maximum load reduction of –30 % for a period of 30 minutes and after following 30 minutes the load reduction recovers back to the level before the DSM cut off. Because of increased flow of radiators and other changing heating demands the actual DSM reduction of heating capacity is difficult to define. The results in outdoor temperature –10 to –20 °C and –20 to –30 °C are presented in appendix 2.

Also in Kortepohja Day Center some increase of heat consumption has been noted. The outdoor temperature corrected consumption was increased by about 5 %. As there have been no major changes in heating system, this increase is probably because of DSM preheating. It is not possible to define the exact increase because of DSM as the consumption of heating and ventilation was also decreased by 16 % since the autumn

2001. The use of building is different during different periods and the correction made by outdoor temperature does not take into account the other parameters like the sun and the wind.

The analysis of the temperature and load measurements of the Kortepohja Day Center gives reason to shorten the length of preheating period to reduce the heat consumption and to maximise the network temperature just before the DSM cut off.

The reference measurement data of room temperature by the portable loggers did show that the heating capacity of the entrance hall is not enough. No DSM can be applied in this building before the heating capacity is improved to secure the indoor comfort of this largest living room of the building.

The impact of DSM to thermal power in Kortepohja Day Centre is presented in figure 41. The half an hour thermal power marks are printed as a function of outdoor temperature when DSM is used or not used. Regression lines represent the DSM tendency as a function of outdoor temperature. DSM cuts thermal power about 20 % at maximum and there are no DSM when outdoor temperature is more than +5 °C.

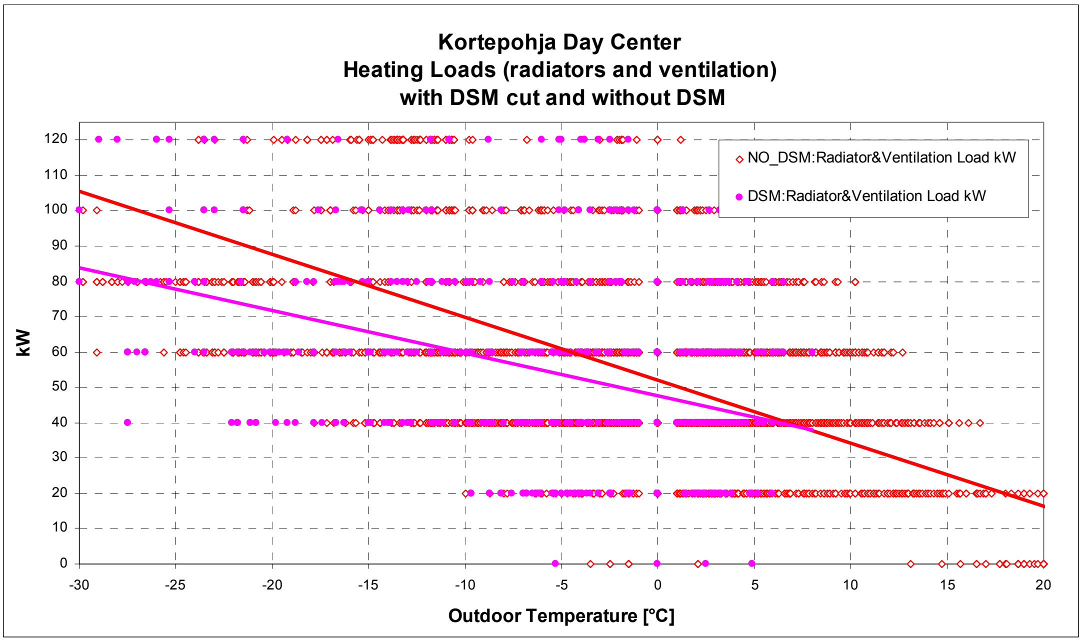


Figure 41. Impact of DSM in Kortepohja Day Centre to thermal power compared to periods without DSM as a function of outdoor temperature.

5.3 Tower Block in Mannheim

5.3.1 Methodology

Due to the large amount of different impacts on the building's heat demand peaks it turned out to be not feasible to evaluate the measures by simply comparing daily heat demand curves with and without measures. As the impacts – particularly the outdoor temperature- vary from day to day so does the daily heat demand peak. It was therefore necessary to develop statistical and graphical software tools to evaluate the results. We did so by using the scientific programming language MATLAB.

We then followed a step by step approach:

- To collect data during periods when the measures have been activated and without measures for comparison
- Data analysis by using a specific software-tool which had been implemented in the course of this project.
- Plotting the characteristic curves: daily maximum as a function of the outdoor temperature with measures and without measures
- Evaluation: The characteristic curve which shows heat demand peaks "with measures" should be substantially lower than the curve "without measures" within the relevant range of outdoor temperatures.
- In order to assess the economic benefit (or loss) the building's heat consumption in kWh per degree hour has also been recorded

The software-tool detects for all days of the data sample the daily maximum of heat demand. It is possible to specify a certain number of daily maximum values to be considered. In our analysis we used the three highest daily heat demand values. These values are stored in an array together with time and outdoor temperature. In order to achieve comparable data samples we have specified a range of outdoor temperatures (–8....+8 °C). Only heat demand peaks, which happened during an outdoor temperature within this range have been considered. We also did not use data collected during Christmas holidays and New Years Eve, due to the not typical operation of the building. Weekends and holidays during which the building's air conditioning system operates at a reduced level have also not been considered.

Around 96,6 % of the heat demand peaks in the district heating network in Mannheim take place between 6–9 h a. m. Heat demand peaks in the building which happen during periods of low load in the network do not have an adverse effect to production costs. We therefore considered heat demand peaks in the building before or after this time range not to be relevant in this context. This means that it will be considered as a success when as a consequence of the measures the building's peak demand is shifted into times of low demand in the network.

5.3.2 DH DSM Measures and Data samples

Two different approaches have been tested to reduce the district heating peak demand in the MVV Tower Block:

1. To shift heat demand to night time by step by step increase of the indoor temperature set point beginning at 2:30 a. m. (measure type 1)
2. To start air conditioning separately at each side (heat loop) of the building beginning at 4:00 a.m. with an 0,5 h time difference (measure type 2)

The system normally operates by using a specific software which only aims to reduce the heat consumption as described in Chapter 2.3. This way of operation serves as reference "without measures". During the two approaches "measure type 1" and "measure type 2" the optimisation software had been deactivated.

To undertake the analysis we used data which had been collected during the last winter 2002/2003. Data of the previous winter had not been used in the final evaluation due to modifications in the measuring concept, particularly the separate measurement of the heat demand for hot water preparation which was only available during the last winter. Previous measurements showed that the impact of the hot water preparation on the buildings heat demand can not be neglected, as had initially been assumed. The time periods during which we have collected the data which formed the basis for the analysis are presented in table 14.

Table 14. Data collection in Mannheim.

Measure	Time of data collection
Without measure	01.11.2002–10.11.2002 18.11.2002–23.12.2002 20.01.2003–31.01.2003 24.02.2003–31.03.2003 12.04.2003–3 0.04.2003
Measure Type 1	11.02.2003–21.02.2003 02.04.2003–11.04.2003
Measure Type 2	03.02.2003–07.02.2003

5.3.3 Results at the MVV Tower block

Figure 42 shows the daily heat demand peaks at the MVV Tower Block, which have been measured during the last winter. For each peak there is presented the value above the corresponding outdoor temperature. The figure has been determined by using the software tool as described in chapter 5.3.1.

In figure 40 we distinguish between the categories "without measures" (blue *), “measures Type 1” (red +), and “measures Type 2” (green x). We then approximate the data with second degree polynomials which fit the data in a least square sense. The polynomials are presented as curves. Additionally for each category we computed the heat energy consumption per degree hour (dh).

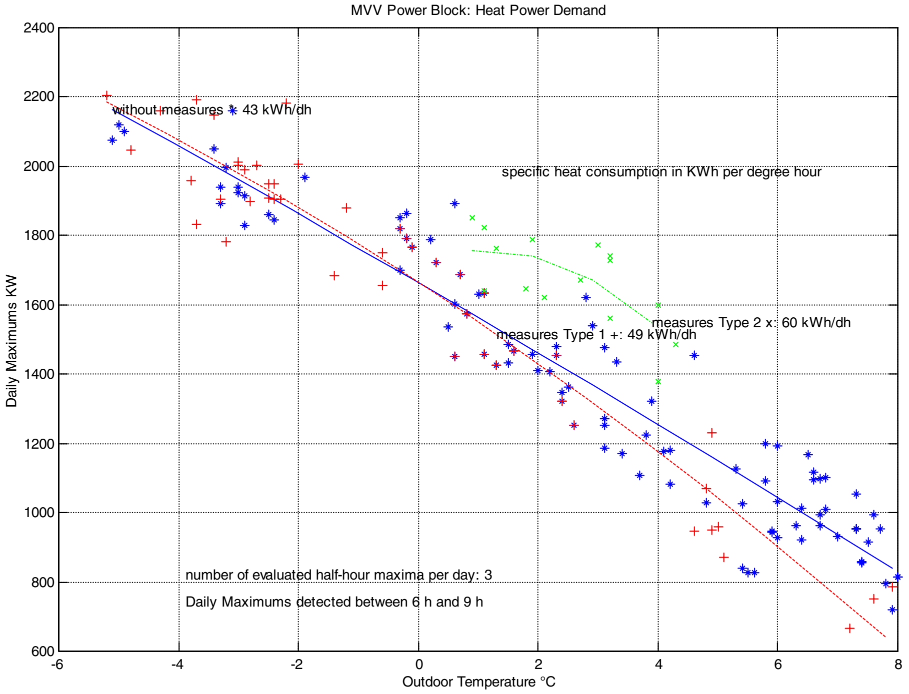


Figure 42. Analysis of the results of DH DSM measures.

As can be seen by comparing the corresponding curves with measure Type 1 we could reduce the average daily heat demand peak at outdoor temperatures above 0 °C. At the average outdoor temperature during the winter seasons (Nov.–Feb.) in Mannheim (around 2,7 °C) measure Type 1 does substantially reduce peaks by around 4,1 % or 50 kW, but is accompanied by the stated increase of energy consumption from 43 kWh/dh to 49 kWh/dh (14 %).

There is no reduction when the outdoor temperature is extremely cold. As also can be seen from the figure we could not achieve any peak-reduction with measures Type 2, but rather the peaks did actually increase.

The dismal result of measure Type 2 may be explained by the behaviour of the PI controllers which are implemented in the building's control system. The valves do open completely during a short time when each heat loop is switch to the "comfort mode". This effect has a more accentuated impact on the peak demand than has the "one after the other" start of the heating loops.

Measure Type 1 has no effect during very cold days. This is due to the fact that the software which normally controls the building's heating system tends to start the air conditioning system earlier when outdoor temperature is lower. It does so to insure the desired indoor temperature of 21.5 °C at 6:30 a. m. Consequently measure Type 1 does not make any difference during cold days.

6. DH DSM in use

6.1 Benefits of DH DSM

6.1.1 Supplier

Peak loads at the customers are the result of the way how the customers operate their heating system. The purpose of DSM is to reduce peak load during the time when marginal costs in production are highest. There are several strategies, which the supplier may engage to reduce peaks in the DH network. A different approach would be to assume control of the customer's heating system.

The most convenient and economic way to DSM depends on various circumstances and is to be defined in this project.

The benefits of DSM in the supplier's view are:

+ Lower network additional investment costs due to the possibility to use pipes more effectively by DSM. This refers to the yearly peak of water flow in m^3/h. Daily fluctuations in heat power megawatt size (MW) demand do hardly influence necessary diameters. DSM is a tool for peak load cutting, not a tool for reducing the dimensions.

+ Lower costs for heat production due to the higher share of co-generation and fewer start up for peak load boilers. Daily fluctuations in heat power demand do influence in production costs. The electricity impact is bigger than thermal impact in CHP-plant. For example remuneration of heat delivery in Mannheim is based on the electric power drop due to heat production at the thermal power plant. The electric power drop per MW heat as well as the energy needed for pumping increases as the heat load increases.

The supplier is only interested in total heat load of the entire network. Peak loads existing at different time in consumers' side smooth the peak load in the DH-network to supplier side. Also capacity of the network helps to compensate peak load. The peak of a specific customer which happens to fall into times of generally low demand does not influence the supplier's costs.

6.1.2 Consumer

A consumer does not think so much of technical aspects living in the house at comfortable indoor climate or using hot water. Thus after increasing bills or not acceptable reliability (indoor temperature varies or there is no hot water) the consumer wakes up to ask reason for that. The consumer is interested in DSM, if he could save money through accepting the DSM and it does not complicate his daily life in the house.

Benefits of DSM for the consumer can be listed:

+ Lower running cost, if heat loss and/or pumping energy are lower.

+ Lower energy cost, if the consumer can decrease consumption and move it to cheaper price period (if two tariff or time depending tariff price is used).

- Through DSM the consumer cannot necessarily lower his investment and fixed tariff cost because of not being guaranteed the cut when peak load will exist.

6.2 How to carry out DSM

The supplier may use appropriate tariffs to encourage peak reduction. Alternatively he may define technical conditions in the contract, which provide for a smooth course of heat demand. Additionally the supplier may offer specific technical advice how to reduce load peaks in a cheap and convenient way.

The DH DSM influences can be divided in two parts: indirect and direct parts

6.2.1 Indirect influence on the demand at the customers

Indirect influences are ways to encourage the customer to utilise DSM himself. The customer can decide, if he wants to accept DSM and to utilise it. The supplier ways are

- customer information
    - peak load effect and when existing
    - saving to customer if peak cut
- technical requirements in the contracts
    - maximum flow to receive
    - requirements for connection
    - minimum outgoing temperature
    - minimum temperature drop (ΔT)
- tariffs based on
    - peak demand (flow, effect)
    - different energy prices during different time periods (ToU-tariffs: Time of Use Tariffs)
    - marginal production costs (dynamic pricing)

Implications to carry out DSM principles:

- flow limiters
- metering
- communication and IT (Information Technology)
- utilisation of customer automation by the customer

6.2.2 Direct load control by the supplier

The supplier controls directly the peak loads of consumers and activates some operation to avoid peak load in the DH-network. The operation of the supplier can be

- supplier controls/limits directly the load at customer when needed
  Implications to operate:
    - should be well defined so that the effect on the comfort at the customers is minimised
    - communication (preferable 2-way)
    - metering
    - integration of customer automation system
- Combination of innovative tariffs and direct load control
    - the supplier can control the load variation by dynamic tariff and the consumer itself will decide when cutting takes place, but in addition the supplier can also cut the loads if needed.
- Organisation way to carry out the DSM
    - customer can save money in contract fixed cost if the customer has accepted DSM operated by the supplier

6.2.3 Direct load control by the customer

The customer controls itself the peak load to save cost through tariff or agreement

- Load control by the customer (need from supplier through communication)
  The customer can operate manually heating system or properties are installed into automated control systems.

