SINTEF Building and Infrastructure

MARK MURPHY

LECO
Simulating Earth to Air Heat Exchangers

Ventilation preheating and pre-cooling

Project report 70 2011

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Preface

This study is included as a part of the research and development project ”LECO, Low Energy COmmercial buildings”.

Energy use contributed to commercial buildings constituted circa 36 TWh in 2007, which corresponds to approximately 45 % of the energy use in buildings. The potential for conserving energy within this part of the building sector, using current technology, is estimated to 6.5 TWh before 2020. (Lavenergiutvalget, juni 2009)

LECO has the objective to gather in existing and to develop new knowledge pertaining to energy efficient solutions that reduce energy use in commercial buildings. Intensions are to produce guidelines with respectively 50 %, 75 % and 90 % reduction of energy use (Factor 2-4-10) to a typical office building of today. (Reference building =300 kWh/m^2 year.)

In the quest to find energy efficient solutions, this report has been constructed to investigate the energy savings potential of earth to air heat exchangers.

The project was completed by Mark Murphy in the autumn of 2010. Bjørn Jenssen Wachenfeldt from Skanska AS has contributed with quality control of the project report.

LECO is a knowledge-building project with user involvement.
The project is led by SINTEF Building and Infrastructure and is implemented in corporation with SINTEF Energy, Erichsen & Horgen AS, Entra Eiendom AS, YIT AS, Entro AS, Hunter Douglas AS, Per Knudsen Arkitektkontor AS, Rambøll AS, Skanska AS, and OptoSense AS.
The project started autumn 2008 and will continue until the middle of 2011.

We give thanks to the project’s partners and The Research Council of Norway for supporting the project.

Abstract

A primary objective with passive houses is to reduce the energy demand for heating and cooling. A well-insulated and airtight building envelope, highly efficient heat recovery within the ventilation system, low-energy windows and doors, and thermal bridge free constructions are common characteristics for passive houses. When all these characteristics are in place, what becomes the next step? What else should one improve in order to reduce the energy use of the building?

One possible answer could be to improve the ventilation system by installing an earth-to-air heat exchanger (ETAHE). An ETAHE utilizes the thermal mass of the soil surrounding or beneath the building in order to preheat or pre-cool incoming ventilation air. With the ground's large thermal capacity and relatively stable temperatures, outdoor temperature variations are dampened and ventilation heating and cooling loads are reduced.

Using the building energy simulation software TRNSYS, this report investigated the heating potential and cooling potential of an ETAHE in a mechanically ventilated passive house, ranging in size from a detached house to a small office. Simulations of the ventilation system within a small office indicate that a parallel piped ETAHE, connected to an efficient air handling unit, will provide energy savings ranging between 6 and 14.6 kWh/m^2 floor space during a normal year with base ventilation at night and 4 air circulations per hour during day.

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1. Introduction

The concept behind an Earth-to-Air Heat Exchanger (ETAHE) is to utilize the thermal mass of the soil surrounding or beneath the building to preheat or pre-cool incoming ventilation air. With the ground's large thermal capacity and relatively stable temperatures, outdoor temperature variations are dampened and ventilation heating and cooling loads are reduced.

As mentioned by Haase and Andresen (2007), ETAHE technology has a multitude of alternative names: Earth Cooling Tube, Ground Coupled Air System, Cool-Tube in-Earth Heat Exchanger, Earth Air Tunnel, Earth Contact Cooling Tube, Earth Tube Heat Exchanger, Buried Piped Cooling System, Underground Solar Air Heater, Earth Air-Pipes Systems, Air-Soil Heat Exchanger, Embedded Duct, Earth Channel, Hypocaust, and Earth-to-Air Heat Exchanger.

As implied by the recurrent use of the word cooling, ETAHEs are primarily used for cooling purposes. But they can also be used for heating purposes during the winter when the outdoor air temperature is lower than the average soil temperature. When the outdoor temperature is between the average soil temperature and the desired indoor temperature, usually 20°C, the ETAHE can be bypassed.

1.1. Ventilation Strategy

Conventional ETAHEs are designed with mechanical ventilation systems that use fans to provide the airflow driving forces. In such systems, the ETAHE can consist of a single duct or a number of parallel ducts. The optimization of this involves minimizing the pressure drop while maximizing the surface area available for heat transfer.

A newer approach to improving building energy efficiency involves the integration of ETAHEs into hybrid ventilation systems. In such a system, the duct of the ETAHE is expanded to a large cross-sectional area in order to minimize pressure drop and take advantage of buoyancy and wind driving forces. Fans are used first when the ventilation exchange rate is insufficient. In the case of Jaer School in Oslo, Norway, the fans were only needed for additional cooling during the summer months (Tjelflaat, 2002).

1.2. Moisture Content

During the winter months, preheating the outdoor air will cause the relative humidity to drop. The opposite occurs when cooling the outdoor air. Condensation and accumulation of water within the ETAHE may then become a problem. To decrease the potential of mould, the air should be filtered and water should be led towards a drain using a slight inclination.

1.3. Available Design Tools

There are several programs available to assist in the design process, including GAEA, AWADUKT Thermo, L-EWTSim, and WKM. ETAHE modules have also been developed for Energy Plus (Lee and Strand 2007) and TRNSYS (Mihalakakou 1994).

