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INNOVATIVE AND COST-EFFECTIVE COLD STORAGE APPLICATIONS IN SWEDEN

IEA Annex 7

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ABSTRACT

Within the IEA Storage Programme entitled "Innovative and Cost Effective Seasonal Cold Storage Applications" different energy systems with seasonal cold storage have been analysed by the participating countries. This report describes an open system (aquifer) and a closed system (duct storage in rock) applied in a cold climate in office buildings. The reference buildings are of different age but with similar geometry, four floors and an gross floor area of 12,000 m^2. The differences between the "New Building" and the "Retrofit Building" are mainly glass areas, shading coefficients, heat transmission coefficients of walls, roofs and windows.

These design studies show that an energy storage system can be competitive to a conventional energy system. Both storage systems can be built at the same cost as a conventional system. The energy costs are also lower which makes the storage systems more economic.

In both new and retrofit buildings it may be possible to reduce the energy consumption with about 40% using an open system. In a closed system electricity is replaced by cheap district heating during summertime. The aquifer store will reduce the emissions and give an environmental saving of about 50% in both new and retrofit buildings. The closed system will increase the emissions about 10%.

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APPENDICES

1 INTRODUCTION

Within the IEA Storage Programme entitled "Innovative and Cost Effective Seasonal Cold Storage Applications" different systems with seasonal cold storage have been analysed by the participating countries. This report describes an open system and a closed system applied in a cold climate.

The design data for the buildings are given by "IEA ANNEX 7, Reference cooling/ heating loads - Sub-soil design conditions - System design format, June 1992".

The reference building is an office building with four floors and a gross floor area of 12000 m^2 and a net floor area of 8400 m^2. The length of the building is 150 m. The "New Building" and the "Retrofit Building" are similar with respect to geometry. The differences are mainly glass areas, shading coefficients, heat transmissions coefficients of walls, roofs and windows.

2 ENERGY DEMAND

The buildings are designed for "extreme climate" with use of daily temperature data from Winnipeg. The climate is characterized by very cold winters and hot summers, cf Table 1.

Table 1 Monthly mean temperatures in Winnipeg.

Month	T mean	Month	T mean	Month	T mean
January	-17.7	May	11.3	September	12.8
February	-15.5	June	16.5	October	6.2
March	-7.9	July	20.2	November	-4.8
April	3.3	August	18.9	December	-12.9

The energy consumption has been calculated with ENORM, a computer program based on the Swedish Energy Regulations. The program uses daily meteorological data for several of places in Sweden but the program also allows use of other input data. The program includes not the cooling, because cooling design is not regulated in Sweden. The cooling demand is generally designed based on the use of each building. The calculation of the cooling demand has been made by Caneta Research Inc., cf the Canadian Report within the IEA Annex 7.

The result of the energy calculations for a conventional energy design with heat recovery is summarized in Table 2 and the detailed monthly values are presented in Appendix 1. The total energy demand (both for heating and cooling) is 1.8 GWh/year for the retrofit building and 1.4 GWh/year in the new building, assuming heat recovery of ventilation air.

Table 2 Energy demand for a New and Retrofit Building.

	New Building	Retrofit Building
Transmission (MWh/year)	985	1649
Ventilation nets (MWh/year)	743	743
Internal heat production (MWh/year)	788	788
Hot water, MWh/year	84	84
Heating: - demand (kW) - consumption (MWh/year)	 650 1062	 1160 1404
Cooling: - demand (kW) - consumption, (MWh/year)	 500 348	 750 396

3 PRINCIPAL DESIGN AND ENERGY SYSTEM

3.1 Storage systems for energy production

The energy system has the same layout when using open storage (aquifer) or closed storage (rock). No heat pumps are within the system and the storage temperatures will be within the yearly air temperature variations. Therefore, it is important to get a high temperature difference in the storage. This is given by a new type of heat exchanger that prevents freezing and allows working close to or at the freezing point. This implies that the system can use ground water directly for preheating of ventilation air and cooling of the building, see Figure 1. By this design the traditional ethylene-glycol circuit and one heat exchanger can be avoided. This gives the following advantages:

- a higher effective use of the temperature difference in the storage,
- increased possibilities to increase the storage of energy
- less expensive installation with less maintenance demand and
- reduce the risque for environmental impact compared with traditional system.

For the design of the system it has been assumed that energy balance has to be reached within the storage. The new heat exchanger increases the possibilities to adjust the energy balance by heat exchange with the air. It may then be possible that the energy system can cover the total energy demand both for preheating and cooling. However, in this study it has been assumed that all cooling and about 70% of the heating of ventilation air can be provided by the storage system.