    - cuts for a while his space heating if hot water is used
    - can utilise a heat storage if installed
    - let inside temperature of the whole building decrease
    - let some room temperatures decrease; rooms where there is nobody at the moment (room control needed)

6.2.4 Third party access

The same principle as ESCO- contract.

- A service company makes a contract with the consumer to take care of the building. The service company will finance investments and his own costs by savings. However, the indoor climate circumstances of the consumer must beguaranteed by the service company.

6.3 Share of the benefits

The DH-cost of supplier and consumer consists of investment, energy, driving and maintenance. The most largest part of DH-costs become investment and used energy (Tables 15 and 16). The smaller part of costs consists of energy used in auxiliary devices and operation staff. The maintenance costs has a tendency to increase when devices are ageing.

Table 15. DSM investment activities of supplier and consumer.

DSM Investment Activities	
Supplier	Consumer
less boiler capacity	addition to building automation system
less pump capacity	
addition to flow limiter	
addition to metering	
addition to communication	
addition to heat storage tank (if not before)	

Table 16. Saving in driving through DSM to supplier and consumer.

Saving through DSM	
Supplier	Consumer
lower pumping energy at peaks	lower fixed cost; connected capacity is limited
fewer starts of peak boilers	lower driving cost, if ToU-tariff is used
lower fuel cost	

6.3.1 Case study in Jyväskylä

6.3.1.1 Background

In the case of Jyväskylä city there is a district heating network with about 300 MW_{th} maximum consumption. It was estimated that there are so many customers connected to demand side management that the daily peak demand can be reduced by 10–20 % when needed. From this basis it was assumed, how many starts of heat-only boilers could be avoided annually. Peak cut of 20 % in Jyväskylä means about 160 buildings of the size of the Governmental Centre (20 000 m^3) or 460 buildings like Pensioners' Day Centre (7 000 m^3) in Jyväskylä. As a town building area it amounts to 150–300 hectares (about 370–740 acres). The time the boiler was assumed to feed the network with the capacity, which it has based on DEM simulation. When the boiler is shut down, there was assumed to be about a half hour tail heating period for the boiler in 25 % load what was before shut down. When the boiler is started, the pre-heating load is assumed to be a half hour in 25 % load when connected to the network.

Shifting the heat load of a building is based on exploiting the thermal mass of the building and the secondary networks. The research made in two case buildings during winter 2002–2003 shows that the maximum heat load of a massive building (body of concrete) can be temporarily (during 2–3 hours) reduced as much as 20–25 % on the average. In cases studied the room temperature was temporarily lowered or raised at maximum 2 °C, but this large temperature changes did not occur during the normal test conditions. When this kind of measures are performed in a large number of buildings simultaneously, the total load of a district heating network can be lowered up to 25 %.

The peaks usually occur in the morning and/or in the evening due to simultaneous starting and shut-down of building heating systems, especially in commercial buildings (offices, schools, etc.). These time bounded peaks in typical buildings can be easily shifted by timer controlled DSM measures. A more sophisticated DSM can also include active reducing of certain key customers' load so that their load would be high when the other's is low and vice versa.

Cutting down the total load in a district heating network can be avoided starting some peak heat-only boilers during a 24-hour period. However, the same amount of heating energy (or slightly more) needs to be produced as without any DSM measures. This energy can then be produced in a more efficient way than with a heat-only boiler, for example with a combined heat and power (CHP) plant.

Avoiding the starts of heat-only boiler(s) results in direct savings (or profits) for the heat and power producer, which can be categorised in four groups:

- Saving the labour costs related to starting the heat-only boiler(s)
- Saving the fuel that is consumed in the heat-only boiler(s) during start-up and tailing (i.e. when the boiler is off-line, not feeding the district heating network)
- Producing heat with more inexpensive fuels than what heat-only boilers consume
- Producing electricity with the heat load in a back-pressure CHP plant

If demand side management can be successfully used, the designed heat demand can be reduced. This results in savings in the investment of district heating systems but may increase the investment of heat exchangers, secondary piping and radiators because the heating and ventilation load peaks during DSM recovery period. The best feasibility of DSM in the whole district heating and house system can be reached by keeping the use of DSM actions within limited outdoor temperature range.

6.3.1.2 Calculation results

Data for calculation

Heat-only boilers (HOB) are assumed to be run at load, based on simulation without any DSM activities, at each start-up (heating up and cooling off without feeding the district heating network). The boiler efficiency is taken as 85 %.

The fuel of heat-only boiler is heavy fuel oil (HFO), the current price of which is about 28 €/MWh (excluding VAT). The fuel for Rauhalahti CHP plant and Savela HOB B is milled peat, the price of which is about 12 €/MWh. Process steam for paper mill Kangas is taken out from intermediate pressure of turbine in Rauhalahti. Part of the process steam in Rauhalahti can also be produced in a separate HFO fired boiler. The increased DH- output of 20 % can received then from Rauhalahti CHP plant. The boiler efficiency of the CHP plant is assumed to be 90 % and power to heat ratio 0,45. The heating capacity data is presented in prioritised order in table 17. The temperature of outgoing DH water has a maximum 115 °C in winter and a minimum 75 °C in summer.

Total heat demand variation is presented in figure 43. Production is covered first by milled peat and after that by heavy fuel oil. Maximum heat was 343 MW in 2002 and total heat demand was 954 GWh. Electricity maximum power was 232 MW and electricity energy demand 971 GWh as shown in figure 44.

Table 17. Heat production data of boilers in starting order in Jyväskylä.

Unit	Heat output [MW]	Electricity output [MW]	Fuel	Obs !
Rauhalahti CHP	140	87	milled peat	process steam 65 MW
Savela boiler B	25		milled peat	
Savela boiler A1+A2	2x40		heavy fuel oil	These can be started
Kortepohja boiler	3x11		heavy fuel oil	also in reversed order
Varikko boiler	30		heavy fuel oil	
Nisula boiler 1 and 2	40+20		heavy fuel oil	
Kuokkala boiler	40		heavy fuel oil	
Savela boiler CHP	62	28	heavy fuel oil	

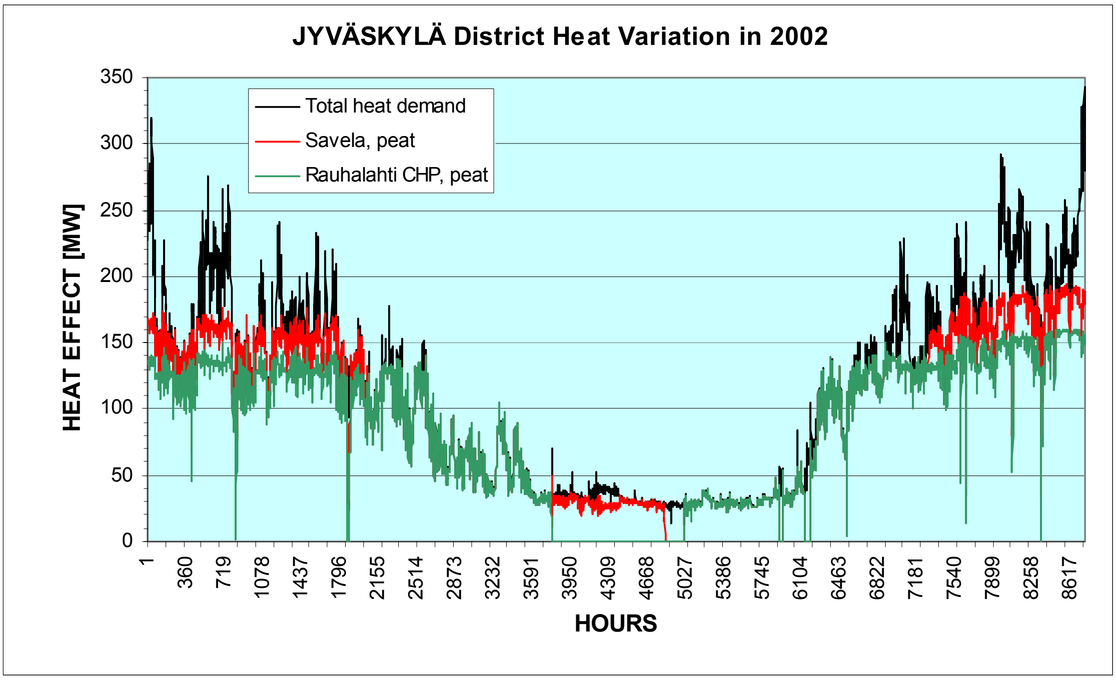


Figure 43. Heat demand and heat production by milled peat and heavy fuel oil in Jyväskylä.

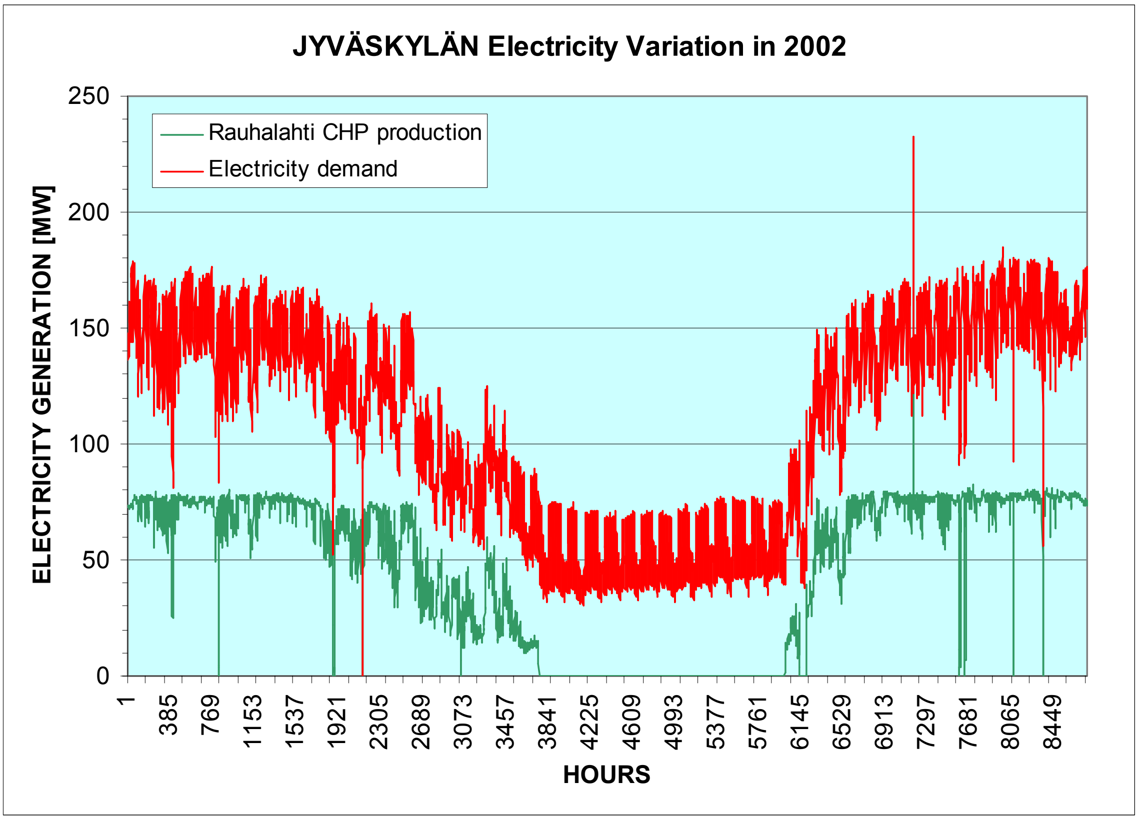


Figure 44. Electricity demand in Jyväskylä in 2002.

Calculation and results

Demand side management is done during 3 hours in the morning from 6:00 to 9:00 am, if HOB by HFO could be avoided to start or could be shut down. The post-heating period follows, when the cut energy was produced to balance the house circumstances. The DEM model finds 131 shut downs of boilers shown in table 18. The boiler shut downs are presented also in figure 45 shown with minus values and post heating periods are shown with positive values.

Table 18. Boiler shut downs when DSM is used in Jyväskylä.

Unit fuel	Savela peat	Savela hfo	Kortepohja hfo	Varikko hfo	Nisula hfo	Kuokkala hfo	Total
Shut down	0	85	1	38	1	6	131

In the case study the starts of heat-only boilers do not cause any additional man-hour costs, because the boilers are started and shut down using remote control. Also saved pumping in DH network during cut will be used afterwards in lifting period. The pumping head needed during off peak period is somewhat lower when the district heating network is operated at load condition where the additional heat is delivered by increasing the flow rate. If the DSM controlled customer is located at hydraulically most critical point of the network the savings of pumping can be remarkable through the whole heating season.

As there are no additional labour costs, the saving potential of DSM consists of three (3) components:

1. The fuel wasted when starting and shutting down the heat-only boilers
2. The net profit of back-pressure CHP electricity sales (average 10 €/MWh)
3. The differences in fuel prices and boiler efficiencies ($P_{hfo}/\eta_{HOB} - P_{peat}/\eta_{CHP}$)

Based on simulations of the DEM model of how to use energy production capacity, the total saving is 13 000 €/a in Jyväskylä case, when DSM is in use. Share of saving in the start-ups and tails of HOB is about 8 500 €/a. Thus it means an average saving of 82 € for each one of 160 consumers. There is a DSM investment of 845 € per consumer (5 %, 15 a).

If we assume to save an investment of 20 MW HOB (1,8 milj. EUR) because of DSM and we divide it to 20 years with 5 % interest, the additional saving will be 144 000 €/a and in addition maintenance and other fixed cost. It amounts to about 900 €/a per consumer in the Jyväskylä case.