A common characteristic among these programs is the assumption of fully developed turbulent flow that enables the use of corresponding empirical correlations to determine the heat transfer coefficients between the airflow and the duct walls.

Experimental results from Wachenfeldt (2003) showed that typical empirical correlations significantly underestimated the heat transfer coefficients within a hybrid ventilation ETAHE system. CFD simulations performed by Zhang and Haghighat (2005) showed that entrance effects, vertical thermal stratification, and reversed flow phenomenon are significant in large cross-sectional ETAHEs.

Another complication comes from ground temperature modeling. An extremely complex model that takes into consideration surface conditions such as vegetation and snow, ground composition, and surface/ground heat transport mechanisms would be computationally intensive.

2. Method

The task of simulating an ETAHE can be approached using either CFD methods or by using various programs and their corresponding empirical correlations.

Without CFD, complex phenomenon such as entrance effects, vertical thermal stratification, and reversed flow within large cross-sectional ETAHEs cannot be simulated. Nor can one study with detail the thermal storage capacity of the surrounding soil and its ability to be loaded with either excess heat or cooling energy. Through the use of an ETAHE, the annual temperature variation in the surrounding soil will become phase shifted relative the variations in untouched soil. The possibility of using this phase shift for seasonal storage is left for future research.

The following study accepts the assumption of fully developed turbulent flow, which enables the use of corresponding empirical correlations. This assumption limits the scope of the project to focus on mechanically ventilated ETAHEs. The performance of mechanically ventilated ETAHEs is then investigated through a parameter study using TRNSYS.

3. TRNSYS Parameter Study - Setup

3.1. Component Type

Horizontally buried pipes used for preheating and pre-cooling incoming ventilation air can be simulated with Type 997 Horizontal Ground Heat Exchanger. The model takes into consideration heat transfer between a pipe with a circular cross section, or a network of circular pipes, and the surrounding layers of soil.

This model calculates the heat transfer coefficient between the pipe and the enclosed air using the well known Colburn equation for fully developed turbulent flow in smooth tubes:

$$Nu = 0.023Re^{0.8}Pr^{\frac{1}{3}}$$

where Nu is the dimensionless convection heat transfer coefficient given as function of the dimensionless parameters Reynolds number (Re) and Prandtl number (Pr).

The model assumes a smooth pipe surface, a pipe with circular cross section, and fully developed turbulent flow. To be well above the transitional fluid flow regime, the Reynolds number should be greater than 10,000.

3.2. Simulated Pipe

ETAHEs predominately use plastic pipes, but ETAHEs with large cross sectional areas have also been built in concrete. The latter has a high vapor permeability that can lead to additional humidification of the ventilation air as water is transported through the concrete pipe to the air. Choosing a plastic material can avoid this excess humidification.

PE/PP plastic pipes, used already for underground ventilation systems, were simulated with the average thermal conductivity 0.28 W/m·K (1 kJ/hr·m·K) and inner and outer diameters according to technical descriptions (Uponor, 2008). The picture to the right shows a ventilation pipe being installed at Karlskrona Högskola with the type of plastic that was simulated (Source: Uponor).

3.3. Simulated Ventilation System

The ETAHE is connected to the ventilation system as shown in the figure below. The ETAHE is buried under 2 meters of homogeneous dirt with density 1900 kg/m^3, thermal conductivity 2.0 W/m·K, and specific heat 2.2 kJ/kg·K. The incoming ventilation air passes through the buried pipe before entering the air handling unit located within the building. A potential bypass is installed in order to bypass the ETAHE when the temperature dampening of the ETAHE may be considered counter productive.

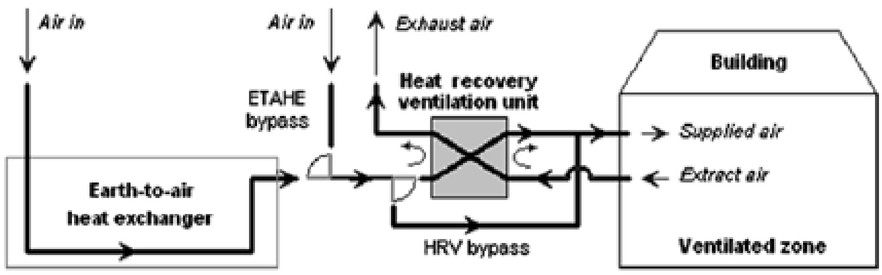

Figure 1: Systematic representation of the simulated ventilation system
(Source: S. Thiers and B. Peuportier, 2008)

The air handling unit is simulated using Type 334 Air Handing Unit (AHU). It is set to 80% temperature efficiency with bypass and frost protection. A bypass on the extract air controls how much exhaust air is needed to heat up the incoming fresh air to a set temperature without overheating. Meanwhile, a bypass on the incoming fresh air, controlled by the temperature of the outgoing exhaust air, prevents frost on the heat exchanger. After the heat exchanger, the supply air can then be heated or cooled to a desired temperature before leaving the air handling unit and entering the building.

For simplicity, the building is simulated as a well mixed thermal zone of constant temperature. The incoming supply temperature is tempered to 19 °C all year round and the temperature of the air extracted from the zone into the air handling unit is held constant at 21 °C all year round.

