GAS FREE SWIMMING POOLS: A REVIEW OF INTERVENTIONS AND THEIR IMPACT

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ABSTRACT

Swimming pools have a high energy demand due to their high indoor temperatures and large ventilation rates to control the humidity. There is a big challenge in reducing this energy consumption as this is mostly provided by natural gas. This paper gives an overview of different interventions that are used to reduce the energy consumption of swimming pools, with a focus on the natural gas consumption. A reference pool is used to determine the impact of these different interventions. Results show that the required heat consumption can be reduced with the orientation of the building. Good insulation and air heat pumps have a large impact on gas reduction and can eliminate gas use for space heating. For fresh shower- and pool water several interventions can be used, like heat recovery and/or preheating of water with an external source, to significantly reduce the gas consumption. Heat pumps can be used to eventually deliver the required heat in an efficient electrical way to the swimming pool to eliminate the gas consumption completely.

KEYWORDS: *Swimming pools, sustainable, interventions, gas consumption, energy reduction*

I. INTRODUCTION

In the Netherlands energy is mainly generated with fossil fuels. It is therefore important that in the near future these fossil fuels will be replaced with renewable energy sources. One of the priorities of the Dutch government is to reduce the natural gas consumption, which is generally used for heat production, to zero (Rijksoverheid, 2018).

The Netherlands counts over 700 public swimming pools. Of these pools, 340 are indoor pools, 220 outdoor pools, 120 combined pools and the other 20 are beach or nature baths (CBS, 2015). Together these pools consume approximately 1.6 million MWh natural gas and electricity (RVO, 2015), which can be compared to the energy consumption of approximately 90.500 households (Milieucentraal, 2018). Due to the high temperature of the pool water and the surrounding air, a large amount of natural gas is needed as a heat source to maintain this temperature. Swimming pools however must continue to exist due to their important social functions, contribution to swimming safety, livability and attractiveness of residential and business climate, sports, health and learning achievements (Recron, 2012). Above all, swimming is one of the most practiced sports in the Netherlands (Sportmonitor, 2013).

A large fraction of the swimming pools, 32%, are owned by municipalities. From all municipal buildings, swimming pools can be considered to be the most energy consuming. Often, municipalities can meet their CO2 target by reducing the energy consumption of swimming pools (Marx, 2013). It is therefore paramount to eliminate natural gas consumption completely for both existing swimming pools and newly designed swimming pools as well as to reduce the overall energy consumption. Therefore, the next research question shall be answered in this paper:

What interventions can be applied to a(n) (existing) swimming pool to eliminate natural gas consumption and reduce the overall energy consumption?

To answer this research question first a reference swimming pool is introduced in Chapter 2. This reference swimming pools forms the basis to measure the quantitative impact of different interventions such that they can be compared to each other. Subsequently, in Chapter 3, case studies are performed on sustainable swimming pools in the Netherlands. The case studies are used to determine the possible sustainable interventions that can be applied to swimming pools that affect the energy consumption and reduce gas usage. Chapter 4 till 6 describe in more detail the different types of interventions that can be applied to a swimming pool. Chapter 7 provides a summary of the results of the individual interventions. Chapter 8 shows a case where different interventions are applied to the reference pool to eliminate the natural gas consumption completely. Chapter 9 concludes the results of this paper. Chapter 10 contains the references.

II. REFERENCE SWIMMING POOL

The influence of interventions on the gas and electricity consumption of swimming pools is highly dependent on the current situation. In other words, depending on the context, some interventions may yield different quantitative results. To be able to compare different type of interventions with each other a reference pool is introduced. The gas and electricity consumption of swimming pools is often based on the surface area of the swimming pool. Hence, an estimation of the energy consumption can be made by multiplying the surface area with the benchmark energy consumption of swimming pools. At this moment, swimming pools consume around 51 [m^3 / m^2] gas and 136 [kWh / m^2] (Sipma, 2016). This paper provides insights in the gas and electricity consumption of a small – middle sized swimming pool (~2500 [m^2]). Water consumption that is related to the energy consumption is included as well.

A reference pool is introduced with a surface area of 2500 [m^2]. This pool is still largely dependent on gas, and as such falls in the category of older, still to be renovated, swimming pools. The reference pool will help to understand the different flows within the pool and to become more numerate with the flows. More information on the reference pool can be found in Appendix 10.1. Based on the data that is provided by Meijer and Verweij (2009) and the aforementioned gas-electricity ratio, a Sankey diagram can be constructed (Figure 2.1, left). This Sankey diagram shows the yearly energy requirements in terms of natural gas and electricity. Most noticeable is that gas is predominantly used for the purpose of space heating. Next to this diagram a Sankey diagram (Figure 2.1, right) the future (goal) scenario is shown, which shows that the swimming pool is no longer dependent on natural gas for its energy requirements.

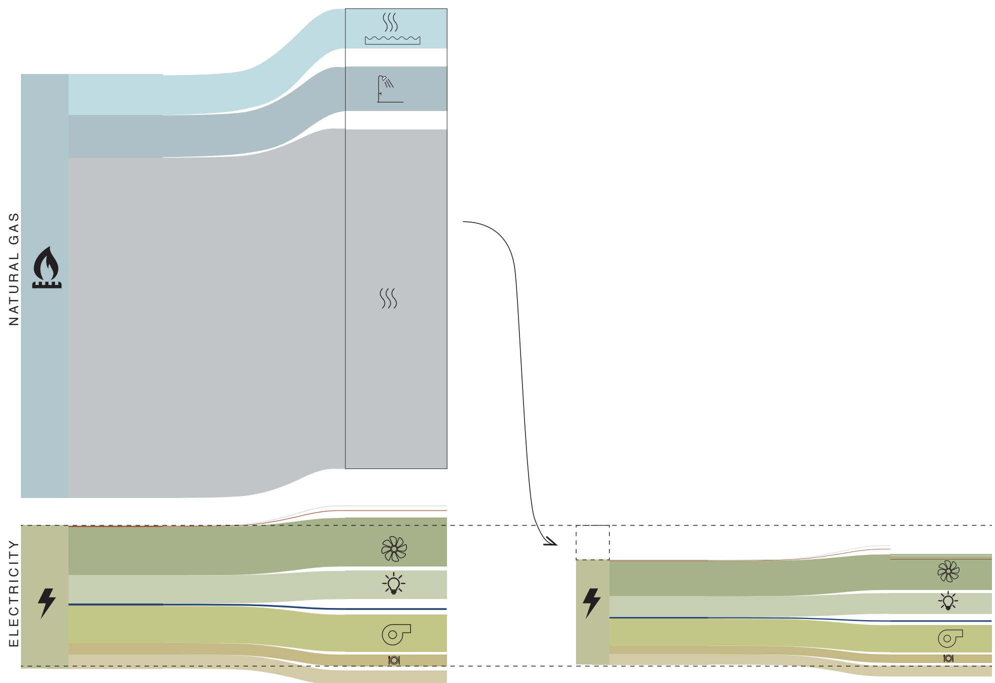


Figure 2.1. Yearly gas and electricity requirements for the reference pool. The energy requirements are normalised in MJ and the width of the different bars show the proportionate relations. Left: Current scenario which includes a large amount of natural gas. The natural gas is used for (top to bottom): Heating of the swimming water, heating of shower water, and heating of the space (air). The electricity is used for (top to bottom): Ventilation, lighting, pumps, café and other (computers, gate-system etc.). Right: Future goal situation. Natural gas consumption is eliminated and the electricity consumption is reduced. Some of the heating that in the current situation is generated by gas shall be generated by using electricity in the future situation.

Figure 2.1 shows that a striking amount of energy, natural gas, is used for space heating. Interventions that have an effect on this aspect are for this reason most interesting to reduce natural gas consumption. In swimming pools, lots of heat gets lost through ventilation. The water of a swimming pool is approximately 28-30 [°C]. The air around a swimming pool needs to be 1-2 [°C] higher than the water temperature to create a good balance between heat loss from the swimming pool and to reduce evaporation of the pool water (Owen, 2012; Sun et al., 2011). Condensation of this moisture needs to be avoided and therefore, this air needs to be ventilated to control the humidity level (Johansson & Westerlund, 2001). The relative humidity of swimming pools should be between 40-65% for reasons of comfortability (Sun, Wu, Wang, & Xu, 2011; Wildt, 2016). Due to this high ventilation rate large amounts of heat is lost. The conventional way in which the humidity level is being controlled is with the use of outdoor air, which has a significant lower humidity level than the air within the swimming pool. This fresh air needs to be heated, hence this leads to the high heating demand of swimming pools.

Figure 2.2 introduces a more detailed diagram that shows the different flows, and how these act within the systems boundaries. The quantified flows in this diagram make it possible to understand how and where interventions can be placed, and what their effect may be. Gas and electricity input values for different functions within swimming pools are derived from (Meijer & Verweij, 2009; Sipma, 2016). All other values can be found in Appendix 10.1. The swimming pool itself requires hot water. Cold water is provided to the boiler which heats up the water. The water in the swimming pool is continuously put through a filtration system. During the process of filtration some of the water is lost in the form of rinse water. This rinse water leaves the system through the sewage system. Also some of the water evaporates and enters the indoor space. This form of heat (called latent heat) cannot be felt by humans, but is stored inside the water when it transitions from a liquid to a gas through evaporation. Warm water that is used by visitors to shower is heated in the same way as the pool water, and also leaves the system through the sewage system. Most gas is used by the Air Handling Unit (AHU). The AHU heats both the outside air to the required inside temperature and ventilates some of the from the inside to the outside. Ventilation of the air is required because the humidity of the swimming pool must be kept at a certain level for reasons of comfortability of the visitors. This stream is shown in the diagram as output from the indoor space to the AHU. The indoor space also loses some of its heat directly due to its contact with the outside, through the floor, walls and roof. Also indicated in the diagram are the heat inputs from the lighting that is caused by inefficiencies, and visitors that provide body heat to the swimming pool and inside space. The electricity consumption of the swimming pool is quite straightforward. The diagram shows the electricity requirements for ventilation part of the AHU, the lighting, pumps that pump around the pool water, the café and other. The latter is a flow consisting of miscellaneous energy requirements such as computer systems, gate-systems etc.