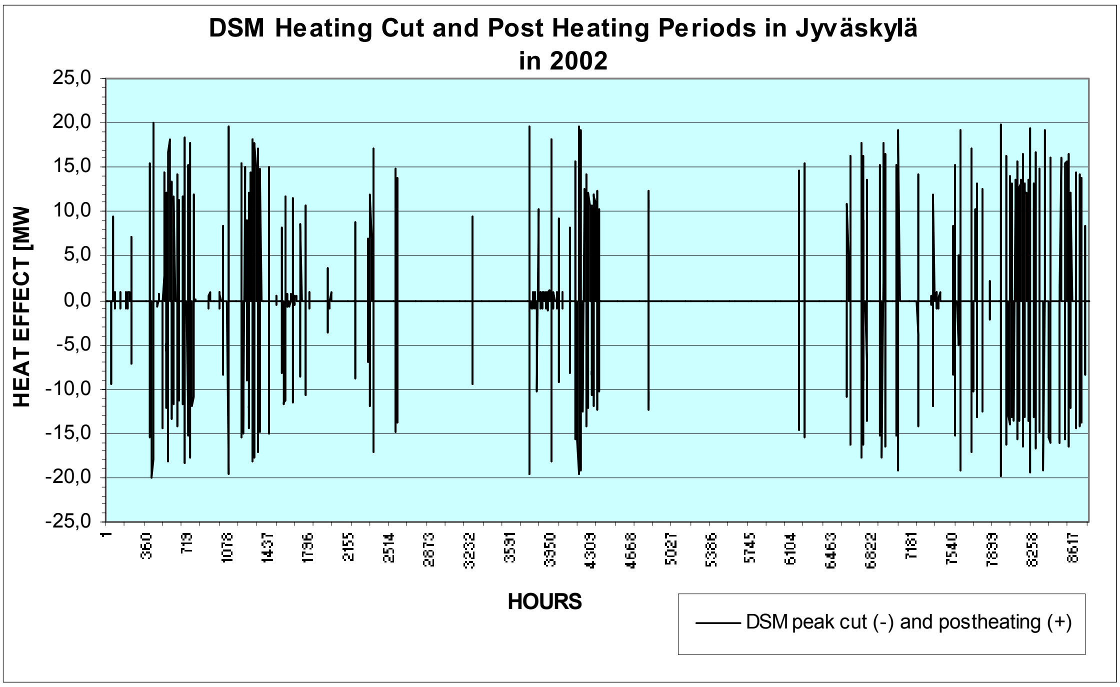


Figure 45. Peak cut and post heating periods in Jyväskylä.

Investments for DSM

The minimum investment to realise a simple autonomous (time and outdoor temperature guided) DSM control in a district heated building is around 900 €. This most simple version of DSM control lowers the heating loads always when the outdoor temperature is bellow the temperature limit where peak DH capacity is normally needed (0 °C) but still well above the temperature, which is critical for the recovery of normal heating mode (–20 °C). When heating system is dimensioned very close to the actual need there is no possibility to use DSM measures during the highest demand of heating. This would endanger the comfort of indoor climate as there is not enough capacity to raise the indoor temperature after a DSM reduction. If the whole heating system should be oversized just because of DSM, the DSM investment would not be economically feasible.

On demand operated DSM is possible to be realised either by TCP/IP protocol (via the internet) or by GSM-modem. As easy to operate and low cost DSM control technology is already available and it can be utilised to a large number of new and existing buildings the technological basis of DSM is solved. A GSM-modem may lead to the lowest investment cost (1 200 €/building) but the operation cost gets higher as the number of DSM controls is large.

Such as this study shows 20–25 % of the daily peak loads could be cut off using DSM. This large demand shaving by load shifting requires about 160 buildings with size of 20 000 m^3 (Governmental Center in Jyväskylä) to be connected to the DSM system. In buildings having size of 20 000 m^3 (heating load >500 kW) the investment should be as simple as possible and still be able to carry out DSM operations effectively. Pay-back time will be 15–20 years (5 %) in Jyväskylä case. If we assume to compensate DSM investment (160 x 900 € =144 000 €) with boiler investment then the estimated pay-back time for the rest of DSM investment (1200 – 900 = 300 €) will be about 4 years.

Appropriate measuring and data storing equipment is required in the registering of peak heating demand.

6.3.2 Case study in Mannheim

Almost the entire heat demand of the district heating network in Mannheim is met by the coal fired power plant in Mannheim GKM (see Figure 46). The power plant produces electrical power and heat in a co-generation process. Additionally there do exist two boiler houses in Mannheim, which are actually used as back-up heat sources.

The GKM is equipped with so called “district heating turbines” and with conventional turbines which use the River Rhine to condense the steam leaving the turbine. The steam leaving the “district heating turbines” flows into condensers which use district heating water as the cooling medium. A simplified diagram, which explains the process of district heat production at the GKM, is presented in figure 47. As a matter of fact, specific production costs per MWh do actually depend on the level of thermal power production. The application of demand side management with the objective to reduce peak demand will have an economic benefit.

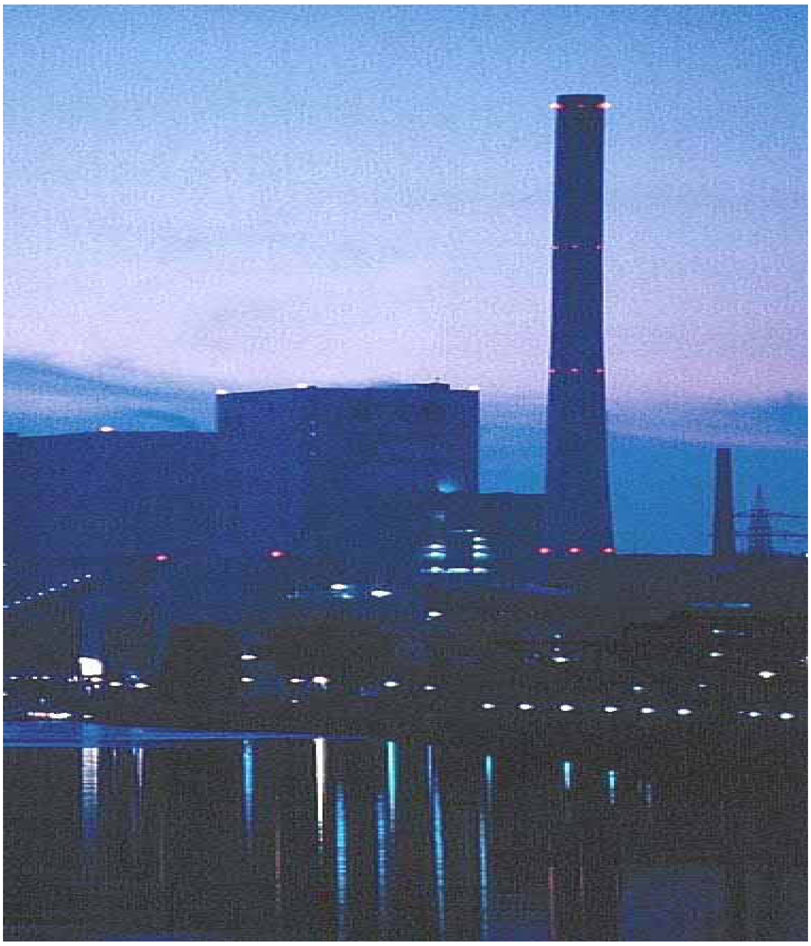


Figure 46. Power Plant in Mannheim GKM.

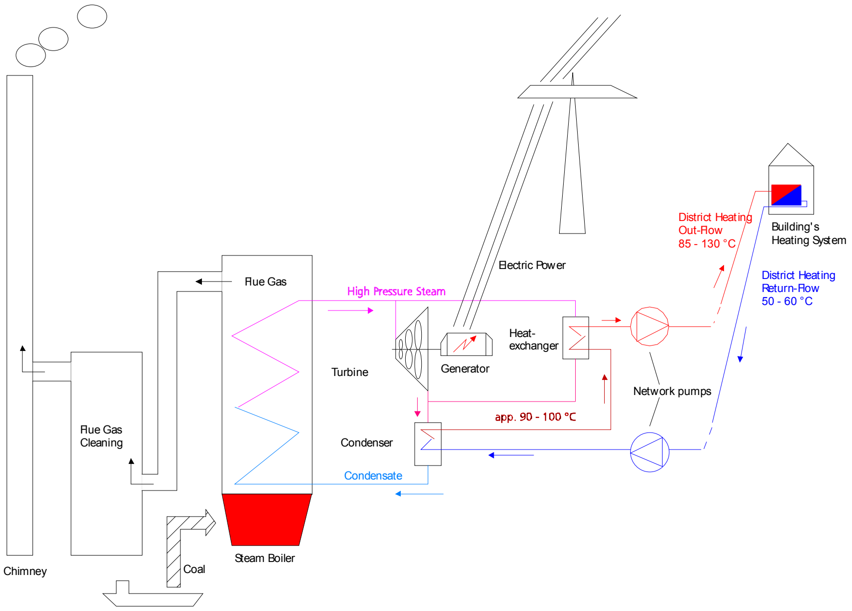


Figure 47. District heat production at the Mannheim GKM.

As can be seen in figure 47 the return flow of the district heating system enters the condenser of the steam turbine. In a co-generation process the district heating water condenses the outgoing steam and in the same time will be heated up to 90–100 °C. It therefore makes use of heat which otherwise would be left to the river Rhine.

Due to the fact that the maximum heat power, which can be extracted from the condenser is limited, the GKM is also equipped with heat exchangers which are heated by high pressure steam. These heat exchangers do operate in a similar way as peak boilers. The share of district heat which is produced by high pressure steam increases with the heat demand in the network. A reduction in the peak heat demand in the network would reduce the share of high pressure steam at the district heating production and simultaneously increase the share of co-generation. As high pressure steam could alternatively used to produce electrical power, the electrical power drop due to heat production and therefore the efficiency of heat production depends on the heat demand peaks.

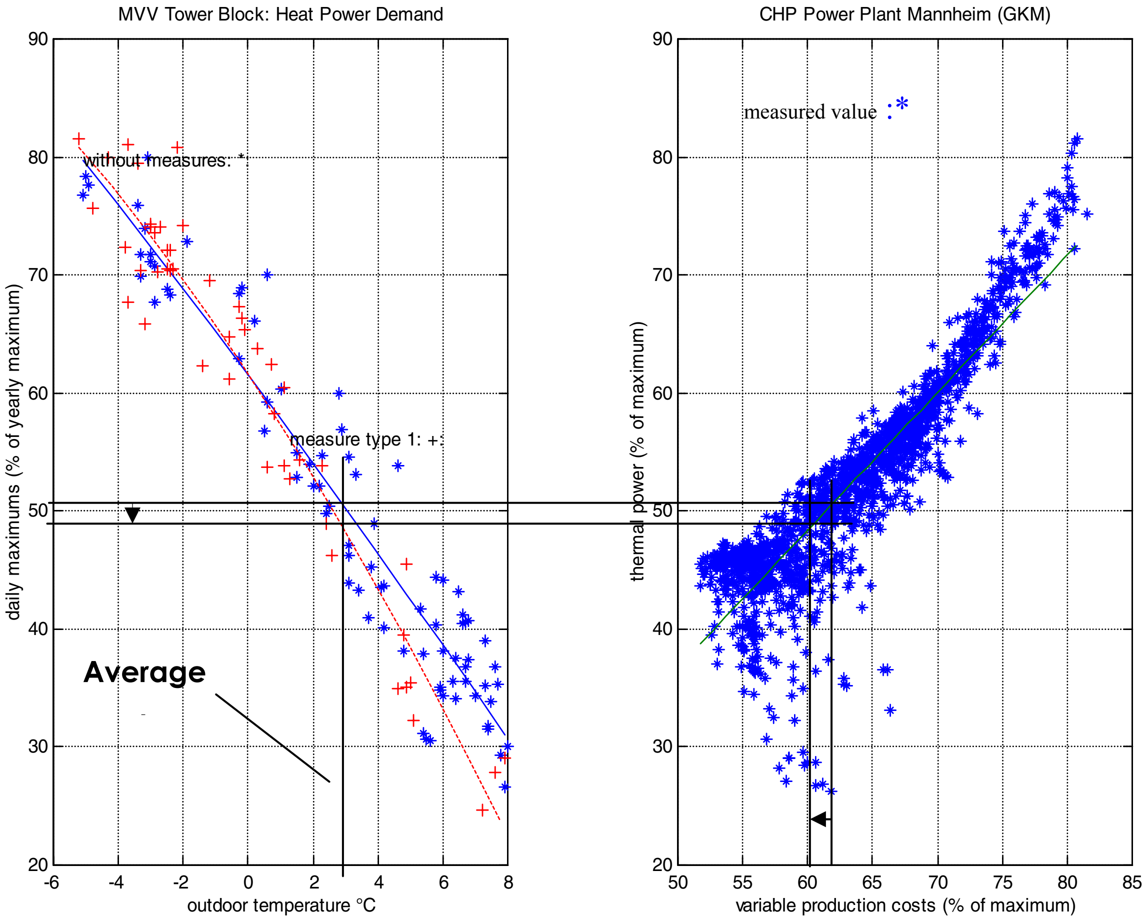


Figure 48. Heat demand and production costs.

The relationship between thermal power and specific production costs per MWh*th* at the GKM is presented at the right side in figure 48. At the left side of figure 46 is presented the diagram from figure 42, which shows the achieved reduction in heat demand with measure type 1. Both diagrams have been combined in order to determine the impact of the peak demand reduction on production costs and therefore the efficiency of the overall system. To make the quantities comparable the numbers at the y-axis at both diagrams represent the heat power demand as percentage of the recorded maximum. As can be seen by tracing the achieved peak demand reduction at the average winter temperature (left diagram) to the right diagram the efficiency gain will be two percentage points from the recorded maximum or approximately 3 % from the average. This increase in efficiency will happen during peak demand time which means during around 1–2 hours per day.

Evaluation of the results

During the project we could reduce the peak heat demand at the MVV Tower Block by using relatively simple measures by 4.1 %. This increases the efficiency of heat production at the power plant by 3 %. Unfortunately, as an unintended result of the DSM measures, due to the necessary preheating, the quantity of heat consumed by the building does substantially increase by 14 %. The recorded higher consumption does far outway the economic gains from the increased efficiency at the heat source. We therefore could not achieve any economic gain by DH DSM.

6.4 Suggestion for a new DH-tariff encouraging to utilise DSM

An essential question is to divide the benefits to supplier side and to end-customer side according to how much they will invest and be active to utilise DSM. A portion of the benefits should be offered to the customers, so that they would be willing to invest in demand side management (equipment and/or programming). The benefit has to be clearly visible in district heating rates.