Within the TRNSYS simulation environment, the simulated ventilation system appears as shown in figure 2 below. Bypasses are then added as switches to regulate the airflow when the outdoor temperature ranges between the average annual temperature and the desired supply temperature.

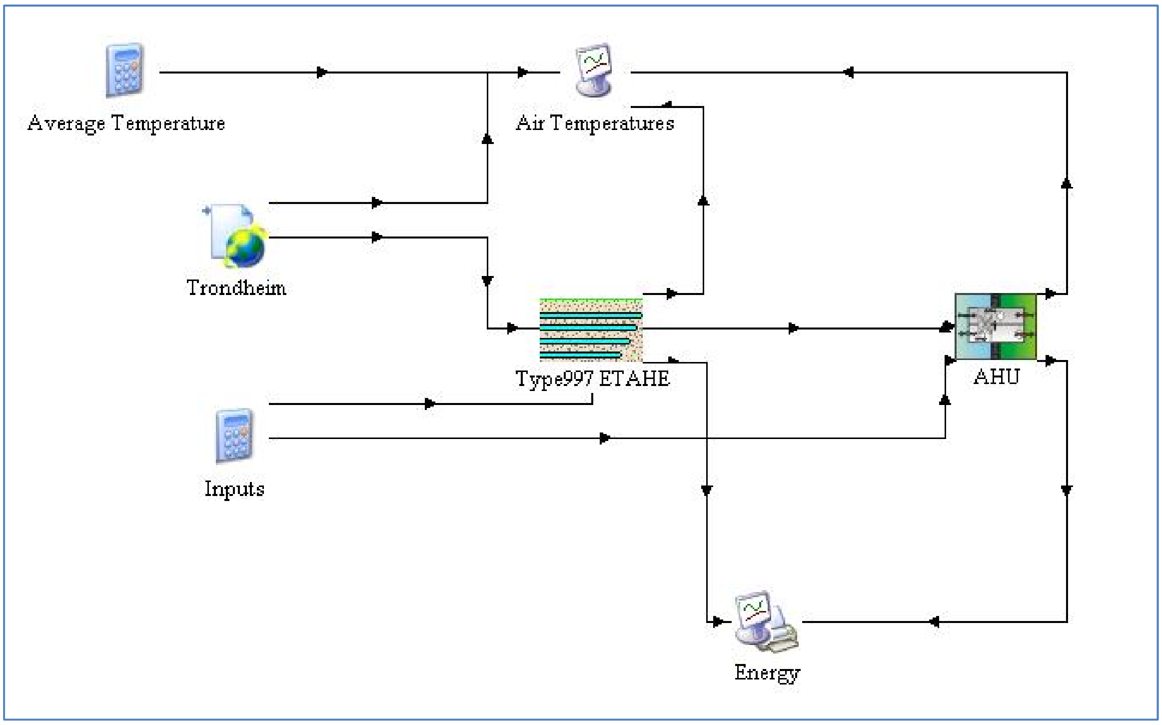

Figure 2: TRNSYS Model with Type 997 ETAHE and Type 334 Air Handling Unit

To investigate the control strategy, the lower temperature boundary was regulated with an additional parameter x. The ETAHE bypass was then governed by the following expression:

$$(T_{avg} + x) < T_{outdoors} < T_{supply} \tag{1}$$

When the outdoor air temperature ranged between the desired supply temperature and the lower temperature boundary, the ETAHE was bypassed and all incoming air entered the ventilation system via the air handling unit. The heating and cooling demand within the AHU was then used to compare the different control strategies.

4. Simulation Results

The size of the structure, and its simulated ventilation system, start with a small passive house and increase in size up to a small office building.

4.1. Small Houses

The ventilation system of a small house was simulated assuming a floor area of 180 square meters, a ceiling height of 2.4 meters, and an air exchange rate of 0.5 circulations per hour. The system was simulated for a year using climate data from Trondheim Norway, Copenhagen Denmark and Kiruna Sweden.

The ventilation energy demands together with the number of hours during which the frost protection bypass within the air handling unit was operating are shown for Trondheim in table 1 below.

Table 1: Ventilation Energy Demand and Hours Defrosting in Trondheim

	Trondheim		
	[kWh]		Hours
	Heating	Cooling	Defrosting
Without ETAHE	1149.6	-21.1	1165
With ETAHE	716.4	0	55
Bypass starts at	------	-	--
Tavg	**686.6**	0	55
Tavg-1	693.9	0	55
Tavg+1	681.9	0	55
Tavg+2	680.0	0	55
Tavg+3	**679.4**	0	55
Tavg+4	681.4	0	55
Tavg+5	685.8	0	55

The hours defrosting represents the hours during which the air handling unit operates at decreased efficiency, caused by the opening of a bypass within the air handling unit. The simulated frost protection strategy starts to open the bypass whenever the temperature of the exhaust air decreases below 2 degrees centigrade. With such a strategy, the number of hours spent defrosting can be drastically reduced through the use of an earth to air heat exchanger. In Copenhagen, the number of hours spent defrosting decreased from 556 to 0. While in Kiruna, the number of hours with reduced efficiency caused by defrosting decreased from 3884 to 3001.