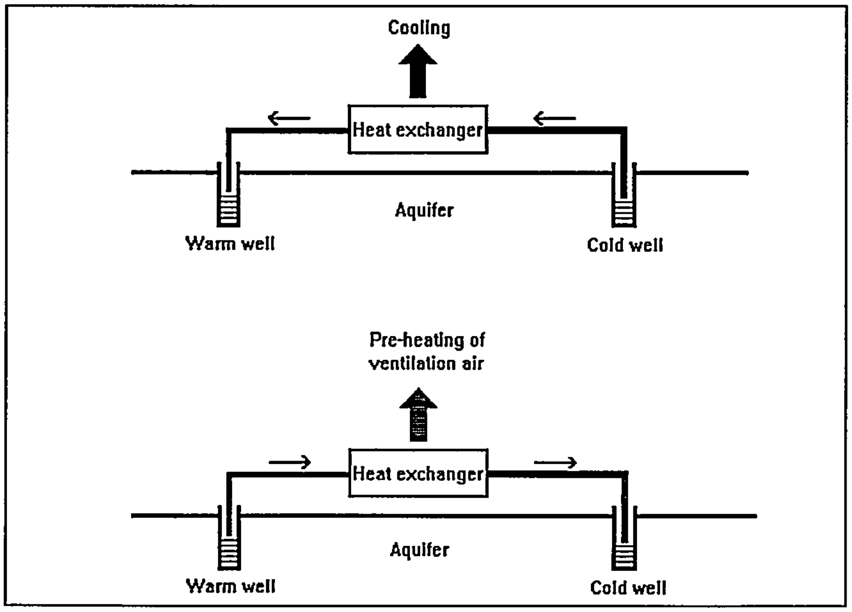

Figure 1 *Principal layout for the systems*

3.2 Conventional system for energy production

In a conventional energy system the heat will be supplied by district heating. Heat exchangers for the ventilation air is used to reduce the heating of the ventilation air. The cooling will be produced by electrical cooling-machines.

The investment cost for the conventional systems has been calculated to 0.8 MSEK for the New building and 1.0 MSEK for the Retrofit building, Table 3.

Table 3 Investment cost (kSEK) for conventional energy systems for energy production in a New and Retrofit building.

	New Building	Retrofit Building
Cooling machines	420	550
Air cooling (cooling tower)	200	260
Heat exchanger, district heating	25	35
Heat recovery unit	135	135
Other	20	20
Total	**800**	**1000**

3.3 Distribution system

The distribution of energy within the building is identical for all the studied alternatives. The proposed distribution system uses conventional components. Each building will be heated by water radiators. Cooling is provided by natural convection coolers mounted above the windows. Cooled water circulates through the convectors and creates a natural cooled downdraught. The ventilation system is mainly designed to meet hygiene ventilation requirements.

The investment cost for a such conventional distribution system is the same for a new building or for a retrofit building, about 1100 SEK/m^2. With an area of 12 000 m^2 the total cost will be about 13.2 MSEK.

4 OPEN SYSTEM

4.1 Storage design

The data for the aquifer is given by the conditions in the IEA-report. However, for the aquifer storage the following have also been assumed:

- it can be located at or very close to the building
- it is possible to drill wells around the building without large extra cost.

Based on calculations of the energy demand, it can be shown that two wells are enough. However, for backup and peak load reasons four wells (two warm and two cold wells) are proposed. The minimum distance between the cold and warm wells has been calculated to about 70 m for both buildings, assuming that preheating can cover about 75% of the ventilation demand that is equal for the two buildings.

The wells are situated around the building and have individual pipes to the energy central. The total pipe length for each well has been assumed to 80 m, with 50 m inside the building and 30 m outside the building. The unit cost for pipe installation inside both buildings is estimated to 200 SEK/m. For the pipes outside the buildings it has been assumed that the unit cost will be higher for the retrofit building, 700 SEK/m compared with 500 SEK/m for the new building.

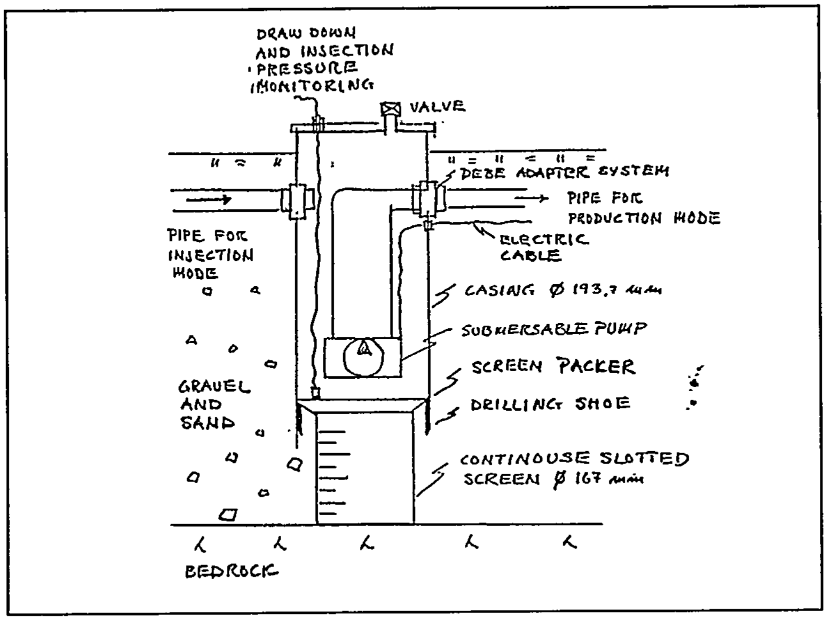

Figure 2 *Principal well design*

The wells are drilled by the ODEX and have a lost screen completion. The casing diameter is roughly 200 mm and the screen 165 mm OD. It is assumed that the wells are set in an esker with a thickness of 10 m and a transmissivity of 10^{-2} m^2/s. The screen length is set to 2 m which allows a flowrate of 40 m^3/h each well.

In the wells submersible frequency controlled pumps are installed with a lifting capacity of 40 m.w.p. for product mode. For the injection mode the annulus between the riserpipe and casing is used. The principal solution is shown in Figure 2.

The well construction cost will be in the order of 15 000 SEK per well and installations (pumps and wellhead) some 10 000 SEK. The frequency control is another 25 000 SEK each well. The total cost will then be roughly 200 000 SEK.

4.2 System layout - installations

The distribution system within the building is equal or almost equal for the alternatives. The system layouts are uncomplicated with only a few components, see the layout for the aquifer storage system in Figure 3. The system contains mainly two heat exchangers and the pumps located in the ground water wells.