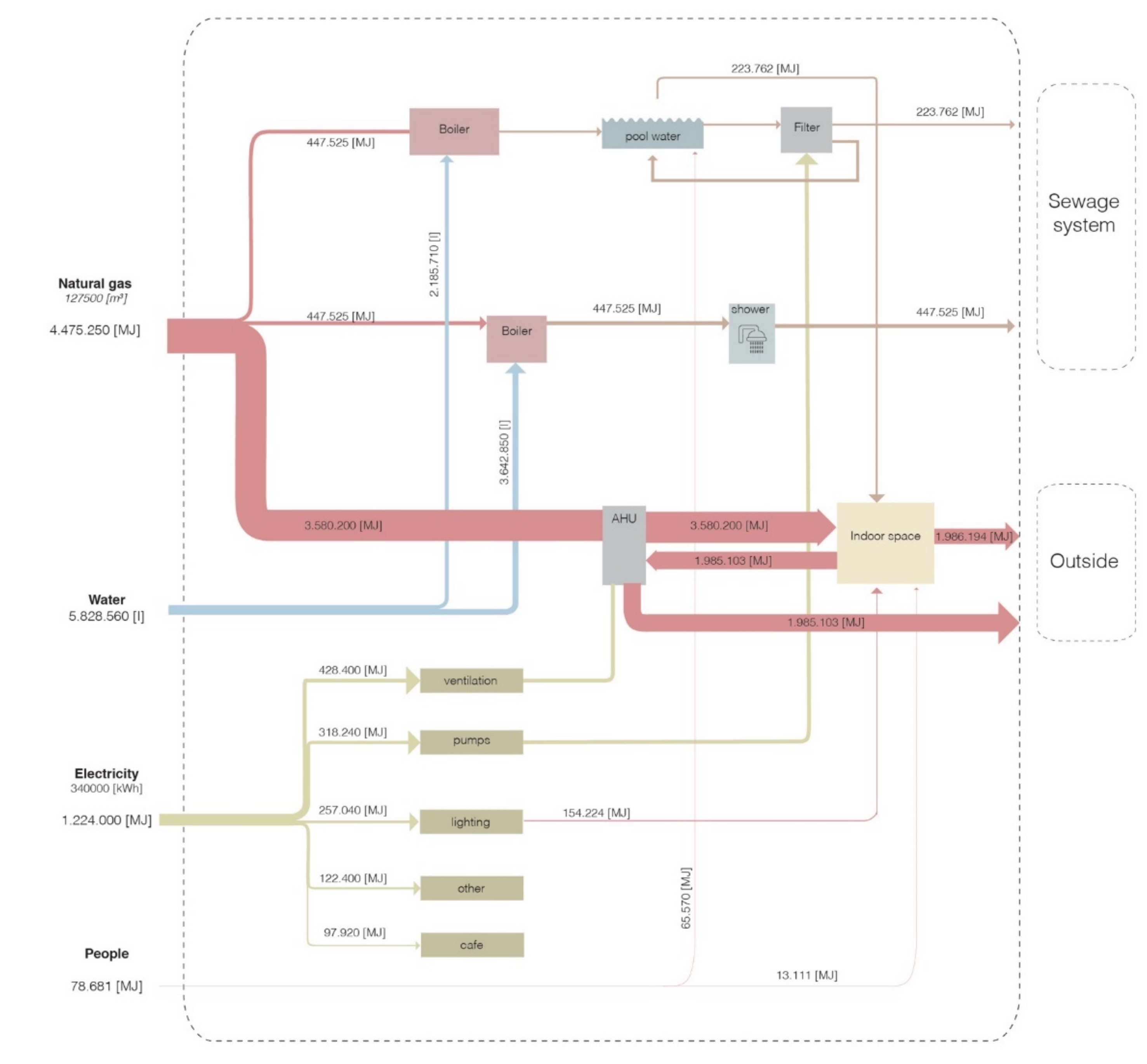


Figure 2.2. Detailed flow diagram of the reference swimming pool in the current situation. On the left hand side of the figure different flows enter the system boundary of the swimming pool. The right-hand shows how the flows leave the system, either to the sewage system in the form of hot water, or to the outside environment in the form of hot air.

III. CASE STUDIES

In the previous section a reference pool has been introduced to quantify the different flows of a swimming pool. To reduce the gas and electricity consumption interventions can be placed within the system. There are a lot of different interventions that can be applied. Therefore, five case study swimming pools in the Netherlands have been analyzed to define the different interventions that can be applied to reduce the energy consumption of swimming pools. From these case studies, two swimming pools have been newly build, and three have been renovated. One of the newly build pools and one of the renovated pool have succeeded in completely eliminating natural gas consumption. This set of case studies makes it possible to compare what energy measures are taken in the pools. This paper discusses both the gas reducing intervention as well as the electricity reduction/production interventions.

From the case studies a number of interventions are derived that are used in the different pools to reduce the energy consumption. One strategy to reduce the energy consumption is Trias Energetica (Tillie et al., 2009). This strategy consists of three steps in the following proposed order of considering the energy consumption of buildings:

1. **Reduce consumption**: The reduction of energy consumption can be achieved through passive and active interventions. Passive interventions include orientation and organization of the building, insulation and pool covers. There are also active interventions that reduce electricity consumption which are led lighting and a frequency pool water pumping system.
2. **Reuse waste energy streams**: These are active systems that utilize as much waste streams within the building, and recover existing heat as much as possible.
3. **Use renewable energy sources**: These are active interventions that can be applied to produce energy using the natural system, and systems to decrease the difference in temperature between the desired indoor temperature and the natural supply temperature.

The reason that reduction of consumption is placed first, is that this ensures that energy that is recovered in the second step or generated in the last step will not be lost immediately. This framework shall be used to consider the different interventions that can be applied to eliminate the gas consumption and reduce the overall energy consumption of swimming pools. Table 3.1 provides an overview of the analyzed case study swimming pools and their used interventions. Each intervention is categorized according to the Trias Energetica. In the subsequent chapters, each interventions shall be discussed in more detail.

Table 3.1. Overview of interventions that are applied in swimming pools to reduce energy consumption

		Urk	**Drachten**	**A'dam**	**Zeist**	**Maastricht**
	Status	Renovated	Renovated	New	Renovated	New
	Natural gas use	No	Yes	Yes	Yes	No
1	Orientation and organisation of the building			•		•
	Improved Insulation	•				•
	Pool covers	•			•	
	Led Light					
	Frequency pool water pumping system	•		•	•	
2	Heat exchangers and heat pumps for ventilation	•	•	•	•	•
	Heat recovery and heat pump for shower water			•		
	Heat recovery and heat pump for pool water			•		•
3	Geothermal heat					•
	Sewer heat recovery	•				
	PV Panels		•	•		•
	Solar collectors			•	•	•
	PVT Panels		•			

IV. INTERVENTIONS THAT REDUCE CONSUMPTION

The following subsection deal with all the interventions that reduce the energy consumption of the swimming pool according to the first principle of Trias Energetica.

4.1. Orientation and Organization of the Building

The Sun provides heat through radiation. Buildings can benefit from this when they are designed in such a way that sunlight is able to enter. The Sun enters the building through short wave radiation (visible light). This gets absorbed inside the building and long wave radiation is released (infrared light). These waves cannot escape back through the glass and heat up the air inside the building. To make sure that enough of that heat is absorbed, the materials should not reflect all these incoming waves. The albedo of a material determines the degree of reflection. Dark surfaces absorb the heat, which is then released back into the building.

West, East, but mostly South orientated buildings can use solar heat to gain energy. Orientation towards the south is one of the basic passive strategies that can be applied to optimize the heat gain. As such, the Sun naturally heats-up a building so less or no energy is required for heating. This strategy is often used in dwellings, whereas in offices this can lead to overheating due to the internal head gain of appliances. For pools however, the internal heat gain is relatively small and large amounts of heat are needed. Some pools already make use of this strategy. This can be seen in the Noorderparkbad in Amsterdam where the main pool area is orientated to the south. To gain solar energy, and at the same time prevent overheating, the optimal amount of façade openings is between 30-50% (Yanovshtchinsky, Huijbers, & van den Dobbelsteen, 2013). This strategy is depicted in Figure 4.1.1 on the left.

However, it might be more convenient to increase this amount, and create a system (like overhangs) to control the amount of sunlight that enters the building. Compared to windows in the façade, a skylight increases the amount of solar heat that can be captured. Besides this, windows in the façade are not a very effective way of gaining daylight in such big spaces as swimming pools. A more effective way to gain solar energy (heat and visible light) is to create a glass roof through which the Sun is able to enter (weber, 2014). Another way to harvest solar heat, is with the use of a winter garden or double façade, which can be used to pre-heat the incoming air. An increase in natural daylight can also reduce the electricity consumption which is needed for artificial light within the building. However, when a lot of sunlight enters a building it is prone to overheat. There are several ways to prevent overheating. The energy efficient method is to incorporate dynamic shading. This requires very little energy and can shade the surfaces from the Sun to prevent overheating. This is depicted in Figure 4.1.1 in the second image. Subsequently, overheating can be prevented by creating openings in the building. As such the building is naturally ventilated. This is depicted in Figure 4.1.1 in the middle image. A more energy consuming method to reduce overheating is to incorporate mechanical ventilation and cooling. This is depicted in Figure 4.1.1 in the fourth image. Lastly, it is possible to make use of overheating. It is possible to store excess heat during hot seasons and use this during cold seasons and vice versa. As such excess heat from the Sun is not wasted, but used to facilitate heating during the cold season. This is depicted in Figure 4.1.1 in the fifth image.