The bypass for the ETAHE was simulated through various temperature intervals. As can be seen from table 1, the interval $(T_{avg} + 3) < T_{outdoors} < T_{supply}$ gave the best results. The differences between the other bypass intervals are marginal. The difference in energy performance between an ETAHE with or without a bypass is also marginal. At best, only 35 kWh is saved per year through the application of a bypass on the ETAHE connected to a small house in Trondheim.

In table 2 below, the ventilation heating and cooling demands for three different cities are shown. As can be seen, the preheating potential increases noticeable as the climate becomes colder.

Table 2: Ventilation heating and cooling demands for three separate cities

	Copenhagen		Trondheim		Kiruna	
[kWh]	Heating	Cooling	Heating	Cooling	Heating	Cooling
Without ETAHE	767.2	-76.1	1149.6	-21.1	3950.9	-10.5
With ETAHE	432.5	0.0	716.4	0.0	2261.4	0.0
Bypass	-------	----	-------	----	--------	----
Tavg	425.2	0.0	686.6	0.0	2136.9	0.0
Tavg+3	421.3	0.0	679.4	0.0	2132.4	0.0

Without a bypass, the power required to pump 0.5 air circulations per hour through a smooth pipe is constant. During a year, the total energy consumption is only 8.3 kWh for the 30 meter long section of pipe with inner diameter 175 mm. With consideration taken for pressure losses, the annual energy savings potential is shown in table 3.

Table 3: Annual Energy Savings Potential minus pumping losses

Annual Energy Savings Potential

Copenhagen	767.2 + 76.1 - 432.5 - 8.3	=	402.6	kWh
Trondheim	1149.6 + 21.1 - 716.4 - 8.3	=	445.9	kWh
Kiruna	3950.9 + 10.5 - 2261.4 - 8.3	=	1691.7	kWh

The TRNSYS simulations for the small house in Trondheim are shown graphically in the Appendix in order to help visualize the concept behind an Earth-to-Air Heat Exchanger.

4.2. *Row Houses*

The ventilation system of a row house was simulated assuming a floor area of 900 square meters, a ceiling height of 2.4 meters, and an air exchange rate of 0.5 circulations per hour. This represents 5 small houses connected together. Each row house was simulated for one year using climate data from Trondheim Norway, Copenhagen Denmark and Kiruna Sweden. The ventilation heating and cooling demands for the three separate cities are shown in table 4 below.

Table 4: Heating and Cooling Demands for a Row House in 3 locations

	Copenhagen		Trondheim		Kiruna	
[kWh]	Heating	Cooling	Heating	Cooling	Heating	Cooling
Without ETAHE	3836.2	-380.6	5747.8	-105.6	19754.3	-52.7
With ETAHE	2958.6	-116.5	4588.0	-15.6	16100.5	0.0

Without a bypass, the power required to pump 0.5 air circulations per hour through a smooth pipe is constant. During a year, the total energy consumption is only 4.8 kWh for the 30 meter long section of pipe with inner diameter 500 mm. With consideration taken for pressure losses, the annual energy savings potential is shown in table 5.

Table 5: Annual Energy Savings Potential

Annual Energy Savings Potential				
Copenhagen	3836.2 + 380.6 - 2958.6 - 116.5 - 4.8	=	1137.0	kWh
Trondheim	5747.8 + 105.6 - 4588.0 - 15.6 -4.8	=	1245.1	kWh
Kiruna	19754.3 + 52.7 - 16100.5 - 4.8	=	3701.6	kWh

Without the ETAHE, the number of hours spent defrosting the heat exchanger in the air handling unit is the same as in the small house without an ETAHE: 1165, 556, and 3884 for Trondheim, Copenhagen, and Kiruna respectively. With an ETAHE attached to a row house with one large centralized air handling unit, the number of hours spent defrosting drops to 464, 164, and 3572 for Trondheim, Copenhagen, and Kiruna respectively.

4.3. Small Office

The ventilation system of a small office was simulated assuming a floor area of 3000 square meters, a floor to ceiling height of 2.5 meters, and an air exchange rate of one air circulation per hour. Additional simulations with the ventilation rate varying between 1 to 4 air circulations per hour are described and presented in section 4.5. The office building, in all cases, was simulated using climate data from Trondheim.

In Trondheim, the 30 meter long ETAHE reduced the ventilation heating demand by 2000 kWh and the ventilation cooling demand by 220 kWh during a one year simulation. Without a bypass, the power required to pump 1 air circulations per hour through a smooth pipe is constant. During a year, the total energy consumption is approximately 113 kWh for the 30 meter long section of pipe with inner diameter 800 mm. Thus the energy savings potential is around 2100 kWh or 0.7 kWh/m^2 floor space.

4.4. Summary of Simulation Results

The energy savings potential within the small house ranges from 400 to 1700 kWh or 2.2 to 9.4 kWh/m^2 floor space, depending upon the climate. The preheating ability of the ETAHE boosts the energy savings potential in Kiruna, Sweden. As the building structure increases and the volume flow rate through the single buried pipe increases, the energy savings potential per m^2 floor space decreases. In the row houses with 900 square meters living space, the potential savings range between 1.3 to 4.1 kWh/m^2. The savings potential in the small office building with only one air circulation per hour drops down to 0.7 kWh/m^2.