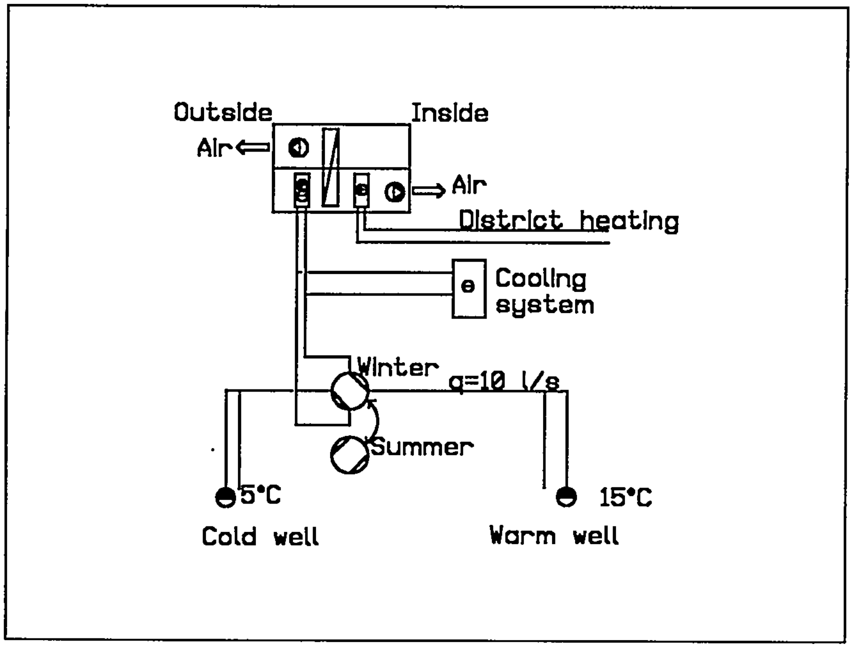

Figure 3 System layout

4.3 Cost

4.3.1 Investment cost

The investment cost for the energy central has been calculated for the buildings. Cost for design and installation etc. is not included because they will be of the same order for conventional energy system. Probably, an ATES system affords less building area for installations than a conventional system. The area reduction will be about 20 m^2 for the storage system because the cooling machines are eliminated. The building cost is for this type of areas about 500 SEK/m, which will be a reduction of 100 kSEK.

The investment cost will be about 1.0 MSEK for the retrofit building and 0.84 MSEK for the new building. The difference can be related to higher cost for pipes and legalisation for the retrofit building, cf Table 4.

The investment costs for a conventional energy system with cooling machines and district heating (or oil) have been estimated to 1.0 MSEK for the retrofit building and 0.8 MSEK for the new building. These costs are equal with the costs for the ATES system.

Table 4 Investment cost in kSEK for ATES in a New and Retrofit Building.

	New Building	Retrofit Building
Storage: - wells - outdoor pipes - indoor pipes	350 - 200 - 80 - 70	370 - 200 - 100 - 70
Heat exchangers: - cooling - preheating - heat recovery - district heating	275 - 60 - 30 - 135 - 50	300 - 60 - 30 - 135 - 75
Pumps, Energy Central	15	15
Legalisation	200	300
Reduced building area	-100	- 100
Control, additional cost compared with conventional system.	100	100
Total	840	985

4.4.2 Energy Cost

The energy system can only deliver energy for cooling and preheating of ventilation air. The heat exchangers have been design in a way such as energy balance can be reached in the aquifer by additional heat storage during summer or additional heat extraction during winter. The total demand of bought energy is about 0.5 GWh lower for the ATES system, both for the new and retrofit building. This give a reduction of the energy demand with about 40% for both buildings (See Appendix 1 for detailed calculations or Table 5 for summarized results).

The cost for electric energy is about 0.60 SEK/KWh and about 0.40 SEK/kWh for district heating. With these energy prices it can be shown that annual energy will be reduced with about 0.2 MSEK/year for the both buildings.

Table 5 Annual Energy Use and Energy Cost for New and Retrofit Building with ATES or conventional energy system.

	ATES	Conventional	Difference
New Building			
- District heating	542 MWh	1062 MWh	-520 MWh
- Electricity	270 MWh	328 MWh	- 58 MWh
- Energy cost	0.38 MSEK	0.62 MSEK	-0.24 MSEK
Retrofit Building			
- District heating	847 MWh	1404 MWh	-557 MWh
- Electricity	276 MWh	344 MWh	- 68 MWh
- Energy cost	0.50 MSEK	0.77 MSEK	- 0.27 MSEK

5 CLOSED SYSTEM

5.1 Storage design

A borehole heat store in rock, with a closed pipe system, was designed to meet the heating and cooling requirements, specified for a presumed building in Winnipeg climate, see Tables 1 and 2. The system works without heat pump.

The borehole heat store consists of a rock volume which is penetrated by a number of vertical boreholes. The holes work as heat exchangers between the rock and the heat carrier that is circulated in the pipes of the boreholes.