The tariff typically consists of several billing components or prices. The determination of an appropriate tariff is by no means easy. The criterias for an efficient tariff determination may be:

- To reach the economic optimum it is desirable that the tariff reflects the supplier's marginal costs (= additional cost to produce the last unit).
- Tariffs must be understood by the customer and should therefore not be too complicated.
- Legal constraints must be considered.

Marginal costs increase as heat power demand increases. Unfortunately it will probably not be feasible to create a tariff that exactly reflects marginal costs. Typically a large fraction of the DH suppliers costs are fixed. Marginal costs are therefore lower than average costs. To cover costs, prices must therefore be higher than marginal costs. Another problem may be that tariffs must be based on data measured at a single customer whereas costs depend on the heat demand of the entire network. It may happen that the peak of a specific customer falls into times of low demand and therefore doesn’t affect costs.

The supplier's network costs depend on the maximum flow of the heat medium, which must be transported. The tariff should therefore include a component which reflects the maximum flow to the customer's system during the peak time.

This benefit can be, for example:

- A compensation of fixed demand fee because of substantially reduced peak heating demand. The amount of this compensation should be based on the actual savings in peak boiler operation costs and CHP production.
- Lower energy price because the DSM measures reduces the production and distribution cost of heat, because the temperature accumulation of network will be smaller and less pumping is needed as the peaks with high heat demand are avoided.

The DSM tariff should be simple and clear for the supplier and consumer side that they could understand when and how they save money, if they take DSM in use.

6.4.1 DH DSM -tariff based on discount in fixed payment

A fixed agreement, where supplier has the right to cut a daily peak load of the consumer by remote control in agreed limits up to 25 % of connected capacity and maximum 3 hour per day in one or two periods. The consumer can have some discount in fixed annual payments. The post heating period should be 1,5–2,0 hours longer than cut period and the thermal effect should be returned linearly to avoid the remarkable post heating peak in the building.

6.4.2 DH DSM –tariff based on changing fixed payment

The consumer can decide how he cut his peak load. Normal energy rates are used for the DH DSM customers. In this the district heating water flow of the customer is continuously measured, and thus we can find out the maximum flow and also the moment of the maximum flow. It is important that the customer not only cuts off the maximum flow, but also moves the moment of the maximum flow earlier so that the energy producer does not have to start the heavy oil heating plants or the producer can cut the total maximum effect of the heat production. Part of this benefit can then be given to the customer lowering the basic rate. This kind of price fixing is quite simple to carry out, and it is also incentive to the customer, because the DH DSM-system does not necessarily cut off the energy consumption. The changes to the existing meters are quite easy, too.

6.4.3 Time-of-year tariff in experimental use for DSM in Jyväskylä

Normally the energy companies use many kinds of energy sources, for instance the basic energy is made by peat, coal or natural gas and the peak energy is made mostly by heavy fuel oil. In Jyväskylä the annual consumption of heavy fuel oil is almost 15 % of all energy sources. The energy rate is the average price of all fuels used by the energy company and it is the same around the year. The basic rate is about 25 % of the total annual energy costs and the energy rate 75 %, although the fixed costs for the energy company may be 40 % or even more. The fixed costs are built up of interests and depreciations of district heating net, power plants and heating plants.

In Jyväskylä the energy company has an alternative energy rate that has been in test use with five customers. First, the basic rate is bigger than in the normal rate, about 40 % of all the rates and thus it corresponds much better the costs of the energy company. The fixed cost formula is

$$H_{\Phi} = a + b * \Phi, \tag{11}$$

where Φ is the consumer's highest hourly thermal power a year. a and b are contants for fixed cost of thermal power.

There are two different energy rates, one for the summer time and one for the winter time. The rate during summer time (April 1 to November 30) is lower, because peat and wood waste, which are much cheaper energy sources than heavy oil, produce almost all energy. During winter time (December 1 to March 31) almost all extra energy is produced by heavy oil, and that is why the energy rate is higher. Also the possibilities to save energy are bigger. The maximum effect per hour is measured all the time, and so the customer can affect his basic rate. The thermal power rate is corrected with the cooling of the district heating water.

Thus the energy cost can described as follows:

$$H = a + b * \Phi + E_w * h_{winter} + E_s * h_{summer}, \tag{12}$$

where E_w and E_s are measured energy consumption in winter and summer time h_{winter} and h_{summer} are heat energy price in winter and summer

This alternative setting of energy rates could be quite suitable to the customers in DH DSM-system.

7. Summary and recommendations

The main objective of the project was to show that lowering the cost of district heating (DH) is possible by using demand side management (DSM). The practical installation of DH DSM in a building is not expensive. Peak cut of 25–30 % is going to be achieved with exploiting the thermal mass of the building and by properly controlling the heating system. Indirect savings will also be evaluated.

The peaks usually occur in the morning and/or in the evening due to simultaneous starting and shut-down of building heating systems, especially in commercial buildings (offices, schools, etc.). These time bounded peaks in typical buildings can be easily shifted by timer controlled DSM measures. A more sophisticated DSM can also include active reducing of certain key customers' load so that their load would be high when the other's is low and vice versa.

A calculation tool for test buildings has been developed for quick evaluation of proper DSM possibilities. The characteristic model of buildings is described using thermal capacity-resistance description.

There were three case study buildings in the project, where the DSM demonstrations were carried out. The Jyväskylä official building located in Central Finland has 6 floors and total floor area is 5 940 m^2, where the heated floor area is 5140 m^2. The building has concrete body covered by brick and the total volume is 19 380 m^3. The window area is about 30 % and the door area about 0,5 % of the wall area. The roofing is tar blanket and covered with small stones. The total heat consumption (corrected by degree days) was 713,1 MWh in 2000 and 867,8 MWh in 2001. A heat exchanger capacity consists of three parts: heating 465 kW, air conditioning 1280 kW and domestic hot water 580 kW. The time constant τ of the building is 135 hours when ventilation is shut off and 92 hours when the ventilation is on.

The dwelling building is senior citizens' Day Centre in Jyväskylä. The building has 2 floors and total floor area is 2150 m^2, where the heated floor area is 2010 m^2. The building has concrete body covered by brick and the total volume is 7100 m^3. The building is covered by a tin roof. The total heat consumption (corrected by degree days) was 308,0 MWh in 2000 and 292,8 MWh in 2001. A heat exchanger capacity of the building is divided in two units: heating and air conditioning together 290 kW and domestic hot water 270 kW. The time constant τ of the building is 72 hours when ventilation is shut off and 45 hours when the ventilation is on.

DSM Control is carried out in Jyväskylä by using multiple temperature control curve applications, where different curves are activated by demand. The curves added to room heating control for DSM application have the same shape as the normal (existing) curve but the slopes of curves are different. DSM –curves are located below the normal curve but for the preheating and heating up procedures there is curve above the normal level.

The third case study building MVV Tower Block in Mannheim is a typical administrative building. It has been constructed in the late sixties and recently renovated. The major part (around 70 %) of the building's heat demand is met by the air conditioning system. Each side of the building is equipped with a separate two pipe water distribution system and pipes for preheated air. All floors of the building are equipped with decentralised air injectors. Each injector is equipped with a hot water/air heat exchanger, which is connected to the distribution system. The indoor temperature is separately measured at each side of the building (average of values measured in four floors). The control of the indoor temperatures is done by adjustments of the temperature of the water circulating through the heat exchangers. This adjustment can be done separately for each side of the building. Heated area of the Tower block is 25 661 m^2 and heat consumption was 2530 MWh in 2000.

The research made in two Finnish case buildings during winter 2002–2003 shows that the maximum heat load of a massive building (body of concrete) can be temporarily (during 2–3 hours) reduced as much as 20–25 % on the average. In case studies the limit of room temperature was temporarily lowered or raised up to 2 °C. When this kind of measures are performed in a large number of buildings simultaneously, the total load of a district heating network can be lowered up to 25 %.

Cutting down the total load in a district heating network can be avoided by starting some peak heat-only boilers during a 24-hour period. However, the same amount of heating energy (or slightly more) needs to be produced as without any DSM measures. This energy can then be produced in a more efficient way than with a heat-only boiler, for example with a combined heat and power (CHP) plant.

The cut of loads were largest at the Finnish DSM control measures because of the thermal capacity of radiator heating network. It takes time before the network is cooled down to the set DSM flow temperature level. When the circulation water reaches the set DSM temperature level the heating load starts to increase up to the load level defined by any current DSM temperature setting. Hot tap water was not included in DSM. The loads of intake air heating are large but the thermal capacity of ventilation intake air heating is small compared to large room heating radiator systems. As the temperature change of ventilation can be felt immediately the DSM-control measures of ventilation must be very small and sensitive while the building is in a normal use. The only way to keep the heat demand of intake air heating low during the DH DSM operations is to slightly reduce the air flow temperatures (by 1–2 °C).

When making the DSM and preheating curves it was noted that the control system is still somewhat too complicated and hard to be adjusted to meet all the needs of this demonstration project. The control was stabilised a lot by changing the control parameters to slow down the controller. Here it might be a better solution to use a same kind of change of temperature level as was used with the compensation of ventilation air controller.

During the transient test of Jyväskylä office building in 2002 the cut off period of heating and ventilation (during night time) was seven hours and the average reduction of the indoor temperature of eight measurements around the building was 2 °C. Based on several temperature control measurements the lowest pre-programmed control curve (–60 %) was taken into use. In the ventilation the temperature of intake air heating remains almost untouched as the temperature compensation of ventilation air is reduced by 2 °C for the DSM period.

At the beginning of the DSM period the temperature reduction leads to maximum load reduction of –80 % for a period of 30 minutes and after following 30 minutes the load reduction recovers to level –30 % to –20 % of the normal heating load. The analysis of the temperature and load measurements of the Governmental Center gives reason to reduce the length of preheating period to maximise the network temperature just before the DSM cut off. By increasing the flow temperature to reach 20 % higher heating capacity this high increase of heating is effective only for a short period (< 1 hour) and for the rest of preheating period (3 hours) there is only +5 % higher heating load than the normal load because of thermostatic valves. Locally the preheating is important in rooms where the risk of freezing is high such as in entry wind boxes. The radiators of entry wind boxes are normally without thermostatic valves. There the preheating of building materials is effective during early morning hours when the doors stay closed.

The increase of heat consumption because of DSM is caused by the preheating period when the temperature of radiator network is high compared to the normal case when some night- time set down of flow temperature is applied. The heat consumption of this case building has increased (about 50 %) during the test period, but the ventilation system with intake air heating is replaced (the capacity is higher than before test period) since the beginning of tests it is not possible to tell what is the effect of DSM. It is evaluated that the share of total increase is 40 % to additional ventilation capacity and 10 % to DSM. The influence of DSM cannot be said exactly while the heat consumption has been rising because of increased ventilation (because of problems with high humidity). The outdoor temperature corrected consumption does not take account the effects of the sun and the wind.

The building of Kortepohja Day Center thermal capacity is high enough to enable effective DSM cuts. The cut off period of three hours by using reduction curve of –60 % (31,5 °C reduction in heating supply temperature) did not alone cause any uncomfortable indoor temperatures even during the extreme cold winter period in January 2003. During the transient test in March 2003 the outdoor temperature was (–3…0 °C) and the cut off period of heating was five hours at maximum and the largest measured drop of indoor temperature was 0,8 °C.

The maximum DSM load reduction level at supply temperature in Kortepohja Day Centre was limited to –60 % of the normal load level. At the beginning of the DSM period this temperature reduction leads to maximum load reduction of –30 % for a period of 30 minutes and after 30 minutes the load reduction recovers back to the level before the DSM start

Also in Kortepohja Day Center some increase of heat consumption has been noted. The outdoor temperature corrected consumption was increased by about 5 %. As here there have been no major changes in heating system this increase is probably because of DSM preheating. It is not possible to define the exact increase because of DSM as the consumption of heating and ventilation was also decreased by 16 % since the autumn 2001. The use of building is different during different periods and the correction made by outdoor temperature does not take into account the other parameters like the sun and the wind.

In the case of Jyväskylä city there is a district heating network with about 300 MW_{th} of maximum peak load. It was assumed that there are so many customers connected to demand side management that the daily peak demand can be reduced 20 % when needed. From this basis it was assumed, how many starts of heat-only boilers could be avoided annually. Peak cut of 20 % in Jyväskylä means about 160 buildings such as Governmental Centre (20 000 m^3) or 460 buildings like Pensioners Day Centre (7 000 m^3).

Based on simulations how to use energy production capacity when DSM is utilised, the total saving is 13 000 €/a in the Jyväskylä case. Share of saving in the start-ups and tails of HOB is about 8 500 €/a. Thus it gives an average saving of 82 € for each one of 160 consumers. Thus a DSM investment of 845 € per consumer (5 %, 15 a) is aloud.

If we assume to save an investment of 20 MW HOB (1,8 milj. EUR) because of DSM and we divide it to 20 years with 5 % interest, the additional saving will be 144 000 €/a and in addition maintenance and other fixed costs. It amounts to about 900 €/a per consumer in the Jyväskylä case.

The minimum investment to realise a simple autonomous (time and outdoor temperature guided) DSM control in a district heated building is around 900 €. A GSM-modem may lead to the lowest investment cost (1 200 €/building) for the DSM system, but the operation cost gets higher as the number of DSM controls is large.

In buildings having size of 20 000 m^3 (heating load >500 kW) the investment should be as simple as possible and still be able to carry out DSM operations effectively. Pay-back time will be 15–20 years (5 %) in Jyväskylä case. If we assume to compensate DSM investment (160 x 900 € =144 000 €) with boiler investment then the estimated pay-back time for the rest of DSM investment (1200 – 900 = 300 €) will be about 4 years. Appropriate measuring and data storing equipment is required in the registering of peak heating demand.

In the German Tower Block case in Mannheim can be reduced peak demand by 4,1 %. This increases the efficiency of heat production at the power plant in average by 3 %. This increased efficiency was reached during peak demand time, which means during 1–2 hours per day. There is no reduction when the outdoor temperature is cold (< 0 °C). This is due to the fact, that the software which normally controls the building's heating system, tends to start the air conditioning system earlier when outdoor temperature is lower. It does so to insure the desired indoor temperature of 21.5 °C at 6:30 a. m. The timeconstant of the air heated building is shorter than the system used by water radiators. If the air heated building is equipped with hot tap water tank as Tower Block, it might be useful to utilise the water tank for pre-heating before cut period.