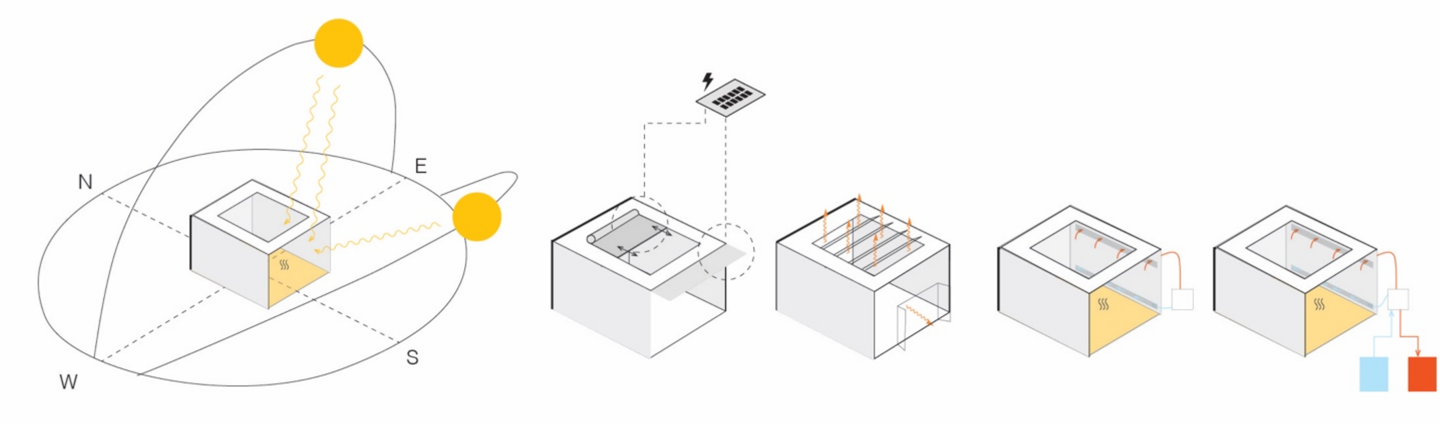


Figure 4.1.1. From left to right: Orientation of the building showing incoming Sun radiation, Sun shading to prevent overheating, opening in buildings to ventilate heat, mechanical air ventilation/cooling, seasonal heat storage to make use of excess heat.

Both newly build pools from the case study have used the organisation of their spaces to reduce heat loss. The pool area has the highest temperature of approximately 28-30 [°C]. Other spaces like dressing rooms, technical spaces, storage, etc. have lower temperatures. These spaces can be used as an extra insulation layer around the swimming pool area (Menerga, 2017). Especially within the Noorderparkbad in Amsterdam this is clearly visible. In the Noorderparkbad the pool area is orientated to the south, the other sides of the pool area are enclosed by the other functions to increase insulation. From the facades, most of the heat is lost through the north façade, where the Sun cannot heat up the surface. In general, the north side is the coldest side, followed by the east side, and then the west side. This is depicted in Figure 4.1.2

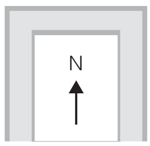


Figure 4.1.2. Representation of the building organisation based on the relative warm and cold sides. When the other functions than the pool are situated at the colder sides, they can function as a thermal buffer.

Due to the complex nature of quantifying the solar heat gain through radiation this intervention has not been quantified. These calculations are difficult to perform without dedicated simulations since heat transfer through radiation depends on the time of day/year, incoming incident angle of the Sun, the geometry of the building and the temperature and radiative properties of the different materials inside the building. However, from the earlier discussed references it can be concluded that for swimming pools in particular skylight may provide a beneficial increase in solar heat, which can reduce the required energy consumption.

4.2. Insulation

Insulation of the building will help to keep heat inside. Almost all pools from the case study did use high insulation to prevent the heat from escaping. This intervention can be applied to both existing and new buildings. A high insulation value ensures that a minimal amount of heat is able to escape. For new buildings there are standards set by the national government. Conservation of energy in buildings starts with good insulation. Especially poor insulation values of glass lead to a large heat loss in existing buildings. Table 4.2.1 shows what kind of interventions are useful to apply based the construction year for dwellings. This can also be assumed for other buildings that have been constructed during similar periods.

Table 4.2.1. State of insulation for dwellings in the Netherlands, and interventions that can be applied with Source: Milieucentraal (2017).

	Before 1976	1977-1989	1990-93	94-2016
Status	Poor insulation	- Double glazing (No HR++) - Mediocre insulation (all sides) - No floor insulation	- 5 tot 7 cm roof insulation - Facade insulation - Floor insulation - Normal double glazing	- On average good insulated buildings
Intervention		1st - Floor insulation - Triple glass/HR++ 2th - Extra roof insulation - Extra wall insulation	- Increase insulation - Triple glass/HR++	- For energy neutral building: Extra insulation - If floor heating is applied, floor should be extra insulated

Insulation is one of the most important methods to reduce energy consumption. Fresh air needs to be provided to the swimming pool which needs to be heated up to a high temperature. When the building is not properly insulated a lot of heat is lost through the contours of the buildings. Insulating the swimming pool can therefore already have a major contribution to reduce the energy consumption. The relation between the insulation and the ventilation is depicted in Figure 4.2.2

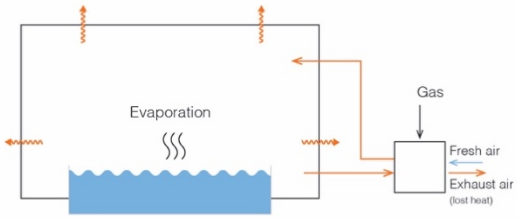


Figure 4.2.1. Schematic representation showing the relation between the ventilation and insulation.

Applying insulation to the reference swimming pool

The reference swimming pool shows that approximately half of the energy that is needed to heat up the building leaves the building through the building envelope due to bad insulation (appendix 10.1.3). Calculations in Appendix 10.2.1 show that the energy savings for buildings that are poorly insulated can decrease heat transmission through the building envelope with 71% when better insulation is applied and windows are replaced with triple glazing. For this reference building, it would mean that an overall gas reduction of approximately 32% can be reached, and a total energy reduction of 24%. More details on this can be found in Appendix 10.2.1. The effect of applying insulation to the reference swimming pool is shown in Figure 4.2.2.

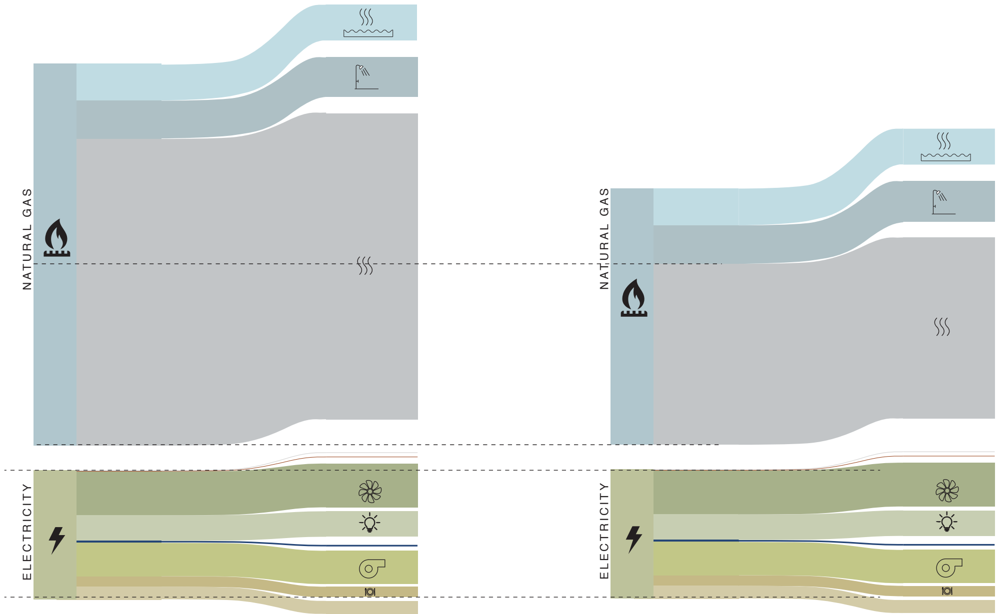


Figure 4.2.2. The effect on the gas consumption of applying insulation to the reference swimming pool. Left shows the situation before insulation and right shows the situation after insulation.

4.3. Pool covers

The pool loses heat by convection, water evaporation, conduction and irradiation. To minimize heat losses, it is important that the area in which the pool is located has a similar temperature (Johansson & Westerlund, 2001; Sun et al., 2011). When water evaporates, it 1) will increase the humidity of the air and 2) the evaporated water needs to be replaced with new water, that needs to be heated as well. The heat loss from the water body takes place through the surfaces area. The heat losses through the bottom and walls of the pool can be neglected. Studies that have been performed on indoor pools in Italy have shown that the heat loss of the water within the pool can be reduced up to 50% by covering up the pool during the night (Zuccari, Santiangeli, & Orecchini, 2017). This does not yet include the ventilation benefits caused by the pool cover resulting in less evaporation and consequently lower ventilation rates. This intervention is, compared to the other interventions, relatively easy to implement in an existing swimming pool.

Applying a pool cover to the reference swimming pool

Less evaporation results in less ventilation, which means less heat losses. When less water evaporates, the fresh input water can be reduced. Since the fresh water needs to be heated up to the swimming pool temperature, this results in an energy reduction. A pool cover has an effect on both the electricity consumption as the gas consumption. For the reference pool 12% of the gas consumption can be saved and 9% of the electricity consumption. Due to less evaporation, there is a reduction in the pool water heating. Consequently, less ventilation is needed which has an effect on the electricity use for ventilation as well as well as the natural gas use since less heat is lost. The overall reduction on the energy use is 13%. More details on this can be found in Appendix 10.2.6. Figure 4.3.1 shows what the effect is of the pool cover within on the reference swimming pool.