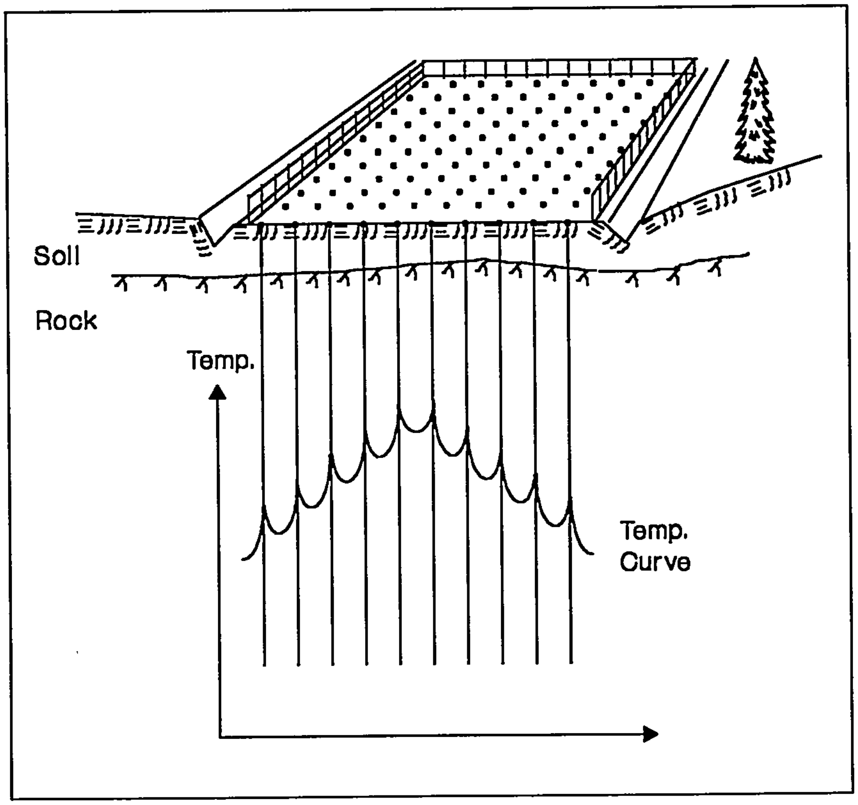

Figure 4 Section of a borehole heat store in rock.

The rock volume is heated when the store is charged and cooled when the heat is discharged. The rock volume is preferably of a compact shape to reduce the heat loss.

Borehole heat stores are most appropriate for seasonal storage at high temperatures (70-90°C). In this case, the store is designed for low temperature, with a heat carrier injection temperature from -10°C to + 40°C. The design is performed with the SmartStore model, which determines the storage design that minimizes the annual storage cost, i.e. the sum of capital, heat loss and maintenance costs during steady-state conditions.

In order to benefit from the qualities of this type of store, the design is optimized for the heat storage task. The cooling task is achieved as a result of the required heat injection. The charged heat obtained from the cooling of ventilation air, is however not adequate to meet the heat demand during the winter. So, additional heat must be injected into the store during the summer. It is assumed that this heat is delivered as secondary heat of the district heating. Since the idea of seasonal heat storage presumes that the heat cost is lower during the charging season (summer) than during the extraction season (winter), it is also assumed that the heat cost is 200 SEK/MWh during the summer and that the value of the extracted heat is 400 SEK/MWh during the winter season. This is a reasonable assumption when low temperature secondary heat is charged.

5.2 Energy System Design

The energy system design is almost equal with the aquifer storage system, see sec 4.2. The only difference is at heating mode when heat from the storage also can be used for additional heating of the ventilation air due to the higher temperature level in the storage. The cooling mode will be the same.

5.3 New Building

The storage task, which was previously defined in Table 2, shows that the annual requirements are 1062 MWh for heating and 348 MWh for cooling. Part of the heating demand, 520 MWh, and all of the cooling demand is supplied by the store. So, 348 MWh is charged into the store and 520 MWh is extracted. Consequently, additional heat must to be charged to level the unbalance which also includes the heat loss from the store. Since the heat loss is 130 MWh, see Appendix 2, 520-348+130=302 MWh must be charged into the store. The additional heat is supplied by district heating.

Design data of the store is given in Table 6. The store consists of 24 boreholes drilled in a hexagonal pattern to a depth of 102.8 m, with a spacing of 4.2 m. The total storage volume is 37,000 m^3. A double U-pipe system (plastic) is installed in the boreholes.

Table 6 Borehole Heat Store Design New and Retrofit Building

	New	**Retrofit**
Drilling Pattern	Hexagonal	Heaxagonal
Borehole Spacing	4.15 m	4.15 m
Borehole Depth	102.8 m	103.4 m
No. Boreholes	24 m	24 m
Storage Land Area	629 m^2	632 m^2
Storage Volume	36834 m^3	37426 m^3
Injected Heat	650 MWh	660 MWh
Extracted Heat	520 MWh	529 MWh
Heat Loss	130 MWh	131 MWh

The flow rate is 0.3 l per pipe, which results in a total borehole thermal resistance of 0.23 K/(W/m). The heating/cooling power varies from cooling power of 194 kW to a heating power of 224 kW, resulting in a mean storage temperature of 13.6°C. These monthly maximum powers that can be raised during short periods of time. This optimization does not give a more exact answer of how long these periods are.

5.4 Retrofit Building

The storage task that was previously defined in Table 2 shows that the annual requirements are 1404 MWh for heating and 396 MWh for cooling. Part of the heating demand, 529 MWh, and all of the cooling demand is supplied by the store. So, 396 MWh is charged into the store and 529 MWh is extracted. Consequently, additional heat must to be charged to level the unbalance which also includes the heat loss from the store. Since the heat loss is 131 MWh, see Appendix 2, 529-396+131=264 MWh must be charged into the store. Additional heat is supplied by district heating.

Design data of the store is given in Table 5. The store consists of 24 boreholes drilled in a hexagonal pattern to a depth of 103.4 m, with a spacing of 4.2 m. The total storage volume is 37,000 m^3. A double U-pipe system (plastic) is installed in the boreholes. The flow rate is 0.3 l per pipe which results in a total borehole thermal resistance of 0.234 K/(W/m). The heating/cooling power varies from a cooling power of 198 kW to a heating power of 227 kW resulting in a mean storage temperature of 13.6°C. These monthly maximum powers can be raised during short periods of time. This optimization does not give a more exact answer of how long these periods are.