The fan power consumption needed to overcome the pressure drop within each simulated pipe is shown in table 6 with its corresponding Reynolds number, smooth tube friction factor, and pressure drop.

Table 6: Fan Power of Simulated Pipes

Inner Diameter [mm]	Outer Diameter [mm]	Cross Sectional Area [m^2]	Volume Flow Rate [m^3/hr]	Air Flow Velocity [m/s]	Reynolds Number	friction factor f	Pressure Drop [Pa]	Fan Power [W]	Annual Fan Energy [kWh]
175	200	0.02	216	2.5	33000	0.023	15.7	0.9	8.3
500	560	0.20	1080	1.5	58000	0.020	1.8	0.5	4.8
800	930	0.50	7500	4.1	250000	0.015	6.2	12.9	112.7

4.5. Additional Small Office Simulations

As the air exchange rate in the small office building increases from 1 to 4 air exchanges per hour, problems quickly arise. As can be seen in table 6, 1 air circulation within the 800 mm pipe gives an airflow velocity of 4.1 m/s. Doubling the volume flow rate causes the velocity to double and to exceed the recommendation of max 7 m/s in the pipe (Uponor). This, in turn, causes the pressure drop to increase and accordingly the annual fan energy increases. To reduce the airflow velocity and the pressure drop, the single pipe can made larger and then buried deeper in order to remain subterranean. Alternatively, one can split the volume flow rate into several smaller parallel pipes, as shown in the figure below.

Figure 3: ETAHE with several parallel pipes (Source: Rehau)

If the volume flow rate is split into 500 mm diameter pipes with 1500 m^3 per hour per pipe, then the energy savings potential increases from the 0.7 W/m^2 floor space in the single pipe system to 2.1 W/m^2 in the parallel pipe system with 5 pipes and 1 air exchange rate (7500 m^3/hr). If the parallel pipe system increases in size with the increase of air exchange rates, the energy savings potential increases, as shown in the table below.

Table 7: Energy Savings Potential within Parallel Piped ETAHEs

Air Exchange Rate [h^{-1}]	1	2	3	4
Number of Pipes	5	10	15	20
Energy Savings Potential [kWh/m^2]	2.1	4.1	6.0	8.0

If the system designed with 20 pipes has a reduced ventilation rate of 1 air exchange per hour, the energy savings potential becomes 4.0 kWh/m^2. This is double the savings from the 1 ach system with only 5 pipes. The system designed with 20 pipes at 1500 m^3/hr per pipe will have an energy savings potential ranging between 4 and 8 kWh/m^2 floor space during a normal year with base ventilation at night and 4 air circulations per hour during the day.

If the ventilation system, in a small office with a parallel piped ETAHE, is used to counterbalance internal heat gains by providing additional cooling through a lowered air supply temperature, then the energy savings potentials in Table 7 will change. The annual ventilation heating demand will decrease and the annual ventilation cooling demand will increase. In the case of Trondheim, the decrease in the heating demand is significantly larger than the increase in the cooling demands. When the ventilation supply temperature drops to 18°C during the springs months of April and May, to 17°C during the summer months of June, July, and August, and to 18°C during the autumn months of September and October, then the energy savings potentials from the bottom row of Table 7 practically double in size, thereby ranging from 3.8 to 14.6 kWh/m^2. If the system is designed with 20 pipes but has a reduced ventilation rate of 1 air exchange per hour, the energy savings potential becomes 5.8 kWh/m^2. This system designed with 20 pipes at 1500 m^3/hr per pipe will have an energy savings potential ranging between 6 and 14.6 kWh/m^2 floor space during a normal year with base ventilation at night and 4 air circulations per hour during the day.

5. Discussion

By splitting the volume flow rate up into several parallel pipes, the specific energy savings potential of the small office exceeded the specific potential savings of the small house in Trondheim. When focusing only on the annual ventilation heating demand, the 30 meter ETAHE in Trondheim decreased the small house's heating demand by 40%, the row house by 20%, and the small office by 15% (5% with the single pipe system). Changing the ventilation supply temperature during the summer resulted in an additional 13% drop (in total, 28% relative the system without an ETAHE) in the heating demand for a small office with a parallel piped ETAHE.

With a frost protection strategy that activates a bypass within the air handling unit whenever the exhaust air temperature decreases below 2 degrees centigrade, the number of hours spent defrosting can be drastically reduced through the use of an earth to air heat exchanger. This is, of course, assuming heat recovery through a cross flow heat exchanger. The application of a rotating heat exchanger, that automatically defrosts itself, will clearly give different results. The down side of a rotating heat exchanger is the marginal risk for recirculated return air.

As the structure increases in size from the size of a single house to that of 5 interconnected row houses, the number of hours the ventilation systems spends defrosting increases. The ability of the ETAHE to increase the temperature of air flow decreases with increasing air volumes.

5.1. Future Research

A future simulation can investigate the phase shifting of the annual temperature variation within the soil, which has the potential of being used as seasonal storage. The impact of the building edge and the section of pipes buried underneath the foundation need to be simulated using a much more complicated model in order to obtain reliable results. As the footprint of the building will over time create a heat cushion under the building, the average temperature of the soil will shift upwards and increase the heating potential of the ETAHE. When the pipes run around the perimeter or under a structure, the higher average soil temperatures under the foundation will most likely change the optimal bypass temperature within the control strategy, as well as the potential energy savings.