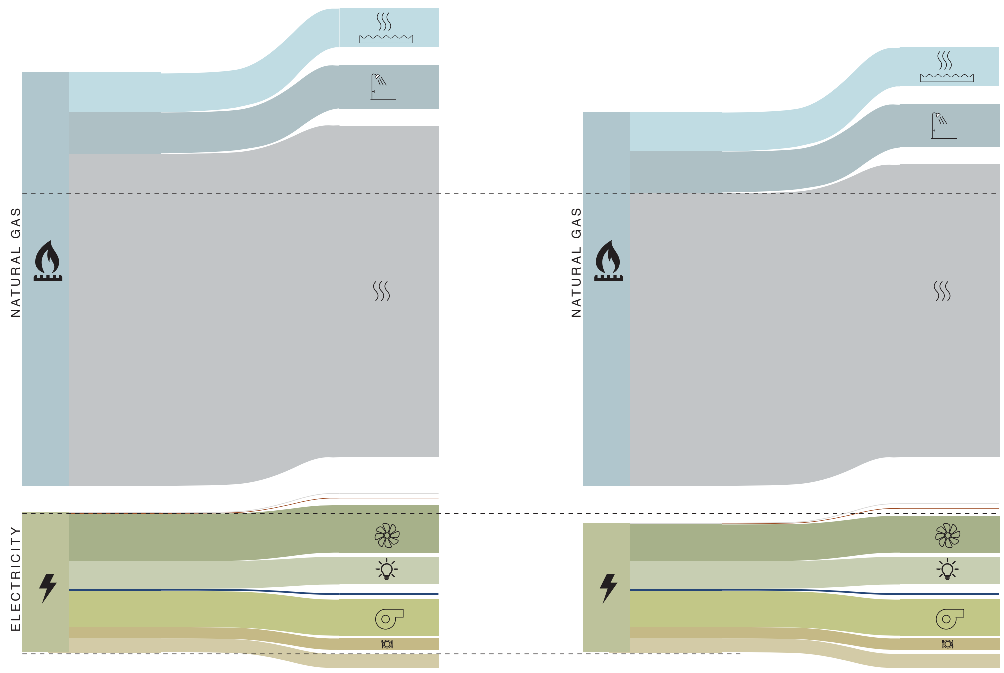


Figure 4.3.1. The effect on the energy consumption of applying a pool cover to the reference swimming pool. Left shows the situation before using a pool cover and right shows the situation after using a pool cover.

4.4. LED Lights

The choice for replacement of the current lights by LED lights depends on what lights are used at the moment. Replacement of a lightbulb with a CFU lamp leads to a saving of 80%, and for a LED light to 90%. To compare, a LED light uses approximately 15% of the energy that is needed compared to a halogen light. Old light bulbs convert approximately 80% of the energy to heat, for halogen lights this is 70%, for energy saving CFU lights this is 60%, and for LED lights this is 50% (Bibiana, 2014).

Table 4.4.1. Energy usage and efficiencies of different type of lights for similar Lumen production (Bibiana, 2014; Lampdirect, 2018)

700-1000 Lumen	Light bulb	Halogen	Energy Saving light bulbs CFU	LED
Watt	75	65	15	10
Efficiency [%]	20	30	40	50

Ironically, more efficient lighting will result in a decrease of air temperature. This decrease should be compensated with another energy source. However, due to the lower energy consumption of the lighting, the net energy consumption is reduced.

Applying LED light to the reference pool

For the reference pool it has been assumed that the current lighting is halogen. LED lights have been applied to replace the halogen lights in the reference swimming pool, and this has resulted in an electricity reduction of 18% and an increase in heat demand of 3%. The overall energy reduction comes down to 1%. More details on this can be found in Appendix 10.2.7.

4.5. Frequency Pool Water Pumping System

Pool water pumps are needed to pump the pool water through the filter of the pool. These pumps consume a significant amount of electricity. The case studies show that some pools have replaced this pump system with a frequency pump system, that consumes less energy. A frequency system in the pumps can have a difference on a year base of 20.000 kWh (Infomil, 2017). This saving is based on the water of a pool that is 15x25 meters and 1.80m depth.

Applying a frequency pump system to the reference pool
The frequency pump system can reduce the electricity consumption with 6%. The overall energy reduction of this intervention on the reference pool is 1%.

V. INTERVENTIONS THAT REUSE WASTE ENERGY STREAMS

The following subsection deal with all the interventions that reuse waste energy streams within the swimming pool according to the second principle of Trias Energetica.

5.1. Heat Exchangers and Heat Pumps for Ventilation

To reduce the heat loss, the incoming air that is used for ventilation can be mixed with a circulation flow from the facility. In this way the heat is exchanged and recovered. It is important that the heat pumps are able to use and recover the non-sensible heat from the moist. This latent heat (i.e. heat that is needed to convert the water into water vapor) is also recovered with such a system. A dehumidifier is able to restore the latent heat within the air. For existing pools, most of the time there is a lot of heat lost through the ventilation process. The heat that is recovered is often only sensible heat, and not the latent heat from the moist air. The efficiency of these systems is therefore usually lower than 50% (Klok, 2009).

Most heat gets lost through ventilation within the pool area. This means that often the Air Handling Unit (AHU) includes a heat pump with a heat exchanger to reduce this loss. The Sankey diagram in Figure 1 showed already the amount of heat that is required for space heating. Marx (2013) explains that the placement of a heat pump and a heat exchanger in a pool Mosaqua in Gulpen has achieved a 40% reduction in natural gas and 30% reduction in electricity consumption.

A short description of the pump is given: Within the evaporator the refrigerant is evaporated, which makes it possible to take the heat of the humid air that comes out of the swimming pool area. Next, the compressor raises the temperature of the vapor. The condenser causes condensation of the refrigerant so that heat is released. Next the flow is combined with the fresh outdoor air. Then the heat enters the condenser where the heat is released to the fresh air. In this case, the condenser is used both for heating the air and heating the pool water.

A difference can be made between a heat pump that uses heat from a water source e.g. geothermal heat, riothermia etc. The performance of a heat pumps is expressed in COP values. The COP value of a heat pump is the Coefficient Of Performance, which is determined on the amount of energy input, in relation to the useful energy. In general it can be stated that geothermal heat pumps have a higher COP value due to the constant soil temperature. These systems are also more expensive in general. For pool water this could be a good solution to heat up the pool water and shower water (Zuccari et al., 2017) .

Heat pumps are rather large systems. When designing a building this should be considered. The units can be placed in such a way that these do not disturb the design of the building. This means that it should be considered is an early stage of the design process to avoid a situation as presented Figure 5.1.1. This figure shows on the left side the situation where the heat pump is placed on the roof and the system, pipes, inlet and outlet are clearly visible. However, it is also possible to integrate the heat pump with the building, such that the system and piping is not visible directly, but only through detailing.

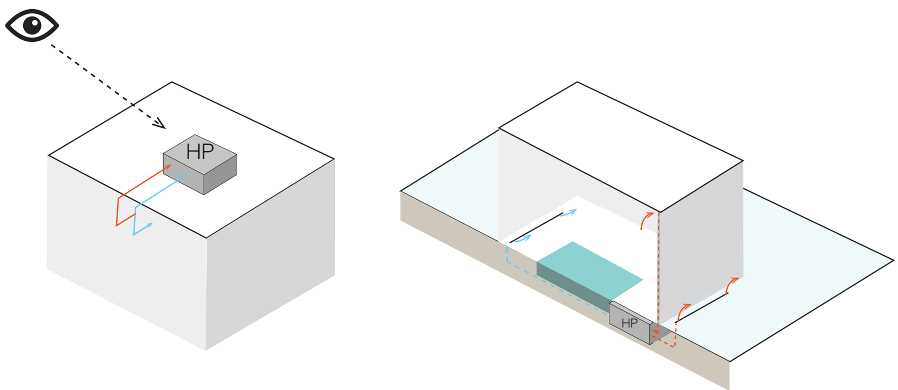


Figure 5.1.1. Design implication of the heat pumps. Left: visible heat pump on roof. Right: Hidden heat pump combined with good detailing in an early design phase. The inlet and outlet of the system are integrated into the floors and walls of the building.

Applying a heat pump and heat exchanger for ventilation to the reference swimming pool

Heat recovery systems have an efficiency up to 95%. For the intervention in the reference pool is assumed an efficiency of 90%. This means that a reduction of 90% in ventilation losses can be achieved. The air heat pump with a COP of 3,5 replaces the energy source natural gas for air ventilation with electricity. For the reference pool, this means a reduction of 80% on the total natural gas use, and an increase of 42% in electricity use. The total energy saving is 71%. More details on this can be found in Appendix 10.2.2. Figure 5.1.2 shows the effect on the Sankey diagram of using a heat pump in combination with a heat exchanger on the ventilation for the reference swimming pool.

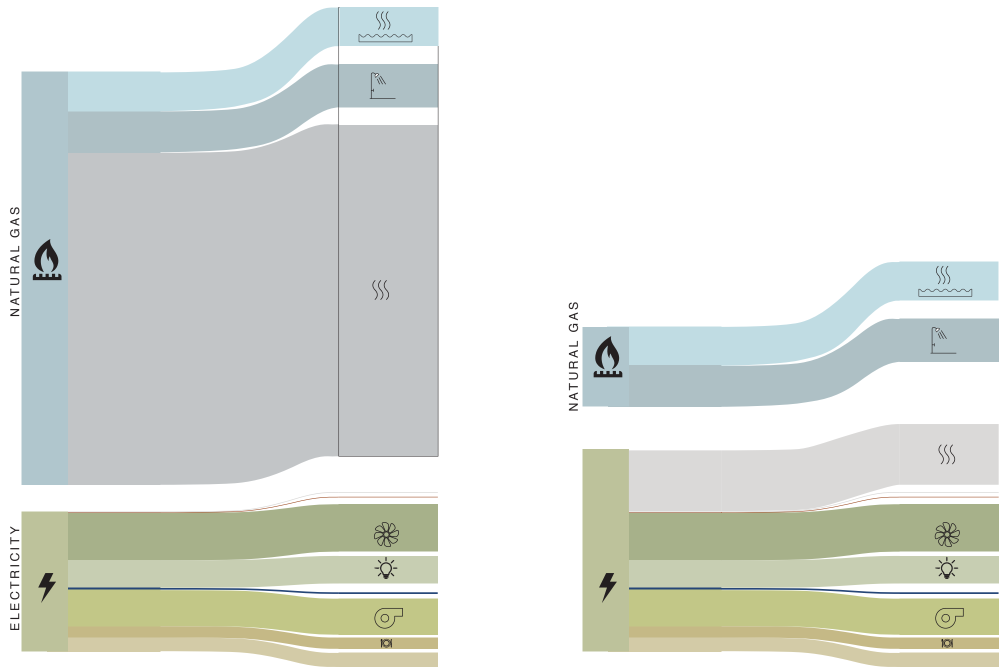


Figure 5.1.2. The effect on the energy consumption of applying a heat pump and heat exchanger for ventilation for the reference swimming pool. Left shows the situation before using the intervention and right shows the situation after using this intervention.