5.5 Cost

The parameters used in the optimization, both specific details of the construction and properties of the ground and pipe materials are listed in Appendix 2. Since the annual operation cost is minimized in this optimization, unit-costs of specific construction details are also given. The investment costs for the new and retrofit building, as specified by the SmartStore model, are listed in Table 7 and in Appendix 2.

The annual energy use and energy cost for the new and retrofit buildings with a borehole heat store are summarized in Table 8. The heat demand is 1062 MWh (1404 MWh) for the new and retrofit building respectively. In the conventional building all the heat is supplied by the district heating. In the new and retrofit building the heat is supplied both by district heating 542 MWh (876 MWh) and by the storage system 520 MWh (529 MWh). Except from the extracted heat additional heat must be charged into the store to cover the heat losses 130 MWh (131 MWh). So, 1192 MWh (1535 MWh) is charged. The charged heat is supplied by waste heat from the air-cooling and by the district heating.

Table 7 Sub-Totals of Investment Cost for New and Retrofit Building

	New Building (kSEK)	Retrofit Building (kSEK)
Storage	**661**	**671**
- Drilling	407	413
- Piping	223	226
- Land	31	32
Energy Central	**149**	**149**
- Heat Exchangers		
- Pumps		
- Control, additional cost compared with conventional system		
Total	**810**	**820**

The cooling demand of the conventional building is supplied by cooling machines, with an assumed COP of 3. In the new and retrofit building the cold is extracted from the store.

The heat cost of district heating was assumed to 200 SEK/MWh during the summer, i.e. the charging period. In the conventional building the heat cost over the year is assumed to 400 SEK/MWh. The cost of electricity is assumed to 600 SE+1Xtem a COP of 15 is assumed,
that is the relation between extracted heat/cold and the electricity demand for the circulation pump.

The heat and cost are also given in Table 8. The annual cost of heat was 0.42 MSEK in the conventional building. In the new and retrofit building the annual cost of heat directly distributed by the district heating net was 0.22 MSEK (0.42 MSEK) for the total heat load. The annual cost of charged district heat was 0.06 MSEK (0.05) MSEK. The annual cost of driving electricity for fans and pumps 0.13 MSEK are equal in the all cases.

The annual total variable energy cost for the heat storage system was 0.17 MSEK and 0.20 MSEK lower than the conventional heating/cooling system, for the new and retrofit building respectively.

By adding the annual capital cost to the variable cost the economy of the different heating/cooling systems are compared, see Table 9. The economy of the storage alternatives is less expensive than the conventional system. Annual cost for the new building with an aquifer system is 36% lower than that of the conventional system. The annual cost for a borehole heat storage system is 5-7% lower than the conventional heating/cooling system.

Table 8 Annual Energy Use and Energy Cost for New and Retrofit Building with a Borehole Heat Store

	Heat Store	Conventional	Difference
NEW BUILDNING	(MWh)	(MWh)	(MWh)
Heat Demand	**1062**	**1062**	
District Heating	542	1062	-720
Pre-Heating (Store)	520		520
Cold Demand	**348**	**348**	
Air-Cooling (Store)	348		348
Heat Supply	**1192**	**1062**	**130**
District Heating	542	1062	720
Charged Heat(incl.heat loss)	650		650
District Heating	302		302
From Cooling	348		348
Cold Supply	**348**	**348**	
Stored Cold	348		348
Cooling Machines		348	-348
Heat/Cold Cost	(MSEK)	(MSEK)	(MSEK)
Direct District Heat	0.22	0.42	-0.20
Stored District Heat	0.06		0.06
Electricity			
Circulation Pumps	0.04		0.04
Fans/Pumps	0.13	0.13	
Cooling Machines		0.07	-0.07
Total Energy Cost	**0.45**	**0.62**	**-0.17**
RETROFIT BUILDING	(MWh)	(MWh)	(MWh)
Heat Demand	**1404**	**1404**	
Direct District Heating	876	1404	-528
Pre-Heating (Store)	529		529
Cold Demand	**396**	**396**	
Air-Cooling (Store)	396		396
Heat Supply	**1535**	**1404**	**131**
Direct District Heating	876	1404	529
Charged Heat, incl. heat loss	660		660
District Heat	264		264
From Cooling	396		396
Cold Supply	**396**	**396**	
Stored Cold	396		396
Cooling Machines		396	-396
Heat/Cold Cost	(MSEK)	(MSEK)	(MSEK)
Direct District Heat	0.35	0.56	-0.21
Stored District Heat	0.05		0.05
Electricity			
Ground Water Pumps	0.04		0.04
Fans/Pumps	0.13	0.13	
Cooling Machines		0.08	-0.08
Total Energy Cost	**0.57**	**0.77**	**-0.20**

6 ENVIRONMENTAL ASPECTS

The environmental concerns in respect to energy production are coupled to emissions of greenhouse gases acids and ozone impactable substances. In order to control and in time minimize those emissions the Swedish Government has put taxes on fuels and flow gases from fuels, see Table 9.

Table 9 Approximated taxes are applicable on fossil fuels (SEK/MWh), early 1993.

Form of tax	Fuel			
	Oil	Coal	Natural gas	Biomass
Basic energy tax	50 - 60	30 - 35	15	0
Fee CO_2	65 -75	80 - 85	50	0
Fee SO_2	0 - 20	5 - 20	0	0 - 20
Fee NO_x	0- 2	0 - 2	0	0
Total tax	115 - 157	115 - 142	65	0 - 20

The fees for CO_2, SO_2 and NO_x shall be regarded as true environmental charges. This also means that any reduction of the usage of fossil fuels is of benefit for the environment and is rewarded by reduced taxes.