6. Conclusions

The problem at hand is in need of more powerful simulation tools. With preliminary results, the *bypass* in the ETAHE is not cost effective.

When considering energy savings potential, mechanically ventilated single pipe ETAHEs are best suited for smaller houses. The smaller pipes are easier to bury and the specific energy savings are greater. The energy savings potential for a small office drops considerably when using a single pipe system. Expanding the system to include an array of parallel pipes with smaller diameter reverses this downward trend and significantly improves the energy savings potential. Lowering the ventilation supply temperature during the warmer months thereafter nearly doubles the energy savings potential for a parallel piped ETAHE located in Trondheim.

Large cross-sectional ETAHEs with low air flow, as those integrated into hybrid ventilation systems, are not analyzed within this project. No conclusions can be drawn concerning such systems based on this parameter study.

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Rehau EcoAir Ground-Air Heat Exchange System http://www.rehau.com/

Ground-coupled heat exchanger http://en.wikipedia.org/wiki/Ground-coupled_heat_exchanger

Appendix

Figures A1 to A3 graphically represent the effects of Earth to Air Heat Exchanger on the ventilation system within a small house.

The color legend for the three figures is listed below in its respective color:

INDOOR TEMPERATURE
OUTDOOR TEMPERATURE
AFTER ETAHE
BEFORE THE HX
AFTER HX WITHIN THE AHU
AIR SUPPLY AFTER AHU
EXHAUST TEMPERATURE
AVERAGE ANNUAL OUTDOOR TEMPERATURE

The air supply temperature after the air handling unit to the zone is held constant at 19°C. The indoor temperature being extracting from the zone is assumed constant at 21°C.

Figure A1 represents a ventilation system with heat recovery, but without an ETAHE. The figure shows how the outdoor temperature is shifted upwards after the heat exchanger to the light green line. The light purple line shows the temperature of the exhaust air leaving the air handling after giving its heat to the incoming fresh air. The difference between the light green line and desired supply air temperature represents the ventilation heating demand. The bypass in the air handling unit prevents overheating after the heat exchanger, but for days where the outdoor temperature rises over 19°C, ventilation cooling is needed.

Figure A2 represents the same ventilation system as Figure A1, but now an ETAHE is installed. The temperature of the outdoor air is shifted up to the dark purple line when the outdoor temperature is below the average annual temperature and down to the dark purple line when the outdoor temperature is above the average annual temperature. The temperature variation in the outdoor air is smoothed out, as is the temperature of outgoing exhaust air. Here, it can also be noted that the exhaust air temperature stays above the 2°C frost protection bypass. Activation of the frost protection bypass can be seen in figures A1 and A2 as periods of time when the exhaust air temperature is perfectly constant at 2°C.

The temperature of the incoming air after the heat exchanger (the light green line) is now shifted upwards and smoothed out. The ventilation heating demand has decreased, while the peaks during the summer that would normally require a cooling load have been completely removed.

Figure A3 represents the same ventilation system as Figure A2 with the ETAHE, but now a bypass has been installed on the ETAHE. When the outdoor temperature ranges between the average annual temperature and the desired air supply temperature to the zone, the cooling effect of the ETAHE is counterproductive. The effect of the bypass is shown in figure A3 with the help of an orange line representing the temperature of the incoming air before entering the heat exchanger within the air handling unit. This line is drawn over the top of the purple representing the air temperature after the ETAHE when the ETAHE is being used and these values are equivalent. During the summer months, a separation between the purple and orange lines shows how the bypass reduces ventilation heating demands by letting the outdoor air avoid the cooling effect of the ETAHE.