5.2. Heat Recovery and Heat Pump for Shower Water

The Sankey diagram of the original situation of the reference swimming pool (Figure 2.1) shows that a significant part of the energy is consumed to heat up shower water. Some of the reference projects make use of shower heat recovery. This means that the warm waste water of the showers is used to heat up the fresh and cold shower water. Using this heat recovery system, a smaller temperature difference is required as the incoming water has already been heated up by the outgoing waste water. This yields a lower energy consumption. The next diagram shows how the shower heat recovery can be used. The water that is used after the shower is still 25 [°C] (Karstin, 2017).

Both the shower heat recovery and the rinse water work very well in combination with heat pumps. With higher temperature differences the heat pump needs to work harder, and consequently more electricity is consumed. This means that these interventions will already preheat the water that needs to be used in order to reduce unnecessary energy consumption.

Applying a heat recovery system and heat pump for shower water to the reference pool

With shower heat recovery, the fresh water (10°C) can be upgraded to 25°C. This leads to a heat reduction of 50% compared to the reference pool. When a heat pump is used, a 10% saving in natural gas consumption can be reached. The heat pump causes a 7% increase in electricity consumption and the overall energy reduction is 7%. More details on this can be found in Appendix 10.2.3. Figure 5.2.1 shows the effect on the Sankey diagram of using a heat pump in combination with a heat recovery system for shower water on the reference swimming pool.

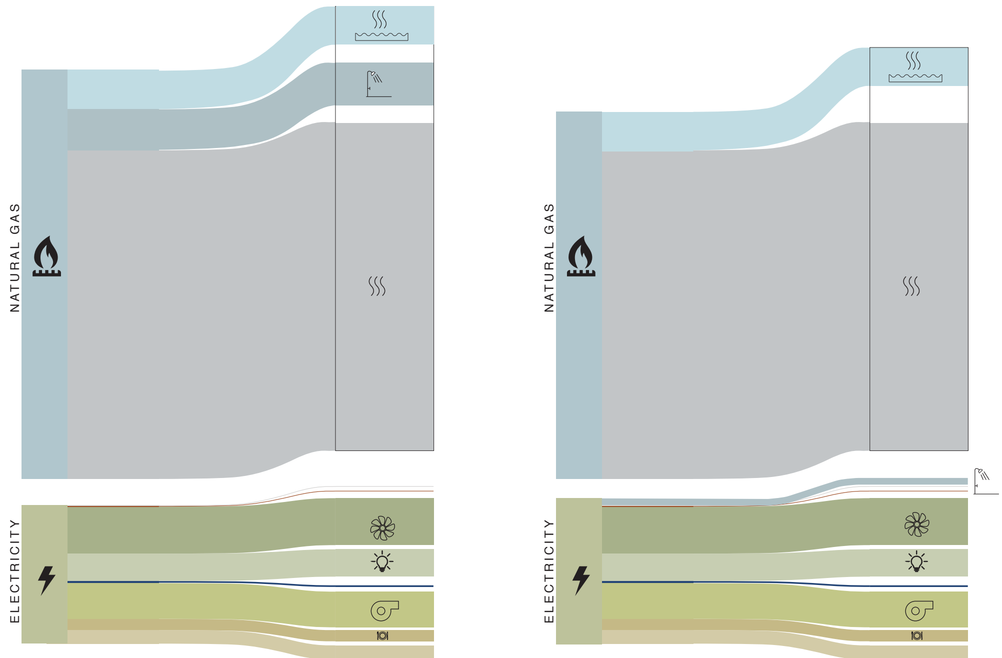


Figure 5.2.1. The effect on the energy consumption of applying a heat recovery system and heat pump for shower water for the reference swimming pool. Left shows the situation before using the intervention and right shows the situation after using this intervention.

5.3. Heat Recovery and Heat Pump for Pool Water

The water of the pools is pumped through sand filters for the cleaning process. The filter needs to be cleaned after some time. This cleanings process takes place by pumping the water in the opposite direction. The unclean rinse water cannot be used again as pool water and is discharged to the sewage. This results in high heat losses as the rinse water has a high temperature (around 30 [°C]) (Klok, 2009). The rinse water that is often wasted to the sewage system can be re-used with the combination of a heat recovery system (Infomil, 2018). As such, the water that is lost (through either rinsing and evaporation) can be used to heat the supplement water. The supplement water is around 30 liters per visitor per year.

Applying a heat recovery system and heat pump for pool water to the reference pool

The fresh supplied water enters the system at 10 °C half of this amount is evaporated and the other half ends up in the sewage system. Heat of the water that goes into the sewage system has an average heat of 30°C. This heat can therefore be used to heat up the fresh water. 60% of this heat can be recovered with a heat exchanger. When this is connected to a heat pump, a natural gas reduction of 10% can be reached. The heat pump increases the electricity consumption with 7%. The overall energy saving of this system on the reference pool is 6%. More details on this can be found in Appendix 10.2.4. Figure 5.3.1 shows the effect on the Sankey diagram of using a heat pump in combination with a heat recovery system for pool water on the reference swimming pool.

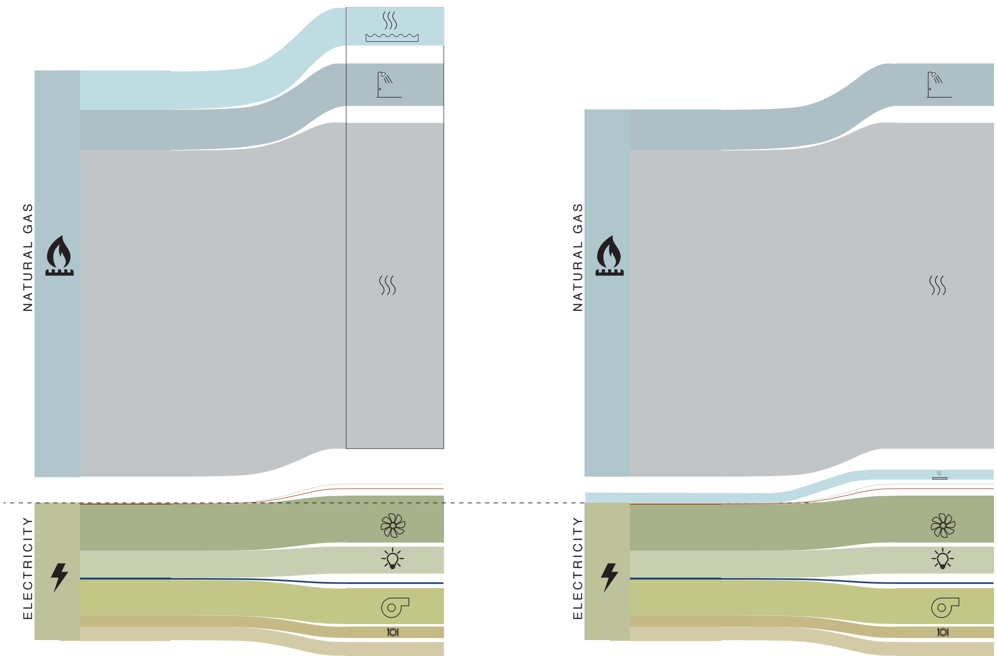


Figure 5.3.1. The effect on the energy consumption of applying a heat recovery system and heat pump for pool water for the reference swimming pool. Left shows the situation before using the intervention and right shows the situation after using this intervention.

VI. INTERVENTIONS THAT USE RENEWABLE ENERGY SOURCES

The following subsection deal with all the interventions that use renewable energy sources for the production of heat/energy according to the third principle of Trias Energetica.

6.1. Geothermal Heat and Sewer Heat Recovery

Different sources can be used as a source for the heat pump, as long as there is heat available (Geothermal heat, Aquifer heat storage, Surface water, outside air, exhaust ventilation air, solar collectors, heat from industries, sewage systems). Sewage heat recovery is only profitable when a new sewage system needs to be constructed, otherwise this is relative expansive intervention (Groot, 2015). When water heat pumps are used in combination with for instance sewer heat recovery and thermal heat, higher COP values can be reached (Yanovshtchinsky et al., 2013).

6.2. PV Panels, Solar Collectors and PVT Panels

The case study swimming pools show that most solar collectors are used in swimming pools to provide heat for outside pools. Solar collectors are generally used to heat-up water (DGMR, 2012). A distinction can be made between glazed and unglazed collectors. Unglazed collectors are often chosen for outdoor swimming as they perform best during the hot seasons. The case studies shows that the Noorderparkbad and the Geusseltad use these collectors to provide almost all thermal energy for the outside pools. Glazed collectors are more suitable to heat up inside pools due to their performance throughout the whole year, including winter time (Dannemand, Furbo, Andersen, Heller, & Madsen, 2017). In the Netherlands, the main types of solar collectors that are used are flat plate collectors, followed by heat pipe collectors. The latter are on average more expensive but produce more heat. The average yearly heat production of a flat plate collector is 0,45 [MWh/m^2/year]. For heat pipes this is around 0,62 [MWh/m^2/year]. Other panels that are used are PVT collectors. These collectors produce heat and electricity with the same panels. These panels are more expensive and since this technology is relatively new they have not yet been widely adopted. PVT collectors have a lower heat production than conventional solar collectors. However the sum of the electrical efficiency and thermal efficiency is higher than that of the conventional systems (Buonomano, Calise, & Vicidomini, 2016). These collectors have an average heat production of 1 - 1,2 [GJ/m^2/year] and an average electricity production of 80-110 [kWh/m^2/year] (E4S Consult, 2013). Normalizing this to Joule gives a combined performance of 1524 [MJ/m^2/year] of which 79% is heat production.

PV-panels are used to produce electricity that can be used as an input source for the electricity demand of the swimming pool. PV-panels conveniently located (South-side under an angle of 15-55 [°C]) can have a production of 150 [kWh/m^2/year] (Schoenmakers, 2018).