Unfortunately, as an unintended result of the DSM measures, due to the necessary preheating, the quantity of heat consumed by the building does substantially increase by 14 %. The recorded higher consumption does far outway the economic gains from the increased efficiency at the heat source. Therefore they could not achieve any economic gain by DH DSM in the Tower Block case. Near the 0 °C outdoor temperature the production is supplied by CHP plant. In colder days there has to be start peak boiler(s). When there is enough peak cutting in Mannheim it will make possible to avoid to start peak boiler(s) and maybe save money.

A tariff used in DSM should be

- Reach the economic optimum it is desirable that the tariff reflects the supplier's marginal costs (= additional cost to produce the last unit).
- Tariffs must be understood by the customer and should therefore not be too complicated.
- Legal constraints must be considered.

Two kinds of tariff structure can be recommended.

A fixed agreement, where supplier has the right to cut daily peak load of the consumer by remote control in agreed limits up to 25 % of connected capacity and for a maximum 3 hour per day in one or two periods. The consumer can have some discount in fixed annual payments. The post heating period should be 1,5–2 hours longer than cut period and the thermal effect should be returned linearly to avoid the remarkable post heating peak in the buildings.

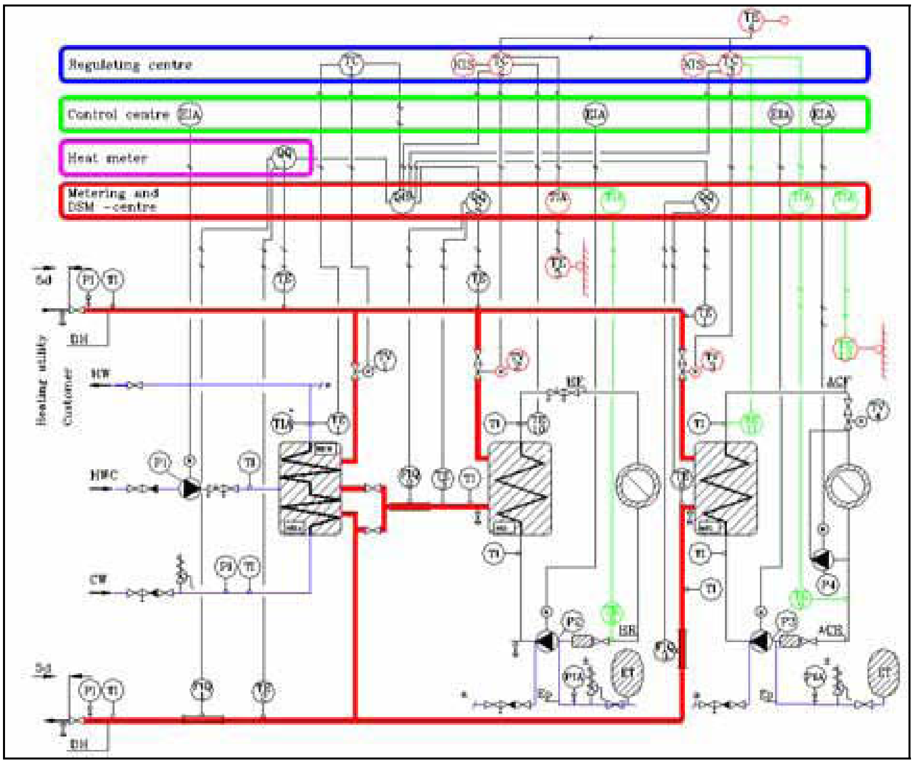
In other case the consumer can decide how he cuts his peak load. Hourly peak load a day will be measured and based on the maximum annual peak load he must pay a fix thermal power capacity payment a year.

The results of the project were presented at the CHP/DHC XXXI Congresse arranged by Euro Heat and Power in June 2003 in Helsinki. The project stand is presented in appendix 3.

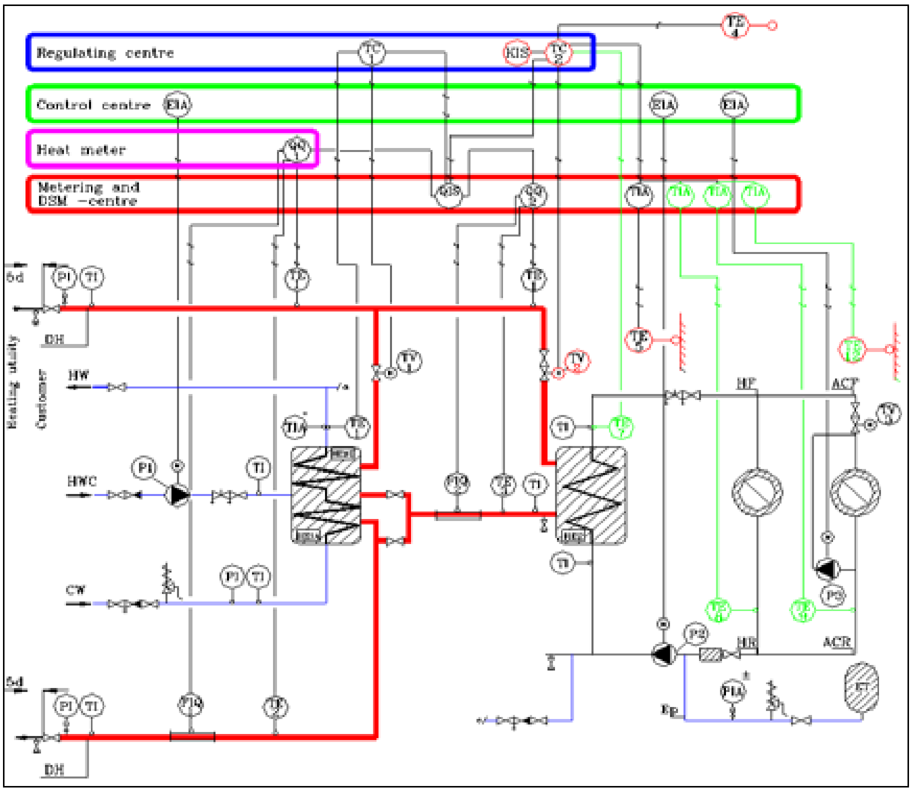
References

Seppo Kärkkäinen, Kari Sipilä, Aulis Ranne, Veikko Kekkonen, Pekka Koponen, Lasse Koskelainen & Jouni Heikkinen. 1999. Demand Side Management in District Heating Systems, Basics and Techniques for DSM (Kysynnän hallinta kaukolämpöjärjestelmissä, DSM:n perusteet ja tarvittava tekniikka). VTT Energia, Tiedotteita 1982. 98 p.

Appendix 1

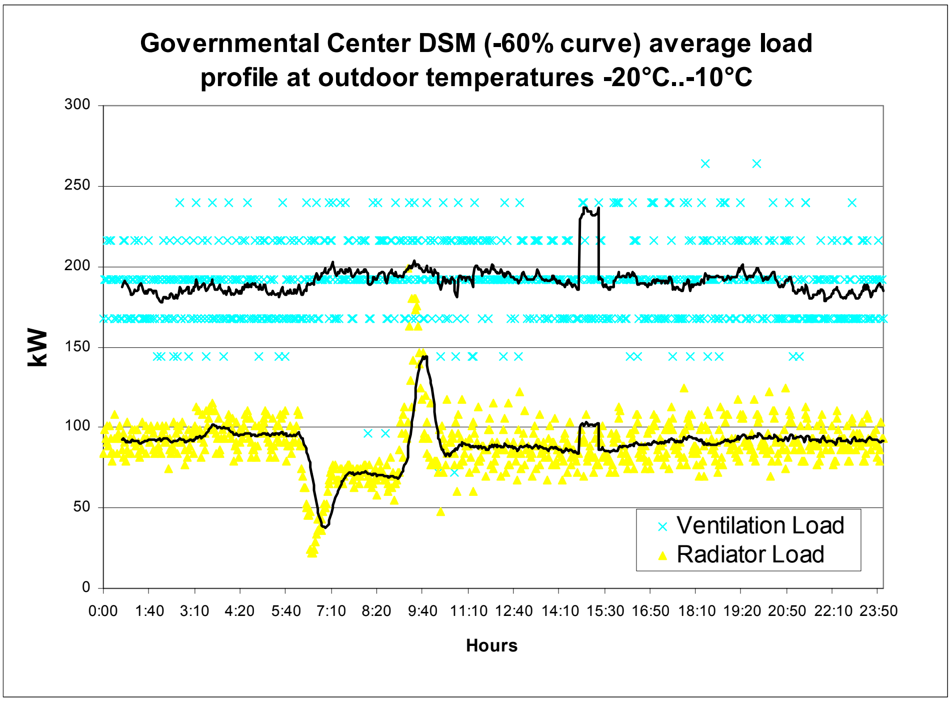


Connection arrangement 1; three heat exchangers

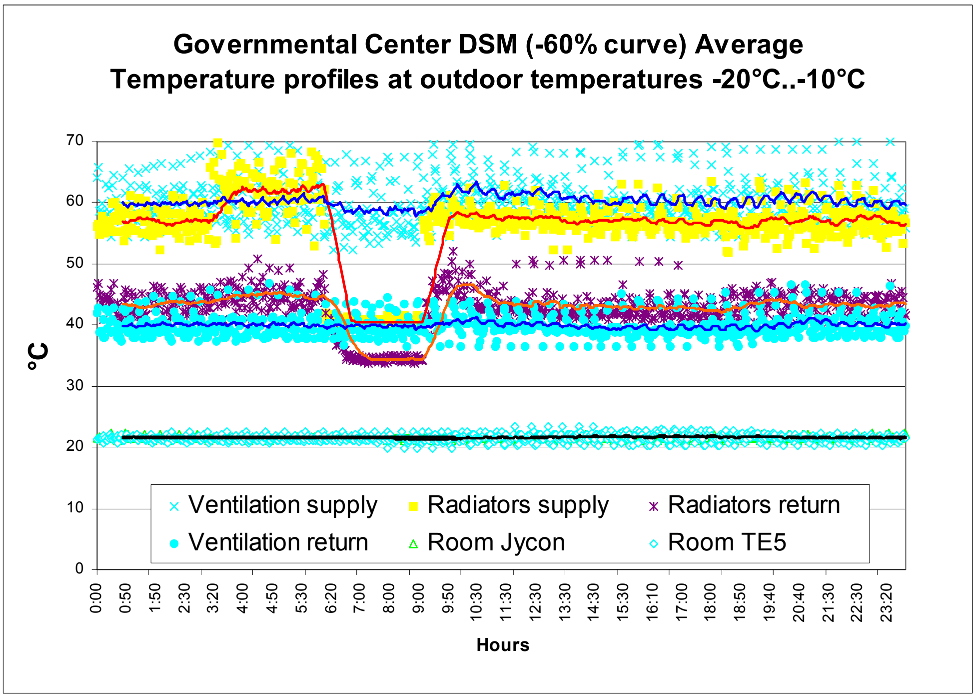


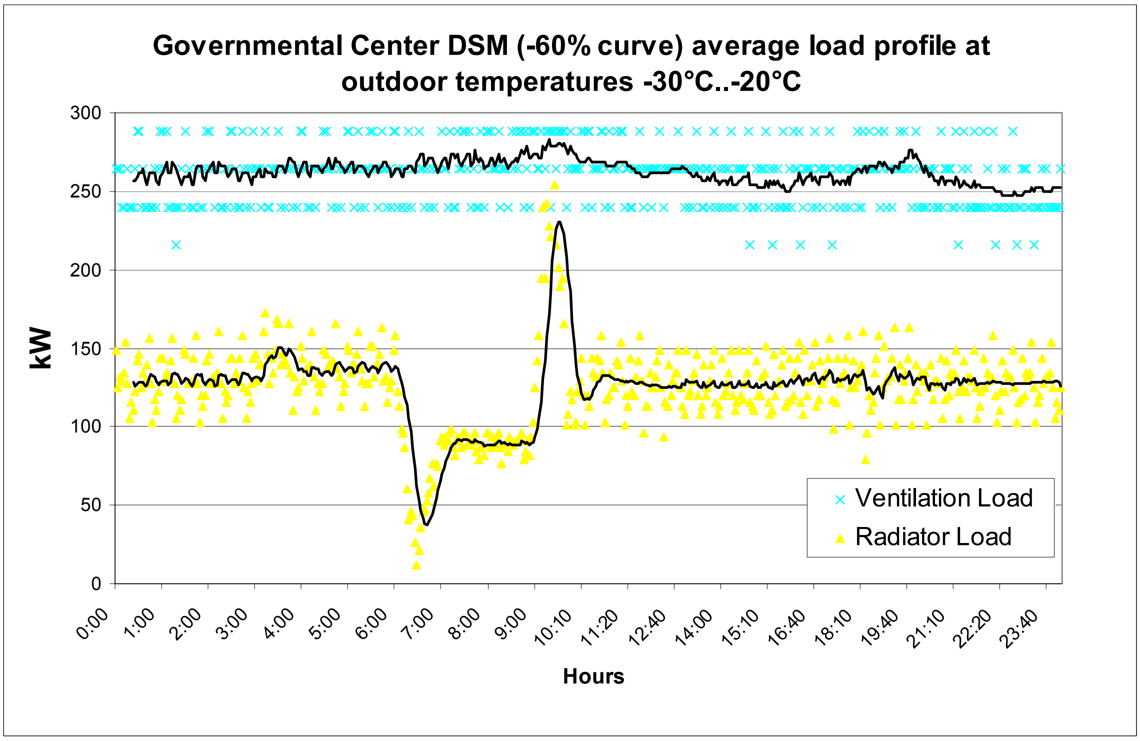
Connection arrangement 2; two heat exchangers