The average emission (kg/MWh) as they are calculated in Sweden can roughly be stated as follows:

	CO_2	SO_2	NO_x
Oil	250	4	1.3
Coal	300	5	1.5
Gas	200	0	1.0
District heating (mixture)	200	2	1.0
Electricity (5-10% fuel)	20	0.5	0.1

In Sweden, conservation of nationally generated electricity will only marginally decrease the CO_2, SO_2 and NO_x emissions. Approximately 5% of the electricity is produced by means of burning fossil fuels, but this figure is slowly increasing.

Based on energy turnover the studied storage concepts it can be concluded that the open storage system in aquifers decreases both the district heating and the electricity consumption, while the closed system in rock decreases the electricity consumption and partly replaces electricity with district heating during summer. So the environmental impact will be higher for the rock store since the emissions from district heating are about 10 times higher than for electricity. However, the aquifer store will give an environmental saving about 50% in both new and retrofit buildings, cf. Table 10.

Table 10 Environmental impact for different energy systems

New Building	**Conventional**	**Storage systems**			
		Aquifer	**Difference**	**Rock**	**Difference**
District heating (MWh)	1062	542	-520	1192	+130
Electricity (MWh)	328	270	-58	270	-58
CO_2 (kg/year)	219 000	114 000	-105 000	244 000	+25 000
SO_2 (kg(year)	2288	1219	-1069	2519	+231
NO_x (kg/year)	1062	542	-520	1192	+130
Retrofit Building					
District heating (MWh)	1404	847	-557	1535	+131
Electricity (MWh)	344	276	-68	276	-68
CO_2 (kg/year)	288 000	175 000	-113 000	313 000	+25 000
SO_2 (kg/year)	2980	1832	-1148	3208	+228
NO_x (kg/year)	1404	847	-557	1535	+131

7 CONCLUSIONS

These design studies show that energy storage system can be competitive to conventional energy system. Both storage systems can be built at the same cost as a conventional system. The energy costs are also lower which makes the storage systems more economic, cf. Table 10.

In both new and retrofit buildings it may be possible to reduce the energy consumption with about 40% using open system. In a closed system electricity is replaced by cheap district heating during summertime.

The aquifer store will reduce the emissions and give an environmental saving about 50% in both new and retrofit buildings. The closed system will increase the emissions about 10%.

Table 10 Economic and energy data for comparison between conventional and storage alternatives.

CRITERIA FOR COMPARISON	CONVENTIONAL DESIGN		STORAGE ALTERNATIVE			
			Open aquifer		Closed rock	
	New	Retrofit	New	Retrofit	New	Retrofit
SYSTEM CHARACTERISTIC						
- Cooling (kW)	500	750	500	750	500	750
- Heating (kW) without heat recovery	971	1043	971	1043	971	1043
- Cooling (MWh)	348	396	348	348	348	396
- Heating (MWh) without heat recovery	1934	2276	1934	2276	1934	2276
- Electrical Peak Demand (kW)						
Summer	140	250	40	40	40	40
Winter	25	25	40	40	40	40
ENERGY CONSUMPTION						
Electricity:						
- Compressors (chillers/HPs) (MWh)	116	132				
- Cooling Tower (MWh)						
- Storage			58	64	58	64
- Distribution (fans, pumps etc.) (MWh)	212	212	212	212	212	212
Gas (1000 m^3)						
Oil (m^3)						
District heating (MWh)	1062	1404	542	847	1192	1535
Heat recovery from Ventilation (MWh)	872	872	872	872	872	872
COSTS						
Total Capital Cost (kSEK)	800	1000	840	985	810	820
- Chillers and HPs (piping, wiring, installed)						
- Cooling towers (piping, fans, pumps, HX)			640	685	661	671
- Storage (design, site inspection, piping pumps,HX)						
- Boilers (service connection, oil tank, ventilation, HRV)			200	300	149	149
- Distribution (incremental costs)						
- Control and other (incremental costs)	80	100	84	99	81	82
	40	50	42	50	40	41
Annualized Total Capital Cost (10%)						
Annualized Total Capital Cost (5%)	620	770	380	500	450	570
Total Annual Energy Cost			0	0	0	0
Total Annual Maintenance Cost	700	870	464	599	531	652
(incremental)	660	820	442	550	490	611
Total Annual Costs (10%)						
Total Annual Costs (5%)						

CALCULATIONS IEA ANNEX 7			930526			Process	30	W/m2	
NEW BUILDING						area	8400	m2	
LOCATION: WINNIPEG									
	Transmission	Ventilation	Vent. net *	Insolation **	Insolation***	Int. heat pr	Hot water	Tot Heating	Tot Cooling
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
JAN	177937	291551	134113	15606	10282	66960	7000	236484	-100695
FEB	157613	258250	118795	17488	12357	60480	7000	205440	-84776
MAR	141313	231543	106510	19420	21961	66960	7000	168443	-52392
APR	74334	121796	56026	11318	26063	64800	7000	61242	16529
MAY	42767	70074	32234	7056	13296	66960	7000	7985	37489
JUN	13608	22297	10257	3508	16319	64800	7000	-37443	67511
JUL	2199	3603	1657	2351	19009	66960	7000	-58455	83770
AUG	3940	6455	2969	2450	17971	66960	7000	-55501	80991
SEP	33344	54634	25132	4512	13238	64800	7000	-3836	44694
OCT	66046	108218	49780	7766	16406	66960	7000	48100	17320
NOV	106987	175299	80638	8706	7813	64800	7000	121119	-34374
DEC	165168	270630	124490	12767	7315	66960	7000	216931	-90893
TOTAL	985256	1614350	742601	112948	182030	788400	84000		
								Cooling	348304
*	54% heat recovery by heatexchange between incoming							Heating	1061908
	and outgoing ventilation air, (FTX)							Balance	713604
								Total	1410212