VII. SUMMARY OF INDIVIDUAL INTERVENTIONS

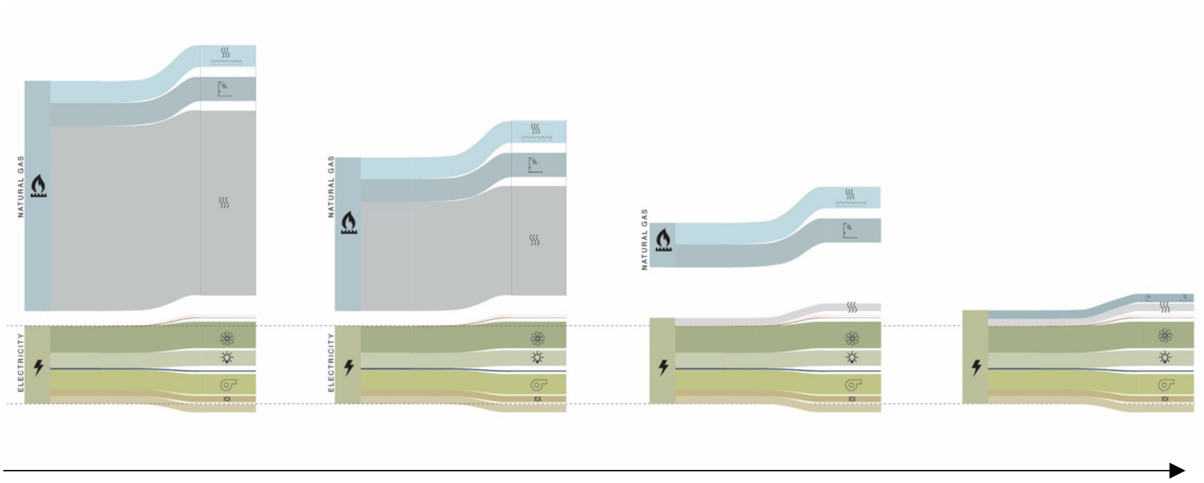
The chapter provides an overview of the results of the individual interventions. These results are depicted in Table 7.1.

Table 7.1: Overview of the different interventions and their effect on the reference pool.

	Pool heating	Shower heating	Space Heating (Gas)	Vent	Pool Pumps	lighting	Total gas	Total electricity	Total energy
Source	**gas**			**electricity**					
Orientation of the building			+			+			
Organisation of the building			+			+			
Improved Insulation			**-39%**				-32%		-24%
Pool covers	-25%		-15%	-13%			-12%	-9%	**-13%**
LED Light			-4%			85%	-3%		-1%
Frequency pump system					6%				-1%
Heat exchangers and heat pumps for ventilation			-100%				-80%	+ 42%	-71%
Heat recovery and heat pump for shower water		-100%					-10%	+5%	- 7%
Heat recovery and heat pump for pool water	-100%						-10%	+ 7 %	- 6 %
Geothermal heat & Swage heat recovery shower + HP		-100%					-10%	+8%	-6%
Geothermal heat & Swage heat recovery pool water + HP	-100%						-10%	+6%	-6%
PV Panels				+	+	+		-150 [kWh/m^2]	-150 [kWh/m^2
Solar collectors	+	+					-0,62 [MWh/m^2/]		-0,62 [MWh/m^2/]
PVT Panels	+	+	+	+	+	+	1 - 1,2 [GJ/m^2]	80-110 [kWh/m^2]	1524 [MJ/m^2]

VIII. COMBINING INTERVENTIONS

Table 7.1 shows that most energy savings can be achieved by using an air heat pump. Secondly, the most effective intervention is insulation the building. When following the Trias Energetica, the building should first be insulated before a heat pump, or heat recovery system is applied. Using this sequence, a combination of interventions can be made to eliminate the gas usage. This is depicted in Figure 8.1.



Status quo	Insulated	Air heat pump	Shower + pool water heat pump and
	Saving gas: 32%	Saving gas: 80%	Saving gas: 100%
	Saving total: 24%	Saving total: 60%	Saving total: 73%

Figure 8.1. From left to right: Status quo reference swimming pool, insulated swimming pool, heat pump swimming pool, heat pump and heat recovery for shower water and pool water. Other interventions can be applied to reduce the electricity consumption such as a frequency pump system and LED lights.

The detailed flows are shown in Figure 8.2. It is clearly visible that the natural gas consumption has been completely eliminated. Some of this required energy for heating has been replaced by electricity. However, due to the insulation and the heat recovery systems almost no energy is lost, and therefore the heat requirements have been significantly reduced. Further energy reductions can be made with applying energy efficient lighting and a frequency pool water pump. The results show that a pool cover will also affect the electricity use, due to the lower ventilation rates. The remaining electricity requirements can be provided by PV panels or another sustainable resource.

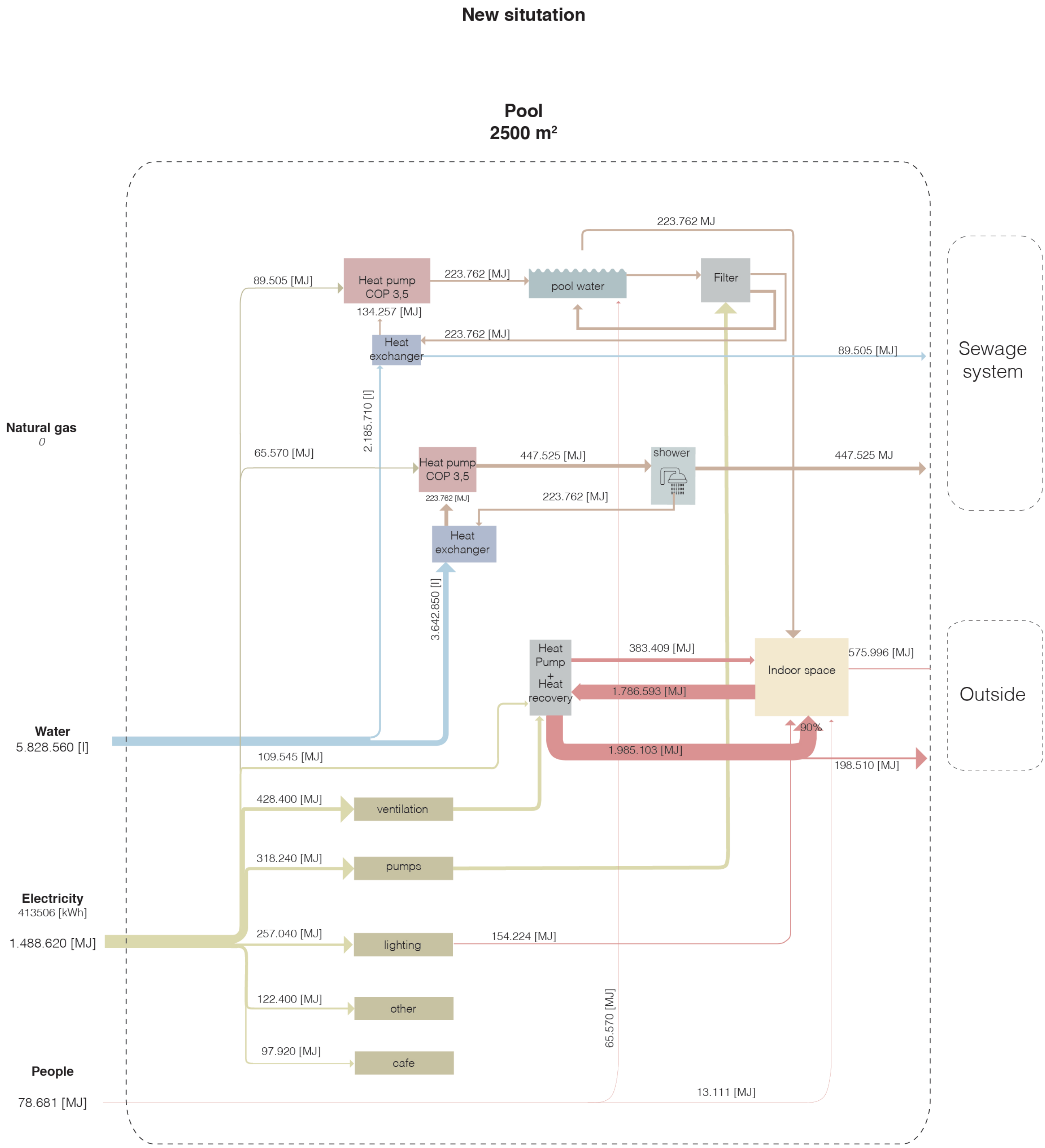


Figure 8.2. Detailed flow diagram containing a combination of interventions. This combination of interventions has resulted in the elimination of natural gas consumption.

IX. CONCLUSION

Different interventions can be used to reduce the energy consumption of swimming pools. This paper focusses on the interventions regarding natural gas consumption. The reference model pool shows that most natural gas is needed for space heating. Firstly, namely for new swimming pools, a significant improvement can be made with the orientation of the building. This should always be used as a starting point because it can be considered as free. Secondly, the results show that gas consumption for space heating can be reduced to a large extend by using good insulating materials. As space heating is one of the major heat consumers due to ventilation requirements, a lot of energy can already be recovered if the exhaust air is used to pre-heat the fresh air. When an air heat pump provides the remaining necessary heat, gas consumption for space heating can be eliminated altogether and a minimal amount of electricity is needed for this heat pump. Fresh water for the showers and the pool is the other large gas consumer as this needs to be heated up as well. When the heat of the pool water and shower water is recovered, and the remaining heat is provided by a heat pump, all-natural gas for the pool can be eliminated. The remaining electricity requirements can be provided by PV panels or other sustainable resources.

The individual results of the interventions have been based on the reference pool and therefore the effect and priority may be different for other pools. However, the way in which the interventions act upon the flows are the same. And this knowledge can be used as a basis for other pools to determine the effectiveness of the interventions. However, with this knowledge, it should always be considered that the production of heat/electricity, or the recovering of waste heat flows, is not as effective when the building is not insulated properly. Also, some interventions are very easy to implement in both new and existing buildings. Both pool covers and LED lights have a positive effect on the energy consumption. Therefore, these interventions should always be considered.