Appendix 2

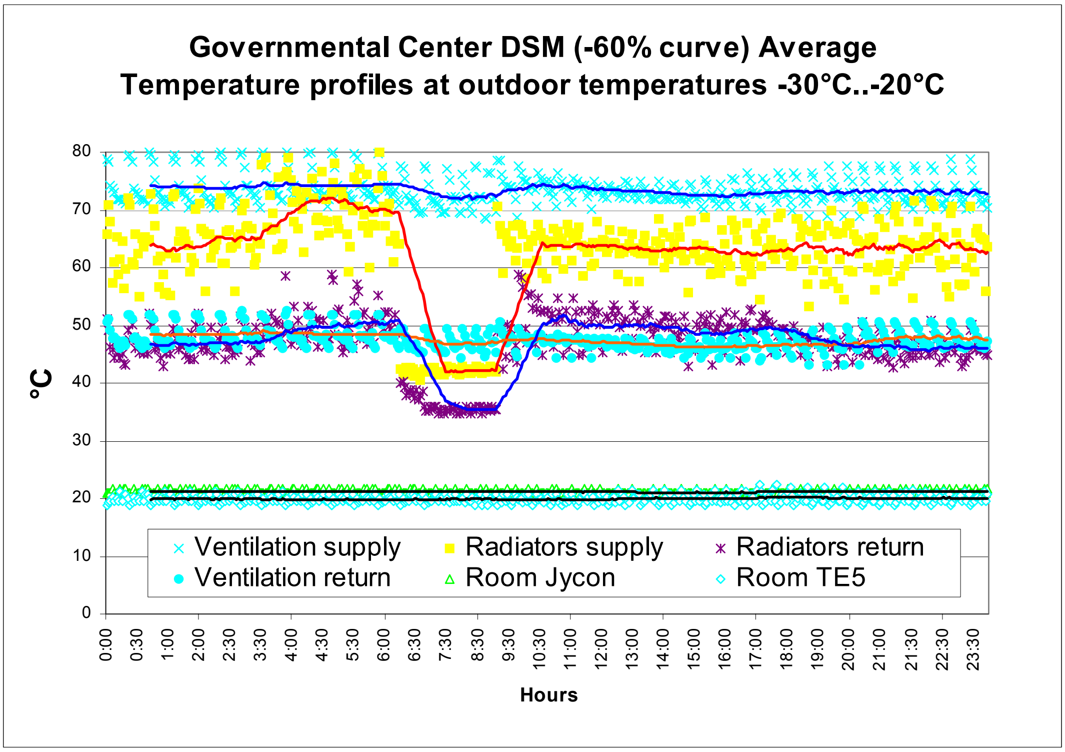


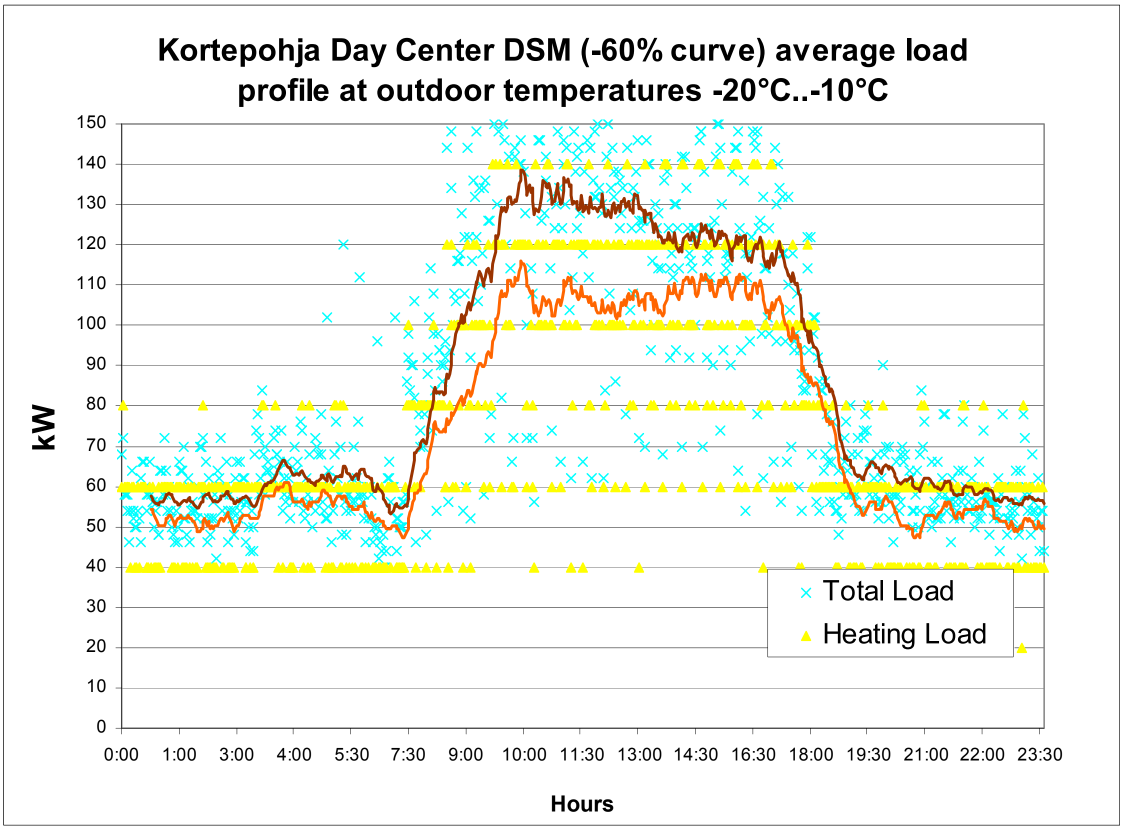
Heat effects at outdoor temperatures –20 ...–0 °C are presented in figure in winter 2003, when peak cut is on and average curve in every hour. Preheating period starts 3:00 am and cut period 6:00 am. The first hour cut and peak after cut period as well are high, but control system compensate them. The real cut is about –2 % when –60 % curve is used. The corresponding temperatures are presented in the next figure.

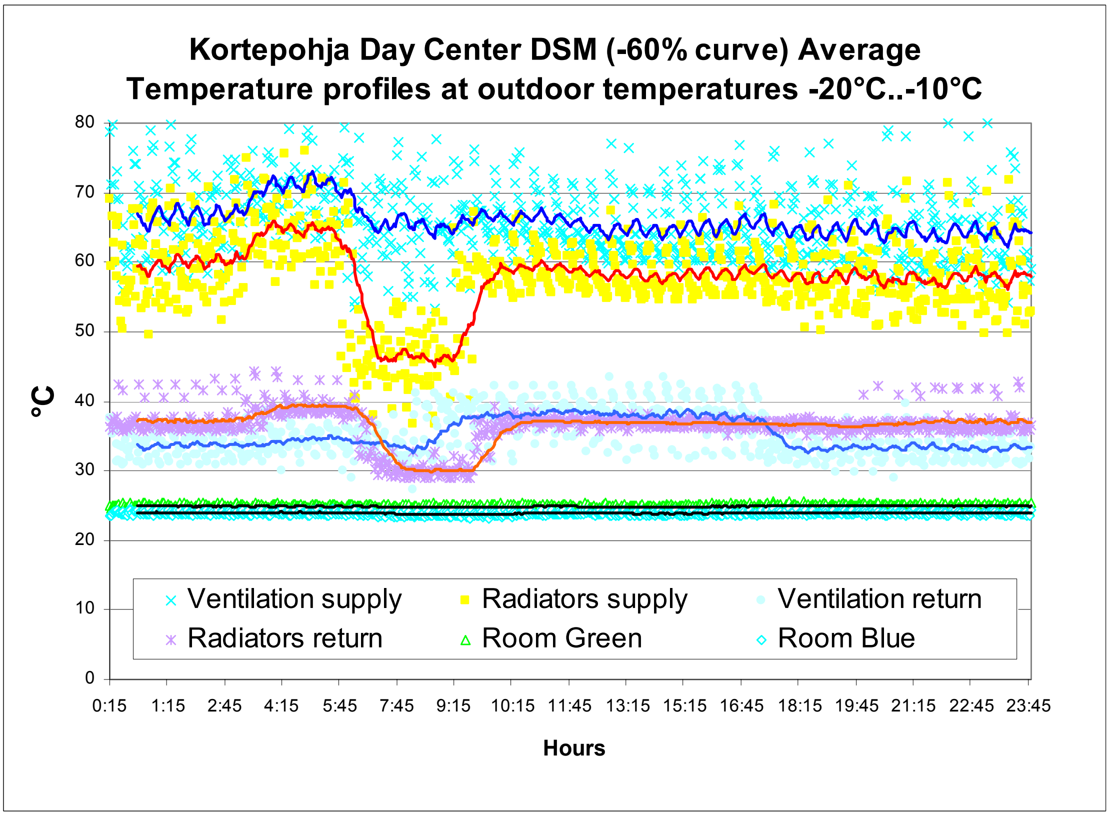


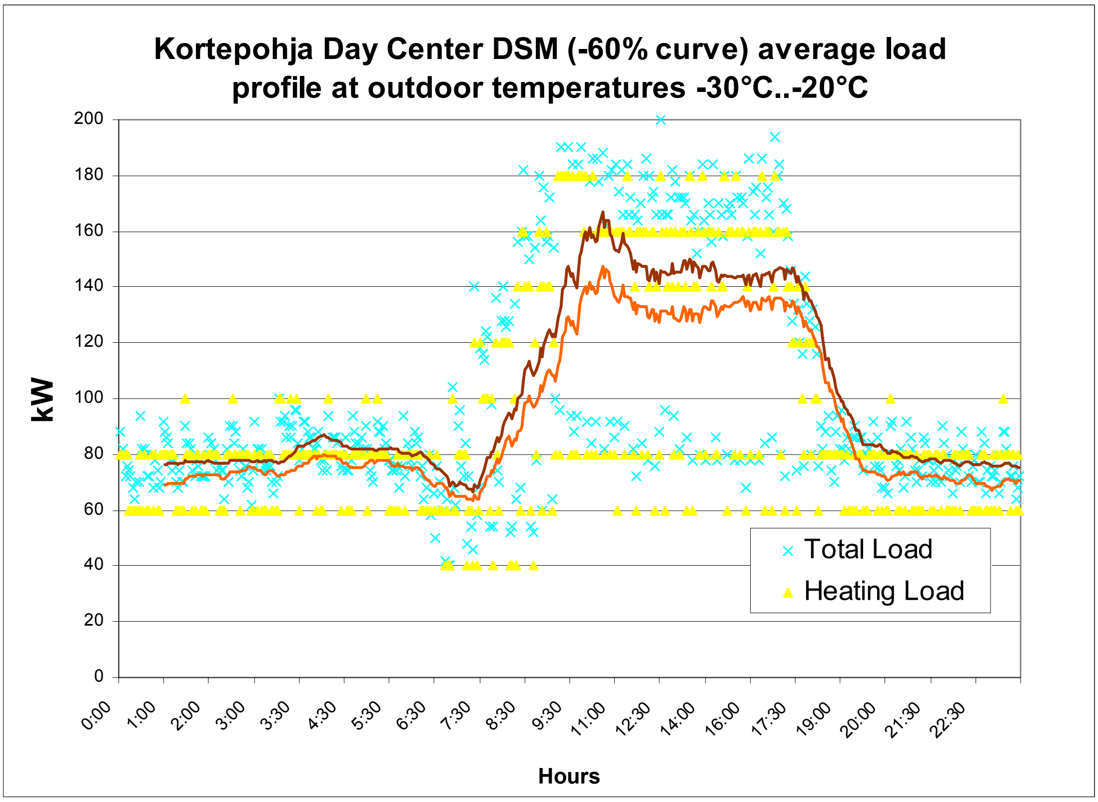


Heat effects at outdoor temperatures –30 ... –20 °C are presented in figure in winter 2003, when peak cut is on and average curve in every hour. Preheating period starts 3:00 am and cut period 6:00 am. The first hour cut and peak after cut period as well are high, but control system compensate them. The real cut is about –5 % when –60 % curve is used. The corresponding temperatures are presented in the next figure.




Kortepohja Day Center DSM (-60% curve) average load profile at outdoor temperatures -20°C..-10°C
kW
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0:00
1:00
3:00
4:00
5:30
7:30
9:00
10:00
11:30
13:00
14:30
16:30
18:00
19:30
21:00
22:00
23:30
Hours
Total Load
Heating Load


Kortepohja Day Center DSM (-60% curve) Average Temperature profiles at outdoor temperatures -20°C..-10°C
°C
80
70
60
50
40
30
20
10
0
0:15
1:15
2:45
4:15
5:45
7:45
9:15
10:15
11:45
13:15
15:15
16:45
18:15
19:45
21:15
22:45
23:45
Hours
Ventilation supply
Radiators supply
Ventilation return
Radiators return
Room Green
Room Blue


Kortepohja Day Center DSM (-60% curve) average load profile at outdoor temperatures -30°C..-20°C
kW
200
180
160
140
120
100
80
60
40
20
0
0:00
1:00
2:00
3:00
3:30
4:30
5:30
6:30
7:30
8:30
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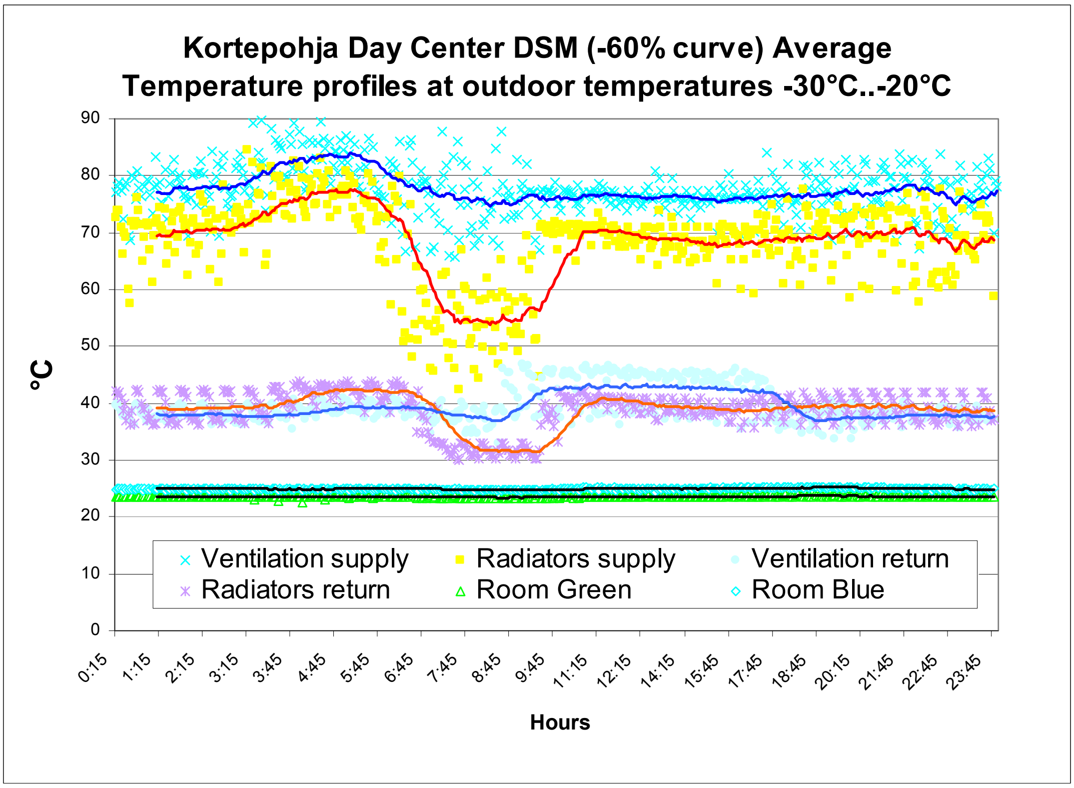
22:30
Hours
Total Load
Heating Load