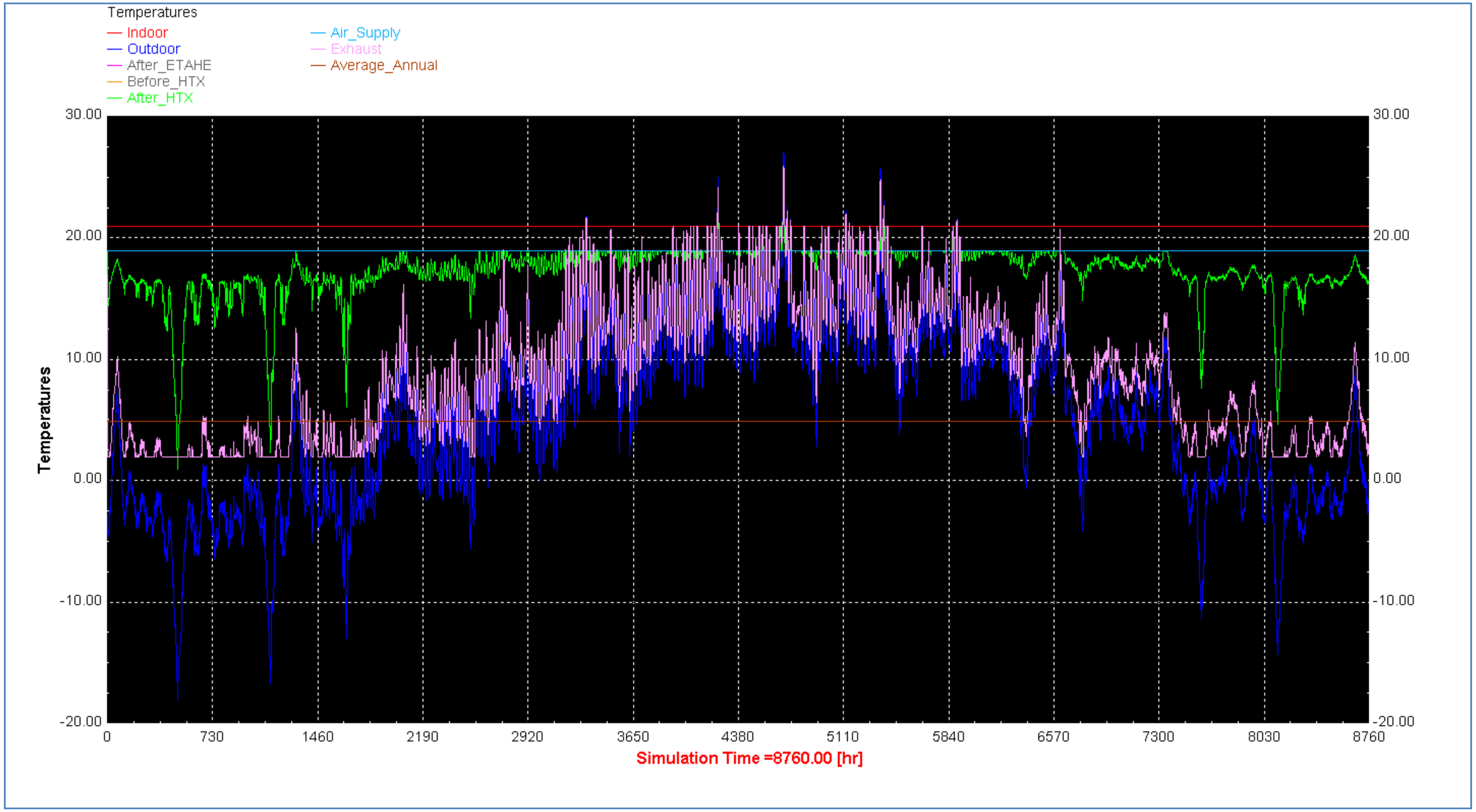

Figure A1: Ventilation System within a Small House without ETAHE

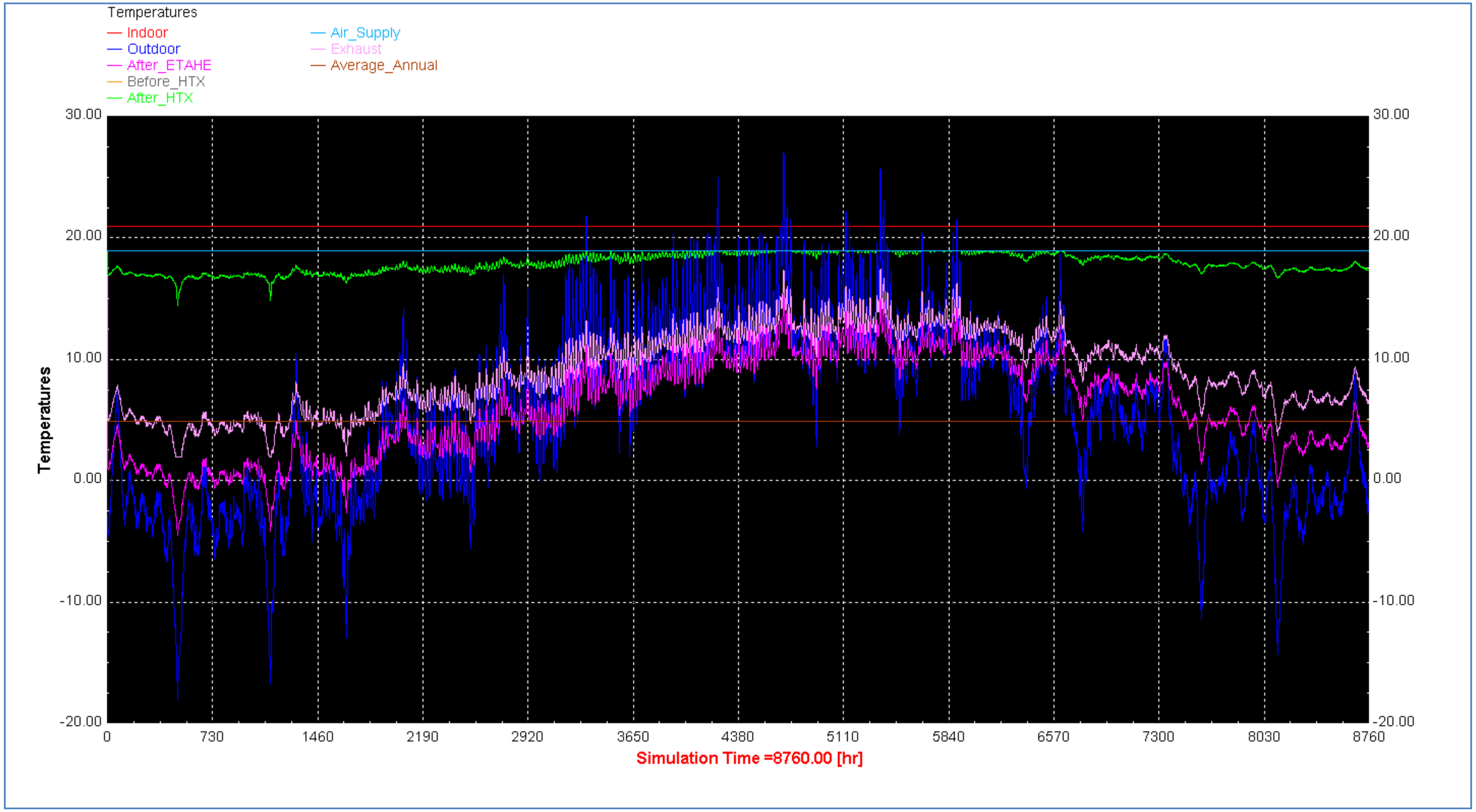

Figure A2: Ventilation System within a Small House with ETAHE