The overall design considerations for the interventions show that for new pools the starting point is the orientation and organization of the building. This is because this can greatly affect the required heat consumption as the Sun can already heat up the building naturally. Moreover, some of the interventions require a significant amount of space, such as heat pumps, and if they are not integrated in the building they may form a nuisance and obstruct views. Specifically heat pumps also have inlets and outlets for fresh and old air. These inlets and outlets may be included in the detailing of the building. In the design phase pool covers should also be considered to establish an integrated design.

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XI. APPENDICES

10.1. Reference Swimming Pool

The detailed flow diagram of the reference swimming pool is shown in Figure 10.1.1. The following subsections provide information about the assumptions and calculations that went into constructing the detailed flows. The input of the swimming pool and the distribution between the flows have already been explained in Chapter 2.

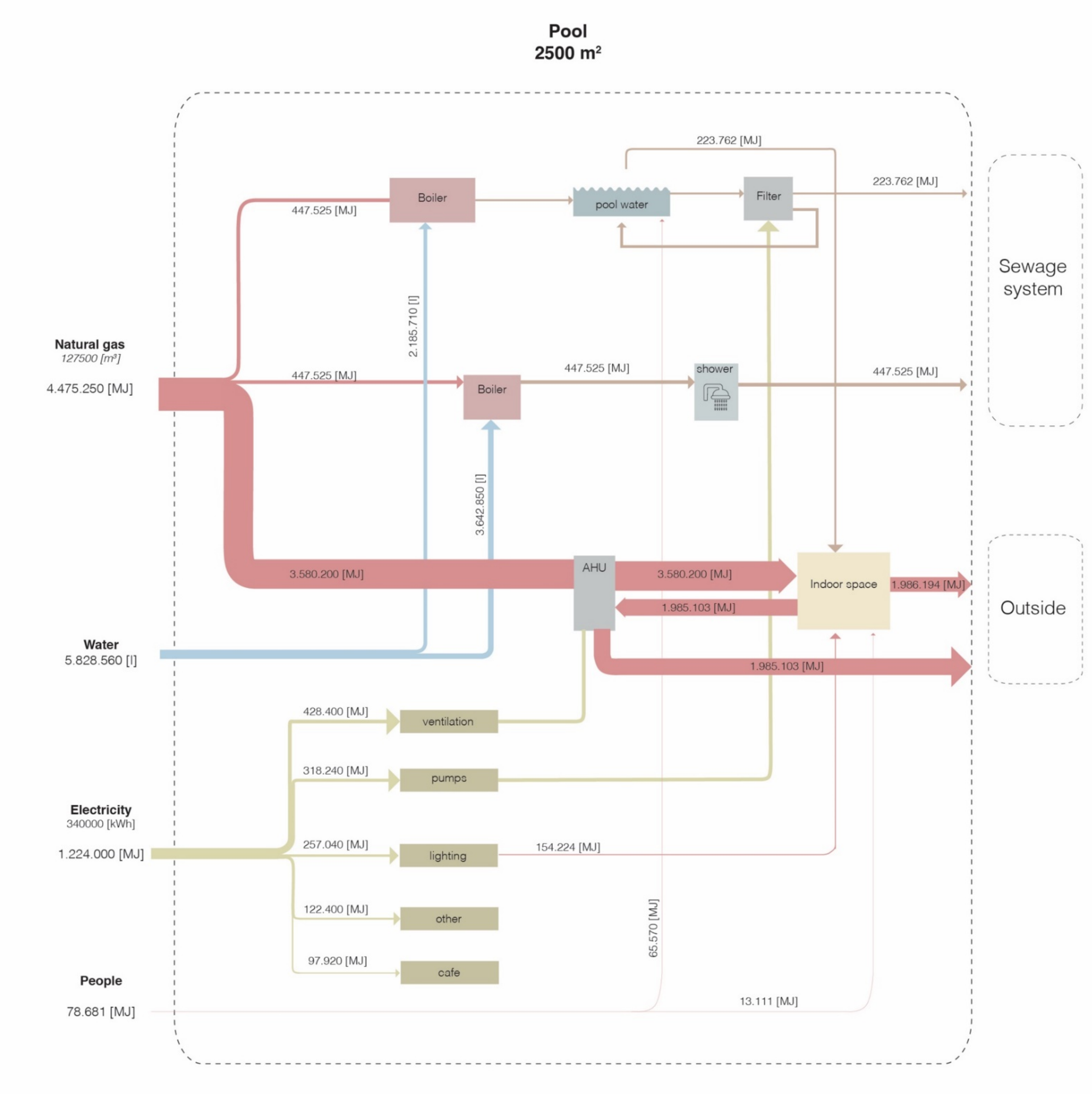


Figure 8.2. Detailed flow diagram of the reference swimming pool.

10.1.1. Shower water

The amount of visitors of the swimming pool can be calculated from the amount of gas that is used by the swimming pool.

1 m^3 natural gas = 35,1 MJ. The specific heat of water = 4,19 kJ/(kg.K). This means that heating 1 liter 1 °C, you need 4,19 kJ / 35 MJ = $1{,}2 \times 10^{-4}$ m^3 natural gas.

It is assumed that the boiler has an efficiency of η=1. The shower needs to be heated from 10 degrees Celcius to 40 degrees Celcius, and a person uses approximately 50 liters for a shower in a swimming pool.

We can now calculate the amount of gas usage per visitor per year.
ΔT = 30 degrees = 30 degrees * 50 liter * $1{,}2 \times 10^{-4}$ m^3 = 0,175 m^3 / visitor / year

Dividing the total gas usage by the gas usage per visitor per year yields the amount of visitors.
12750 m3 / 0.175 m3 = **72.857 visitors / year**

The total amount of water used for showering = 50 * 72.857 = 3642850 [l] or 3643 m^3

10.1.2. Fresh pool water

For each visitor, approximately 30 liters of fresh water is required. This yields a total fresh water amount of:

30 [liter] * 72.857 [visitors / year] = 2185710 [liters]

10.1.3. Insulation

To estimate the transition losses through the building envelope, the surface area of the building envelope is calculated based on the reference pool (2500m2). The facades are 5 meters high, and 20% of the façade consists out of glass (Table 10.1.3.1).

To make an assumption about the energy savings of insulation, the next calculation is used:

$Rtot = Rse + Rsi + Rc$
$U = 1/Rtot$
$q = U\,(Ti - Te)$.

The U value of glass is already available, and for the other façade elements this can be calculated with the Rc value, which is often given. Rc value = insulation value, and U value = heat transfer coefficient. This means the higher the Rc, and the lower the U value, the better insulated.

There is assumed that the reference building is poorly insulated. The Rc values are in this case assumed to be relative low, which means 2 for roof, floor, façade and a U value of glass is assumed as normal double glazing for which the value is 2 (Bouwmeester, 2014). Rsi and Rse are transition resistances, for which average values are used (Kort, 2009).

Table 10.1.3.1. Insulation values used for the reference pool

									Heat transmissi
	Surface m2	RC	Rsi	Rse	R tot	U value	Delta T	q [w/m2]	Watt
Roof	2500	2	0,13	0,04	2,17	0,460829493	20	9,216589862	23041,47465
Floor	2500	2	0,17	0,17	2,34	0,427350427	20	8,547008547	21367,52137
Facade	820	2	0,13	0,04	2,17	0,460829493	20	9,216589862	7557,603687
Glass (facade	205					2	20	40	8200
									60166,59971

The total of 60166,59971 [W] *24 [h] *3600 [sec] *365,25 [days] /1000000 = 1898713,487 [MJ] / year

The total gas imput in space heating had a value of 1897506 [MJ]
1897506 [MJ] / 3580200 = **53 % of the energy is leaving through the building envelope.**

10.1.4. Heat production visitors
Visitor = 1,5 hours in the building
1 hour swimming = 250 W = 250 * 72857 = 18214250 = 18214 kWh → = 65570 MJ to water
0,5 hour building = 100 W = 3642 kWh → 13111 MJ to indoor air

47% lost through ventilation = 13111 * 0,47 = 6162 MJ
53% lost through heat transmission (see previous calculations about insulation values) = 13111 * 0,53 = 6948 MJ

10.1.5. Heat from light
Saving light, CFU lamps, transfer 40% of the energy to light and 60% to heat. Assumed that these lights are used, 257040 MJ * 0,6 = 154.224 MJ heat is produced.

53% lost by transmission = 81.739 [MJ]
47% lost by ventilation = 72.485 [MJ]

10.1.6. Latent heat pool evaporation
The fresh water of the pool that comes in at 10 °C. 30 liters a person needs to be added as fresh water. This is due to evaporation, direct water loss, and rinse water. There is assumed that 15 liters of this is lost in the sewer (at a temperature of 30 degrees (Infomil, 2018)) and 50% (15[l]) is lost through evaporation.
Sewer: 223.762 [MJ]
Latent heat: 223.762 [MJ]

10.1.7. Heat loss through ventilation
There was found that through insulation 53% of the heat was lost, which means that the other 47% is lost through ventilation. The exception is latent heat from evaporation of the pool, which is all lost through ventilation.

Incoming energy for heating: 3.580.200 [MJ] * 0,47 =	1.682.694 [MJ]
Incoming energy from light: 514.224 [MJ] * 0,47 =	72.485 [MJ]
Incoming energy from people: 12111 [MJ] * 0,47 =	6.162 [MJ]
Incoming energy from latent heat :	223.762 [MJ]
	-------------------+
Total loss through ventilation =	**1.985.103 [MJ]**

10.2. Interventions

10.2.1. Insulation

The same calculation as in Appendix 10.1.3 has been done. But now for a good insulated building. The RC values are increased and the U value of glass has been decreased to a value of triple glazing (Bouwmeester, 2014).