Conclusions: Energy cost, (MSEK/year)			
	Aquifer	Convential	Difference
	0.38	0.62	0.24

** Heat gain when the system is heating (given by Caneta Research Inc)
*** Heat gain when the sytem is cooling (given by Caneta Research Inc)

CALCULATIONS IEA ANNEX 7			930526			Process	30	W/m2	
RETROFIT BUILDING						area	8400	m2	
LOCATION: Winnipeg									
	Transmission	Ventilation	Vent. net *	Insolation **	Insolation***	Int. heat pr	Hot water	Tot Heating	Tot Cooling
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
JAN	282401	291551	134113	53908	41347	66960	7000	302646	-174094
FEB	237263	258250	118795	58295	51442	60480	7000	244283	-125341
MAR	210147	231543	106510	61001	91032	66960	7000	195696	-52155
APR	150540	121796	56026	35162	102042	64800	7000	113604	16302
MAY	91703	70074	32234	21910	52764	66960	7000	42067	28021
JUN	37755	22297	10257	10322	62418	64800	7000	-20110	89463
JUL	19202	3603	1657	7257	71107	66960	7000	-46358	118865
AUG	35868	6455	2969	7685	67248	66960	7000	-28808	98340
SEP	72912	54634	25132	14359	50806	64800	7000	25885	42694
OCT	127788	108218	49780	25842	62946	66960	7000	91766	2118
NOV	170229	175299	80638	35395	25333	64800	7000	157672	-80096
DEC	213480	270630	124490	47268	26535	66960	7000	230742	-119985
TOTAL	1649288	1614350	742601	378404		788400	84000		
								Cooling	395803
								Heating	1404361
								Balance	1008558
								Total	1800164

Conclusions: Energy cost, (MSEK/year)			
	Aquifer	Convential	Difference
Retrofit	0.50	0.77	0.26
New	0.38	0.62	0.24

** Heat gain when the system is heating (given by Caneta Research Inc)
*** Heat gain when the sytem is cooling (given by Caneta Research Inc)

	NEW BUILDING			Electricity:	0.60	SEK/kWh	
				District heat.	0.40	SEK/kWh	
	Aquifersystem						
	Heating demand:	650	kW	Heating cons.	1062	MWh/year	
	Cooling demand:	500	kW	Cooling cons:	348	MWh/year	
	District heat	400	kW				
	Heatex. preheat/cool	350	kW (250 kW for heat storage)				
	Heatex. cooling	500	kW				
	Assume pre-heating as		70%	of the total ventilation demand			
	and district heating for the remaining heating.						
				C.O.P	Electricity	District heat	
	District heating	542	MWh	0.00		542	MWh
	Pre-heating	520	MWh	15.00	35		MWh
	Total	1062	MWh		35	542	MWh
	The cooling demand is covered by heat exchange with the storage						
				C.O.P	Electricity	Cooling	
	Heat exchange:	348	MWh	15.00	23		MWh
	El. for pumps/fans				212		
	Bought energy	542	MWh dis.he+	270	MWh el. =	812	MWh
	Annual energy cost	0.22	MSEK +	0.16	MSEK =	0.38	MSEK
	RETROFIT BUILDING			Electricity:	0.60	SEK/kWh	
				District heat.	0.40	SEK/kWh	
	Aquifersystem						
	Heating demand:	1160	kW	Heating cons.	1404	MWh/year	
	Cooling demand:	750	kW	Cooling cons:	396	MWh/year	
	District heat	1200	kW				
	Pre-heating	300	kW (200 kW for heat storage)				
	Heatex. cooling	750	kW				
	Assume pre-heating as		75%	of the total ventilation demand			
	and district heating for the remaining heating.						
				C.O.P	Electricity	District heat	
	District heating	847	MWh	0.00		847	MWh
	Heat exchange	557	MWh	15.00	37		MWh
	Total	1404	MWh		37	847	MWh
	The cooling demand is covered by heat exchange with the aquifer						
				C.O.P	Electricity	Cooling	
	Heat exchange	396	MWh	15.00	26		MWh
	El. for pumps/fans				212		
	Bought energy	847	MWh dis he+	276	MWh el =	1123	MWh
	Annual energy	0.34	MSEK +	0.17	MSEK =	0.50	MSEK
	cost						

	NEW BUILDING			Electricity	0.60	SEK/kWh	
				District heat	0.40	SEK/kWh	
	Conventional system with district heating and cooling machines						
	Heating demand:	650	kW	Heating cons	1062	MWh/year	
	Cooling demand:	500	kW	Cooling cons	348	MWh/year	
	The heat demand is covered by district heating						
	The cooling demand is covered by cooling machines						
				C.O.P	Electricity	Cooling	
	Cooling	348	MWh	3	116	464	MWh
	El. for pumps/fans				212		
	Bought energy	1062	MWh dist.ht	328	MWh el =	1390	MWh
	Annual energy	0.42	MSEK +	0.20	MSEK =	0.62	MSEK
	cost						
	RETROFIT BUILDING			Electricity	0.60	SEK/kWh	
				District heati	0.40	SEK/kWh	
	Convential system with district heating and cooling machines						
	Heating demand:	1160	kW	Heating cons	1404	MWh/year	
	Cooling demand:	750	kW	Cooling cons	396	MWh/year	
	The heat demand is covered by district heating						
	The cooling demand is covered by cooling machines						
				C.O.P	Electricity	Cooling	
	HX:	396	MWh	3	132	528	MWh
	El. for pumps/fans				212		
	Bought energy	1404	MWh dis.h+	344	MWh/el =	1748	MWh
	Annual energy	0.56	MSEK +	0.21	MSEK =	0.77	MSEK
	cost						