Kortepohja Day Center DSM (-60% curve) Average Temperature profiles at outdoor temperatures -30°C..-20°C
°C
90
80
70
60
50
40
30
20
10
0
0:15
1:15
2:15
3:15
3:45
4:45
5:45
6:45
7:45
8:45
9:45
11:15
12:15
14:15
15:45
17:45
18:45
20:15
21:45
22:45
23:45
Hours
Ventilation supply
Radiators supply
Ventilation return
Radiators return
Room Green
Room Blue

Appendix 3

Dissemination in the EuroHeat&Power Congress 15–17 June, 2003 in Helsinki

COVERNMENTAL CENTRE AT JYVÄSKYLÄ

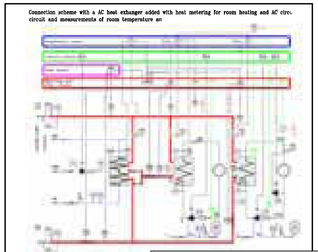
Office building at Jyväskylä City

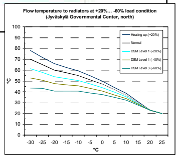
- Heated volume 19400 m³
- Floor area 5940 m² in five floors
- Concrete body covered by bricks
- 3 class windows 30 % of wall area
- Installed substation capacity

*	Heating	465 kW
*	Air conditioning	1280 kW
*	Domestic hot water	580 kW

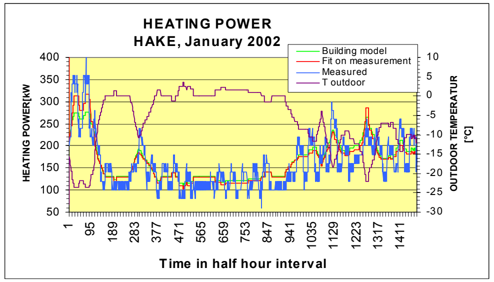
Indirect substation with three heat exchangers (DHW, Heating and Ventilation)

- Load control by secondary supply temperature controllers
- 2 heat meters added for monitoring purposes
- DSM control effecting only room heating and intake air heating
- DSM control by switching between Normal-PreHeating-DSM temperature curves (relative loads 120%,100% and 40%)
- Demonstration control system with timer switch: 3 hours of preheating (120%, 3:00-6:00am), 3 hour DSM period (40%, 6:00-9:00am)
- Temperature setting of intake air heating is reduced by 2°C during the DSM period


Connection scheme with a AC heat exhanger added with heat metering for room heating and AC circ circuit and measurements of room temperature an

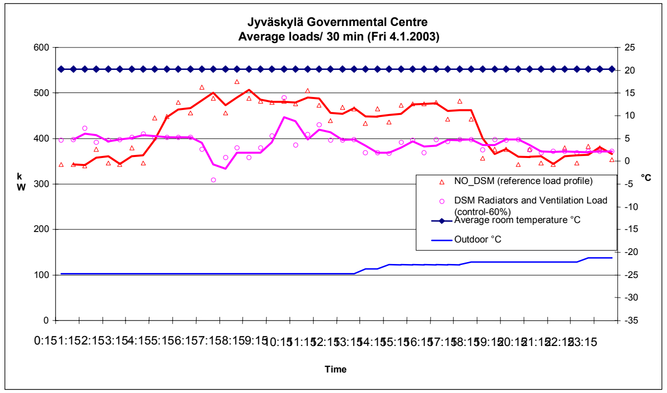

Flow temperature to radiators at +20%… -60% load condition (Jyväskylä Governmental Center, north)

Results of measurement and building model

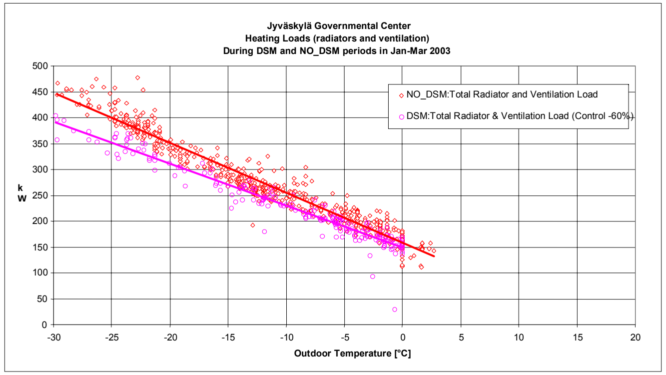


- Indoor temperature drop, when outdoor is -26 °C
  - * 0,5 °C/h, if ventilation on
  - * 0,3 °C/h, if ventilation off
- Specific heat cons. 37 kWh/m³
- Heat consumption 720 MWh/a
- Simplyfied building model for evaluation of DSM

COVERNMENTAL CENTRE AT JYVÄSKYLÄ



The shape of load profile is affected by the means of DSM load control – (DSM supply water temperature reduction <> -60% in the heating load). The indoor temperature of this massive building remains almost untouched during the 3 hour DSM period



Summary of the measurement during DSM periods. The DSM impact is about 10 % in average and maximum 20 %.

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The Fifth Framework Programme
Energy, Environment and Sustainable Development

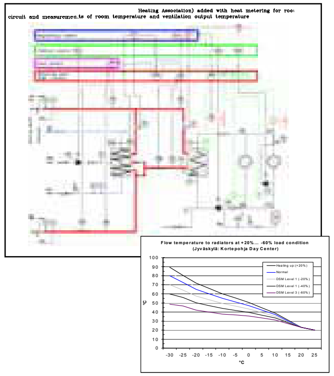
Demand Side Management
of the District Heating Systems
Project: NNES-1999-20156
Contract: ENK6-CT-2000-20156

DH DSM

DAY CENTRE AT JYVÄSKYLÄ

Kortepohja Senior citizen's day centre incl. apartments, nursing, etc.

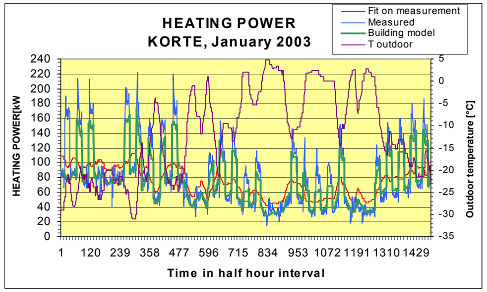
- Heated volume 7100 m^3
- Floor area 2150 m^2 in two floors
- Wooden body covered by bricks
- 3 class windows 13 % of wall area
- Installed substation capacity
  - * Heating
    Air conditioning 290 kW
  - * Domestic hot water 270 kW



Indirectt substation with two heat exchangers (DHW and Heating/Ventilation)

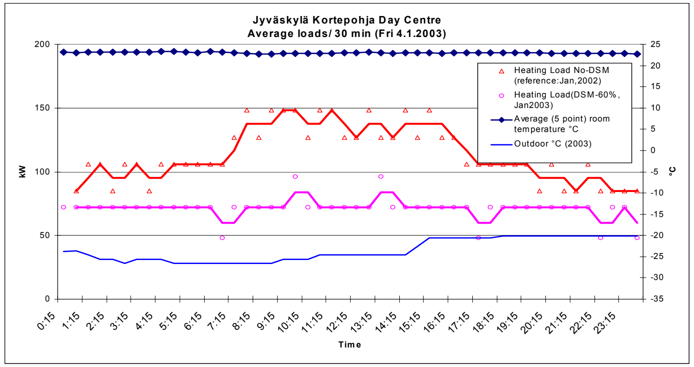
- Load control by secondary supply temperature controllers
- Heat meter added for monitoring purposes
- DSM control effecting only room heating and intake air heating
- DSM control of radiator circuit by switching between Normal-PreHeating-DSM temperature curves
  (relative loads 120%, 100% and 40%)
- Demonstration control system with timer switch: 3 hours of preheating (120%, 3:00-6:00am), 3 hour DSM period
  (40%, 6:00-9:00am)
- Temperature setting of intake air heating is reduced by 2°C during the DSM period.

Results of measurement and building model

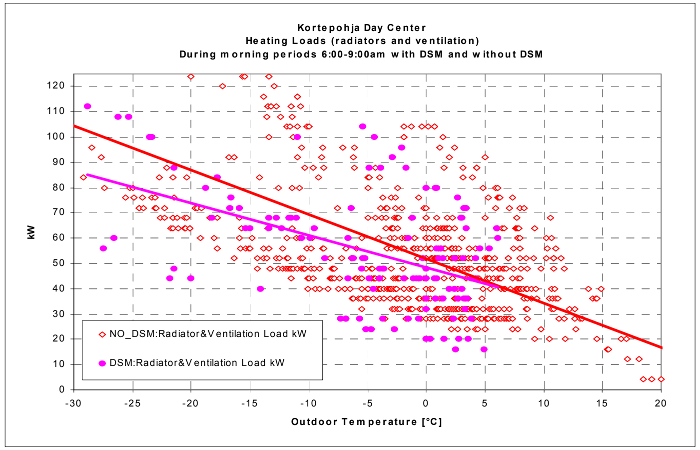


- Indoor temperature drop, when outdoor is -26 °C
  - * 0,3 °C/h, if ventilation on
  - * 0,2 °C/h, if ventilation off
- Specific heat cons. 44 kWh/m^3
- Heat consumption 310 MWh/a
- Simplified building model for evaluation of DSM

DAY CENTRE AT JYVÄSKYLÄ

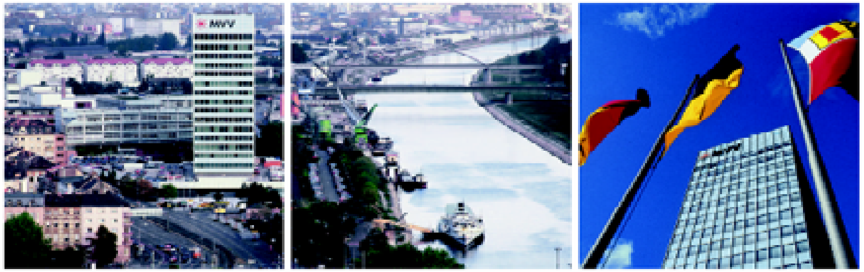


The load profile of a typical winter working day is strongly affected by the means of DSM load control – peak loads are ¨~50% lower than during the normal operation mode (DSM supply temperature reduction <> -60% in heating load).



Summary of the measurements during DSM periods. The DSM impact is about 10 % in average and maximum 15 %.

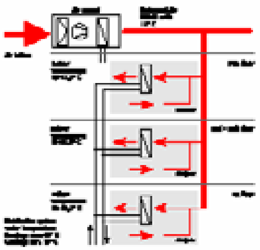
MVV Tower Block in Mannheim



The "MVV Tower Block" (see picture above) is a typical administrative building. It has been constructed in the late sixties and has been renovated recently. The major part of the buildings heat demand is covered by the air conditioning system. There is also a certain heat demand for hot tap water generation. Within the Project-Framework have been installed metering devices in order to record all relevant energy-flows and temperatures for heating and hot water generation separately.

Each side of the building is equipped with a separate two pipe water distribution system (see fig. 1). Heating and cooling demand are supplied (each side separate) by the same pipe system. All floors of the building are equipped with decentralised air injectors which are controlled by the indoor temperature. During night time, sundays and holidays the system operates in an "economy-mode", with a decreased indoor temperature set point of 19°C instead of 21,5°C.

Tower Block
Air Conditioning System - Fig. 1



Description of the Test Building

Heated Area:	29.881 m²
Heat Consumption:	about 2.800 MWh/a
	about 70% Ventilation
	about 17% Hot Water
	about 13% Radiators

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MVV Energie AG · Germany

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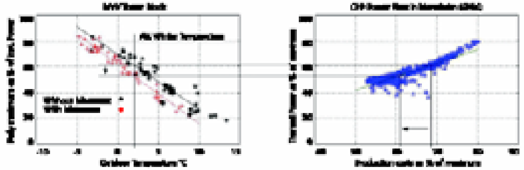
Demand Side Management
of the District Heating Systems
Project: NNE5-1999-20158
Contract: ENK6-CT-2000-20158

DH DSM

Technology and Results in Mannheim

Measures
Increase of the indoor temperature set point during the "economy-mode" from 19°C to 21,5°C at 2:30 a.m.. Start of operation of the air central at 3:30 a.m.. From this follows that the heat demand to increase the indoor temperature to the required 21,5°C is shifted to night times when the air central doesn't work.

Results
The daily maximum heat power in kW decreased by app. 12%
This would reduce heat production costs per MWh by app. 9%



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DH DSM

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Title

Demand side management of the district heating systems

Abstract

The main objective of the project was to show that lowering the cost of district heating (DH) is possible by using demand side management (DSM). The practical installation of DH DSM in a building is not expensive. Peak cut of 25–30 % is going to be achieved with exploiting the thermal mass of the building and by properly controlling the heating system. Indirect savings will also be evaluated. Hot tap water was not included in DSM.

There were three case study buildings, two in Jyväskylä Finland and one in Mannheim Germany, where the DSM demonstrations were carried out. A calculation tool for test buildings has been developed for quick evaluation of proper DSM possibilities. The characteristic model of buildings is described using thermal capacity-resistance description.