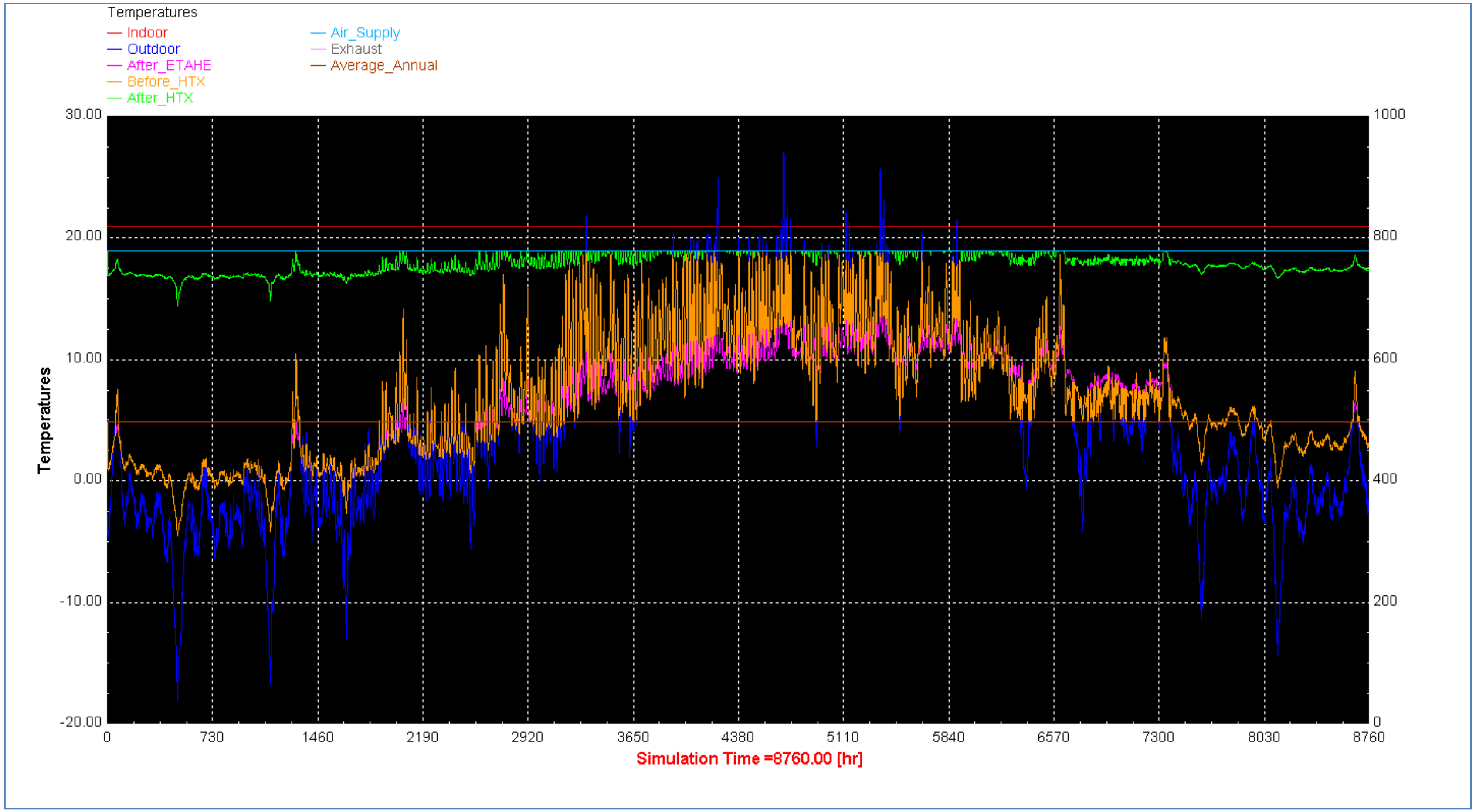

Figure A3: Ventilation System within a Small House with Bypass: Tavg < Toutdoors < Tsupply

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