SMARTSTORE - Borehole Heat Store Design,

OPTIMUM DESIGN	NEW	RETROFIT	
Drilling Pattern	HEXAGONAL	HEXAGONAL	
Borehole Spacing	4.15	4.15	m
Borehole Depth	102.81	103.44	m
No. Boreholes	24	24	
Storage Land Area	629	632	m^2
Storage Volume	36834	37426	m^3
Injected Heat	650	660	MWh
Extracted Heat	520	529	MWh
Heat Loss	130	131	MWh
Recovery factor	80.0	80.2	%

SUB-TOTALS OF CONSTRUCTION COST	[SEK]	[SEK]
Land Cost	31442	31620
Drilling Cost	406576	412909
Piping Cost	223398	226029
Indoor Cost	148600	149124
Administration Cost	0	0
TOTAL CONSTRUCTION COST	810016	819682
Initial Heating Cost	47700	48521
TOTAL INVESTMENT COST	857716	868203

CALCULATED STORAGE DATA			
Maximum Injection Power	224	227	kW
Maximum Extraction Power	194	198	kW
Storage Mean Temperature	13.6	13.6	°C

CALCULATED THERMAL RESISTANCES			
Borehole Pipe Installation	DOUBLE-U		
Fluid/Pipe	0.0190	0.0190	K/(W/m)
Pipe Material	0.0676	0.0676	K/(W/m)
Cont. Resist. Pipe/Filling	0.0200	0.0200	K/(W/m)
Tot. Borehole Thermal Resistance	0.1066	0.1066	K/(W/m)
Borehole/Ground Thermal Resist.	0.234	0.234	K/(W/m)
Vol. Heat Transfer Capacity	0.287	0.287	$W/(m^3,K)$
Total Heat Transfer Capacity	10.567	10.737	kW/K

SPLIT-UP CONSTRUCTION COSTS	[SEK]	[SEK]
Levelling	31442	31620
Total Land Cost	31442	31620
Soil Drilling	96095	97049
Rock Drilling	310481	315860
Total Drilling Cost	406576	412909
Distr. Tank	50000	50000
Borehole Pipe	167416	169987
Connect. Pipe	5982	6041
Total Piping Cost	223398	226029
Pump	15000	15000
Heat Exchanger (224 kW)	83600	84124
Control System	50000	50000
Total Indoor Cost	148600	149124
TOTAL CONSTRUCTION COST	**810016**	**819682**
Initial Heating Cost	47700	48521
TOTAL INVESTMENT COST	**857716**	**868203**

ANNUAL STORAGE COST		
Capital Cost of Investment	67096	67917
Operation and Maintenance Cost	16200	16394
Heat Loss Cost	25920	26100
Total Annual Storage Cost	109217	110411

OPTIMIZATION PRESUMPTIONS
TECHNICAL DATA

Drilling Pattern	HEXAGONAL	
Borehole Installation	DOUBLE-U	
Borehole Diameter	0.115	m
Borehole Spacing	1.0 - 8.0	m ± 0.04 m
Borehole Depth	50.0 - 150.0	m ± 0.31 m
Land Strip Width	5.0	m
Soil Depth	5.0	m
Soil Thermal Conductivity	0.75	W/m,K
Rock Thermal Conductivity	3.00	W/m,K
Rock Thermal Capacity	2100000	J/(m3,K)
Construction Time	1.0	years
Mortgage Time	25.0	years
Interest Rate	6.0	%
Extracted Heat	520	529 MWh
Inj. Water Temperature	15.0 +/- 25.0	°C
Air Temperature	2.5 +/- 18.0	°C
Phase Inj.Water Temp/Air Temp	143.0	days

BOREHOLE INSTALLATION DATA TYPE:	DOUBLE-U	
Borehole Diameter	0.115	m
U-Pipe Outer Diameter	0.0320	m
U-Pipe Wall Thickness	0.0025	m
U-Pipe Shank Spacing	0.0830	m
U-Pipe Thermal Conductivity	0.400	W/m,K
Filling Thermal Conductivity	0.600	W/m,K
Filling Thermal Capacitivity	4100000	J/(m3,K)
Cont. Th. Resist. Pipe/Filling	0.020	K/(W/m)
Volumetric Flow Rate/Borehole	0.0002	m3/s
Reference Temperature	15.0	°C

UNIT-COSTS USED IN OPTIMIZATION
LAND AREA COST

Land Levelling		
- Area Depending	50.00	SEK/m2
Soil Drilling		
- Borehole Depending	4000.00	SEK/bh
Rock Drilling		
- Drilling Cost	100.00	SEK/m
- Drilling Cost Increase	0.50	SEK/(m,m)
Borehole Pipe		
- Borehole Depending	500.00	SEK/bh
- Pipe Cost	60.00	SEK/m
Connecting Pipe	60.00	SEK/m
Distr./Collector Tank	50000.00	SEK
Pump Installation	15000.00	SEK
Heat Exchanger		
-Fixed	50000.00	SEK
-Capacity Cost	150.00	SEK/kW

Operation Control System	50000.00	SEK
Injection Heat Cost		
- Variable	200.00	SEK/MWh
- Annual Cost Increase	5.00	%
Extraction Heat Cost		
- Variable	400.00	SEK/MWh
- Annual Price Increase	5.00	%
Maintenance Cost		
- Variable	1.00	%
Operation Cost		
- Variable	1.00	%