The research made in two Finnish case study buildings shows that the maximum heat load of a massive building (body of concrete) can be during 2–3 hours reduced as much as 20–25 % on the average because of the thermal capacity of radiator heating network. When the circulation water reaches the set DSM temperature level the heating load starts to increase up to the load level defined by any current DSM temperature setting. The loads of intake air heating are large but the thermal capacity of ventilation intake air heating is small compared to large room heating radiator systems. As the temperature change of ventilation can be felt immediately the DSM-control measures of ventilation must be very small and sensitive while the building is in a normal use. The only way to keep the heat demand of intake air heating low during the DH DSM operations is to slightly reduce the air flow temperatures by 1–2 °C.

Peak cut of 20 % in Jyväskylä means about 160 buildings of the volume 20 000 m^3. Based on simulations how to use energy production capacity in DSM, the total saving is evaluated 13 000 €/a in the Jyväskylä case. Thus a DSM investment of 845 € per consumer (5 %, 15 a) is aloud. If we assume to save an investment of 20 MW HOB (1,8 milj. EUR) because of DSM and we divide it to 20 years with 5 % interest, the additional saving will be 144 000 €/a and in addition maintenance and other fixed costs. It means an investment of about 10 000 € per consumer in the Jyväskylä case.

In the German Tower Block case in Mannheim the daily heat demand peak could be reduced by 4.1 %. This increases the efficiency of heat production at the power plant on the average by 3 %. This increased efficiency has been reached during peak demand time, which means during 1–2 hours per day. By simply closing the valve larger reductions would be possible during very short time periods. This is no option because the subsequent peak when reopening the valve would actually increase the daily maximum. It is not feasible to shift peaks in this way to times of low demand in the district heating network because the relevant time span (around three hours) is far too long.

The building is equipped with an air heating system and a computer based control system which tends to start the air conditioning system earlier when outdoor temperature is lower. It does so in order to insure the desired indoor temperature of 21.5 °C at 6:30 a. m. By doing so the computer system automatically flattens the daily heat demand when outdoor temperature is low. As a consequence it was not possible to achieve further peak reductions with DSM measures when the outdoor temperature is very low (<0 °C). The time constant of the air heated building is shorter than of buildings with radiator heating.

Two kinds of tariff structure is recommended. A fixed agreement, where supplier has the right to cut daily peak load of the consumer by remote control in agreed limits up to 25 % of connected capacity and for a maximum 3 hour per day in one or two periods. The consumer can have some discount in fixed annual payments. The post heating period should be 1.5–2 hours longer than cut period and the thermal effect should be returned linearly to avoid the remarkable post heating peak in the buildings. In other case the consumer can decide how he cuts his peak load. Hourly peak load a day will be measured and based on the maximum annual or monthly peak load he must pay a fix thermal power capacity payment a year.

Keywords
demand side management, DSM, district heating systems, buildings, testing, test buildings, measurement, control devices, data collection, data analysis

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Titel

Fernwärme Last Management

Referat

Wichtigstes Ziel des Projekts war zu zeigen, dass es möglich ist, mit Hilfe von Maßnahmen auf der Nachfrageseite (Demand Side Management: DSM) die Wirtschaftlichkeit der Fernwärme zu verbessern. Die für DSM erforderlichen gebäudetechnischen Installationen sind nicht teuer. Mit einer geeigneten Regelungstechnik ist es möglich, unter Ausnutzung der Wärmekapazität des Gebäudes, Lastspitzen in der Wärmeversorgung um ca. 25–30 % zu senken. Sogenannte „indirekte Einsparungen“ werden ebenfalls bewertet. Anlagen zur Versorgung mit Warmwasser waren nicht in die hier untersuchten DSM Maßnahmen einbezogen.

In drei Fallstudien davon zwei Gebäude in Jyväskylä, Finland, und eines in Mannheim, Deutschland, wurden DSM Maßnahmen durchgeführt. Ausserdem wurde ein Software Tool mit dessen Hilfe, basierend auf Messdaten, rasch der Erfolg von DSM Maßnahmen bewertet werden kann, implementiert. Die phyisikalischen Eigenschaften der Gebäude wurde anhand eines thermischen Speicher – Widerstand – Modells nachgebildet.

Die in den beiden finnischen Gebäuden durchgeführten Unteruchungen zeigen, dass das Heizwärme – Tagesmaximum während 2–3 h durchschnittlich zu 20–25 % gesenkt werden kann. Dieses Ergebnis gilt für massive aus Beton errichtete Gebäude, die mit einer Radiator Heizung ausgestattet sind. Die Heizlast steigt auf einen Wert, dessen Höhe von der eingestellten „DSM Temperatur“ des im Gebäude Heizungsnetz zirkulierenden Wassers abhängt. Die erforderliche Heizleistung zur Deckung des Lüftungswärmebedarfs ist zwar typischerweise groß, wohingegen die Wärmekapazität der aufgeheizten Luft klein ist im Vergleich zu einem großen statischen Heizungssystem mittels Radiatoren. Da Änderungen der Lufttemperatur sofort gespürt werden, können DSM-Maßnahmen an Luftheizungs-Systemen nur in geringem Umfang durchgeführt werden. Akzeptabel sind Senkungen der Zulufttemperatur von höchstens 1–2 °C.

Eine Senkung der Lastspitze von 20 % in Jyväskylä würde etwa 160 Gebäude mit einem umbauten Volumen von 20.000 m³ bedeuten. Basierend auf Simulationen der Wärmeerzeugung würde sich in Jyväskylä eine Einsparung von 13.000 €/a errechnen. Diese Einsparung würde eine Investition in DSM-Technik von 845 € pro Verbraucher (5 %, 15a) rechtfertigen. Wenn mit DSM Investitionen in Kesselanlagen vermieden werden können - im untersuchten Fall würde eine Erzeugerleistung von etwa 20 MW (entsprechend 1,8 Mio. €) entfallen- könnten bei einer angenommenen Lebensdauer von 20 Jahren und einer Kapitalverzinsung von 5 % zusätzliche Einsparungen von 144.000 €/a erziehlt werden. Hinzu kommen kommen noch hier nicht quantifizierte Einsparungen für Wartung und Instandhaltung. Unter diesen Annahmen könnten DSM Investitionen von ca. 10.000 € pro Verbraucher durch Einsparungen bei der Wärmeerzeugung finanziert werden.

Durch die DSM – Maßnahmen in einem Verwaltungs-Hochhaus in Mannheim, Deutschland, konnte die Tages-Lastspitze der Wärmeleistung um 4,1 % gesenkt werden. Dadurch würde die Effizienz auf der Erzeugerseite um durchschnittlich 3 % erhöht werden. Diese Effizienzsteigerung würde während 1–2 Stunden täglich, in denen die DSM –Maßnahmen wirksam sind, erzielt. Es ist möglich, während sehr kurzer Zeiträume, durch „schließen des Ventils“ größere Lastspitzen Reduzierungen zu erreichen. Durchgeführte Untersuchungen zeigen jedoch, dass dadurch die dann sehr ausgeprägte Lastspitze beim Wiederöffnen des Ventils, das Tagesmaximum sogar erhöht würde. Da die Lastspitze im Fernwärmenetz sehr lang ist (ca. drei Stunden pro Tag), war es beim untersuchten Gebäude nicht möglich die Lastspitze auf diese Weise in Schwachlastzeiten zu verschieben.

Das Gebäude ist mit einer Luftheizung und einem mittels Computer gesteuerten Leitsystem ausgestattet. Abhängig von der Aussentemperatur startet das Leitsystem die Luftheizung aus Gründen der Wärmekosteneinsparung so spät wie möglich, aber doch so, dass um 6:30 eine Inneraumtemperatur von 21,5 °C garantiert ist. Je kälter die Aussentemperatur um so früher wird die Heizung gestartet. Auf diese Weise wird schon vor Einführung von DSM bei kalten Aussentemperaturen Wärmeleistung in Schwachlastzeiten verschoben und der Lastgang geglättet. Daher war es nicht möglich an kalten Tagen (< 0 °C) mittels DSM weitere Lastspitzen Reduktionen zu erreichen.

Zwei Tarifmodelle sind im Zusammenhang mit DSM zu empfehlen:

Erstens, eine Vereinbarung, in der dem Versorger das Recht eingeräumt wird, innerhalb festgelegter Grenzen, die Lastspitze um bis zu 25 % über maximal 3 h während einer oder zwei Perioden pro Tag ferngesteuert zu reduzieren. Dem Verbraucher würde ein vertraglich bestimmter Abschlag in der Fernwärmerechnung gewährt. Die der Kappung folgende Aufheizphase sollte 1,5–2 länger sein als die Zeit, in der die Kappung aktiv ist. Die Wärmeleistung sollte langsam erhöht werden um die typische Lastspitze am Ende der Kappung zu vermeiden.

Zweitens, ein Tarif in dem stündlich die Wärmeleistung gemessen und entsprechend der höchsten monatlichen oder jählichen Wärmeleistung ein Leistungspreis in Rechnung gestellt wird. In diesem Modell bliebe es dem Kunden überlassen auf welche technische Art und Weise er die Lastspitze reduziert.

Stichwörter

demand side management, DSM, district heating systems, buildings, testing, test buildings, measurement, control devices, data collection, data analysis

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Nimeke

Kysynnän hallinta kaukolämpöjärjestelmissä

Tiivistelmä

Projektin tavoitteena oli osoittaa, että kaukolämpöjärjestelmässä suoritettavalla kulutuksen ohjauksella voidaan alentaa kustannuksia. Rakennusten massaa ja automaatiojärjestelmää hyödyntämällä voidaan saavuttaa 25–30 %:n tehonleikkaus. Projektissa arvioidaan myös epäsuoria säästötoimenpiteitä. Lämmin käyttövesi ei kuulu ohjauksen piiriin.

Kulutuksen ohjausta kokeiltiin kolmessa rakennuksessa, joista kaksi oli Jyväskylässä ja yksi Mannheimissa. Kulutuksen ohjauksen vaikutuksen ennakkoarviointiin kehitettiin yksinkertainen laskentamalli, jossa kuvataan rakennuksen päämitat ja materiaalit. Laskentaperiaate perustuu materiaalien lämpökapasitanssi – resistanssiominaisuuksien laskentaan.

Kokeellinen tutkimus osoitti, että kahdessa suomalaisessa rakennuksessa (betonirunko) tehoa voitiin leikata 2–3 tunnin jaksolla keskimäärin 20–25 % hyödyntämällä rakennusten massaa ja vesikeskuslämmitystä. Kun vesilämmityksen veden lämpötila saavuttaa DSM-toiminnon asetusarvon, automatiikka säätää lämpötilan asetettuun DSM-lämpötilaan. Ilmalämmityksellä lämmitetty rakennus voi ottaa suuren tehon ilman liikkuessa, mutta ilman lämpökapasiteetti on pieni verrattuna vesilämmitysjärjestelmään. Ilman lämpötilan alentuminen aiheuttaa lähes välittömästi korjauksen säätöjärjestelmän kautta. Ainoa tapa estää ilmastoinnin välitön korjaus sisälämpötilan perusteella, on säätää ilman lämpötilan asetusarvo 1–2 °C normaalia alemmaksi.

Jyväskylän kaukolämpöjärjestelmässä 20 % huipputehon leikkaukseen tarvitaan noin 160 rakennusta, joiden jokaisen lämmitetty tilavuus on 20 000 m^3. Simulointilaskelmien perusteella tuotantokapasiteetin käytössä voidaan saavuttaa noin 13 000 € säästöt vuodessa. Säästön perusteella DSM-laitteisiin voidaan sijoittaa 845 € kuluttajaa kohden (5 %, 15 v). Jos DSM:n avulla voidaan välttää yhden 20 MW:n (1,8 milj. EUR) huippukattilan rakentaminen, niin 20 vuoden pitoajalla ja 5 %:n korkovaatimuksella se merkitsee 144 000 € lisäsäästöä ja lisäksi säästetään huolto ja muut kiinteät kulut. Se merkitsee Jyväskylän tapauksessa jo 10 000 € investointimahdollisuutta kuluttajaa kohden.

Saksalaisen MVV:n toimistotornin huipputehoa Mannheimissa voidaan leikata noin 4,1 %. Lämmitystehon säästöllä voidaan parantaa CHP-laitoksen kokonaishyötysuhdetta keskimäärin 3 %. Parantunut hyötysuhde saavutetaan lämmön huippukulutuksessa 1–2 tunnin aikana päivittäin. Sulkemalla kiinteistön lämmityskierron venttiilit voidaan saavuttaa suurempiakin lyhytaikaisia tehon leikkauksia. Venttiilien sulkeminen aiheuttaa kuitenkin sen, että leikkausjakson jälkeiselle jaksolle voi tulla vuorokauden huippukulutustehot ja toivottu vuorokauden huipputehon pieneneminen menetetään. Toimistotorni on ilmalämmitteinen ja 3 tunnin tehon leikkausjakso on ilmalämmitetylle rakennukselle liian pitkä.

Ilmalämmitteisen toimistotornin lämmitysjärjestelmä on tietokoneen ohjauksessa ja lämmitysjärjestelmä aloittaa sisälämpötilan noston aamulla, kun ulkolämpötila on vielä kylmä. Varmistaakseen oikean sisälämpötilan 21,5 °C viimeistään klo 6.30, lämpötilan nosto aloitetaan riittävän ajoissa ja siten jo tasoitetaan vuorokauden lämmitystehon vaihtelua. Mittauksilla todettiin, että ulkolämpötilan ollessa alle 0 °C mitään tehon säästöä ei enää saavuteta. Ilmalämmitteisen rakennuksen aikavakio on lyhyempi kuin vesikiertolämmitteisen.

Tutkijaryhmä suositteli kahta DSM-toimintaa tukevaa tariffivaihtoehtoa. Kiinteän vuosimaksun pienentämiseen perustuva tariffi, jossa lämmön toimittajalla on oikeus leikata kuluttajan huipputehoa maksimissaan 25 % liittymistehosta ja maksimissaan 3 tuntia päivässä yhdessä jaksossa tai jaettuna kahteen jaksoon. Tehon leikkausta seuraava jälkijakson tai kahden jälkijakson pituus voi olla 1,5–2 tuntia leikkausjaksoa pidempi ja teho palautetaan lineaarisesti takaisin ulkolämpötilaa vastaavalle tehotasolle. Toisessa vaihtoehdossa kuluttaja voi valita, miten ja milloin tehon leikkaus suoritetaan. Päivittäinen tehohuippu mitataan ja vuoden tai kuukauden maksimi tehohuipun mukaan asiakas maksaa kiinteän maksun vuosittain tai kuukausittain.

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