										Heat transmission	
Scenario 1										Heat transmission	
		Surface m2	RC	Rsi	Rse	R tot	U value	Delta T	q [w/m2]	Watt	
	Roof	2500	**2**	0,13	0,04	2,17	0,460829493	20	9,216589862	23041,47465	
	Floor	2500	**2**	0,17	0,17	2,34	0,427350427	20	8,547008547	21367,52137	
	Facade	820	**2**	0,13	0,04	2,17	0,460829493	20	9,216589862	7557,603687	
	Glass (facade	205					2	20	40	8200	
										60166,59971	
Scenario 2										Heat transmission	
		Surface m2	RC	Rsi	Rse	R tot	U value	Delta T	q [w/m2]	Watt	
	Roof	2500	**8**	0,13	0,04	8,17	0,122399021	20	2,447980416	6119,95104	
	Floor	2500	**6,5**	0,17	0,17	6,84	0,14619883	20	2,923976608	7309,94152	
	Facade	820	**8**	0,13	0,04	8,17	0,122399021	20	2,447980416	2007,343941	
	Glass (facade	205					**0,5**	20	10	2050	
										17487,2365	**71%**

Previous calculations show that 53% of the heat is transmitted through the building envelope (Appendix 10.1.3). This comes down to 1.986.194 [MJ]. (53% of people heat, incoming gas heat, and heat form lights) When 71% can be saved this means that 575.996 [MJ], is lost, which means a reduction in gas input of 1.410.198 [MJ]. From 3580200 [MJ] natural gas for space heating to 2170002 [MJ] is a reduction of 39% reduction to space heating**, and 32% reduction in the total gas needs**

Insulation		Difference	Total
	[MJ]		
Total natural gas	4475250	1.410.198	- 32%
Total electricity	1224000		
Total people	78681		
Total	5777931		- 24%

The effect of insulation on the flows is depicted in Figure 10.2.1.1.

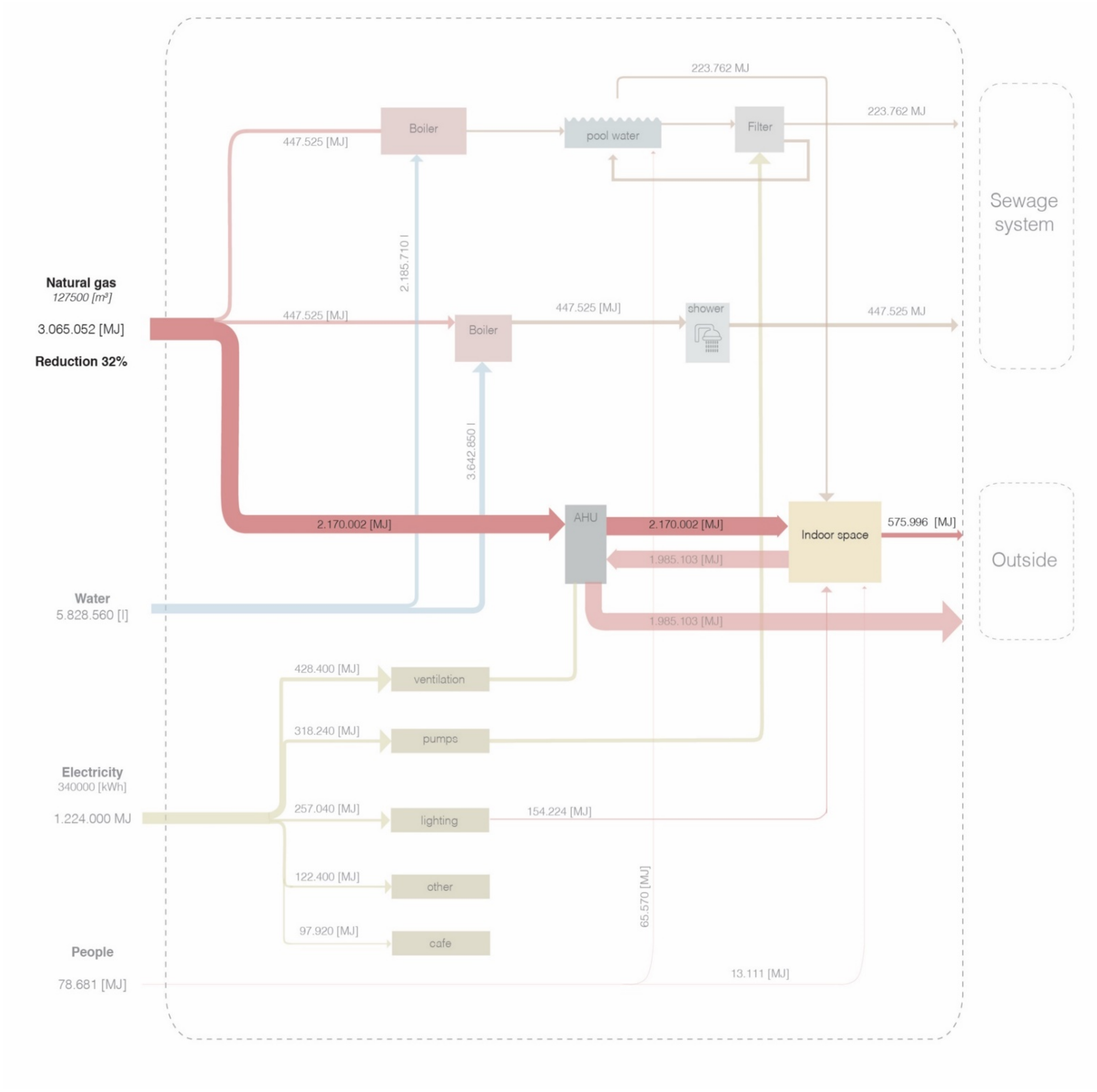


Figure 10.2.1.1. Effect of insulation on the flows

10.2.2. Air heat pump and Heat Recovery

Heat recovery systems have an efficiency up to 95%. For the intervention in the reference pool is assumed an efficiency of 90% . This means that from the outgoing heat through ventilation (1.958.103 [MJ]) **1.786.593 [MJ] can be recovered.**

The gas input will decrease with that amount which results in 3.580.200 [MJ] - 1.786.593 [MJ] = **1.793.607 [MJ]** When this is received through an air heat pump with a COP of 3,5 (not very high, but for a single intervention this is assumed) than natural gas for space heating is eliminated 1.793.607 [MJ] / 3,5 = **512.459 [MJ] electricity.**

	[MJ]	Difference	Total
Total natural gas	4475250	3.580.200	- 80%
Total electricity	1224000	512.459	+ 42%
Total people	78681		
Total	5777931	4.092.659	- 71%

The effect of the air heat pump and the heat recovery is depicted in Figure 10.2.2.1.

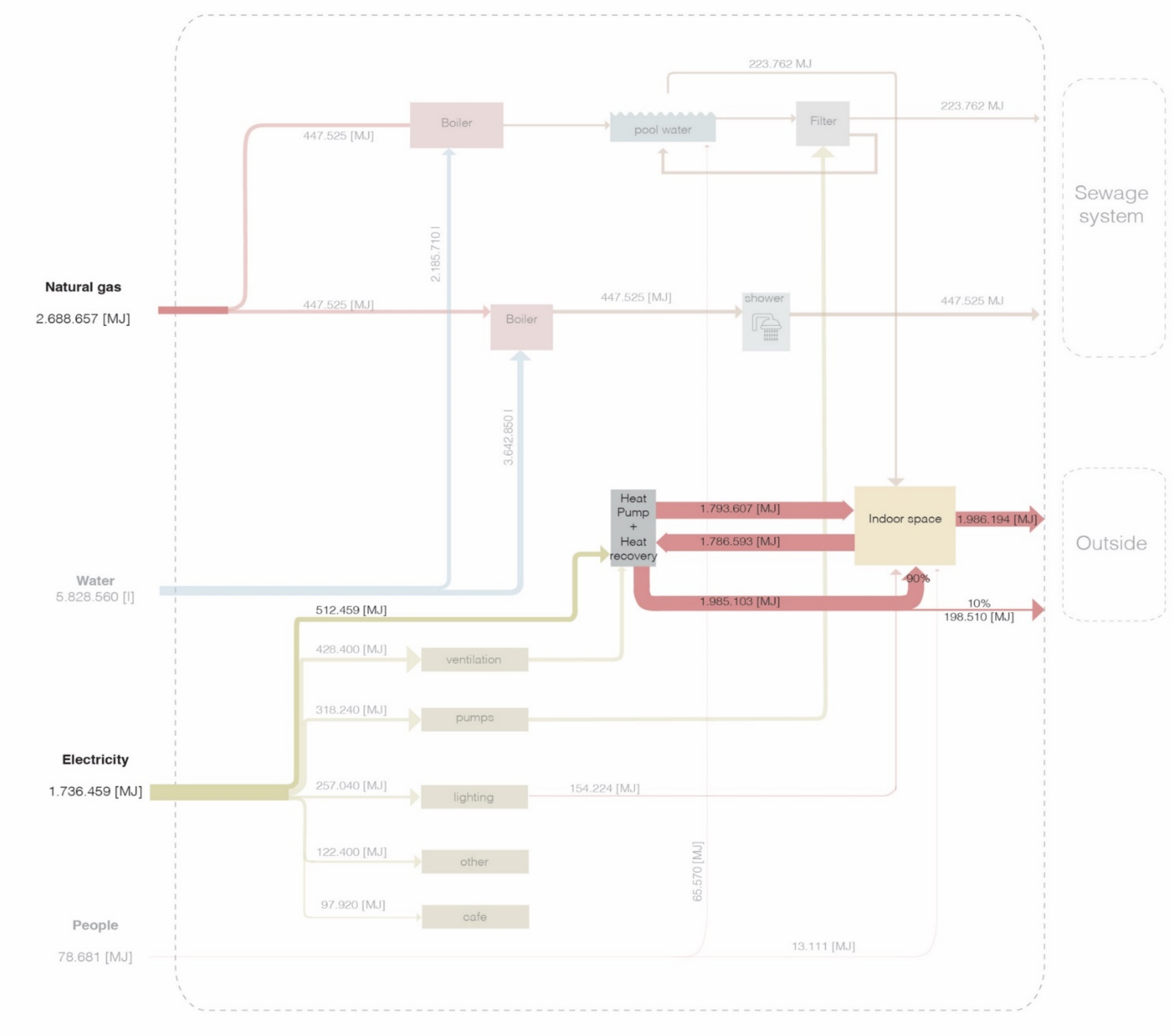


Figure 10.2.2.1. Effect of air heat pump and heat recovery on the flows

10.2.3. Shower Heat Recovery

Impact of the shower heat recovery system can upgrade the supply heat up to 25 °C with a heat exchanger. This means that **ΔT = 15** (instead of 30)

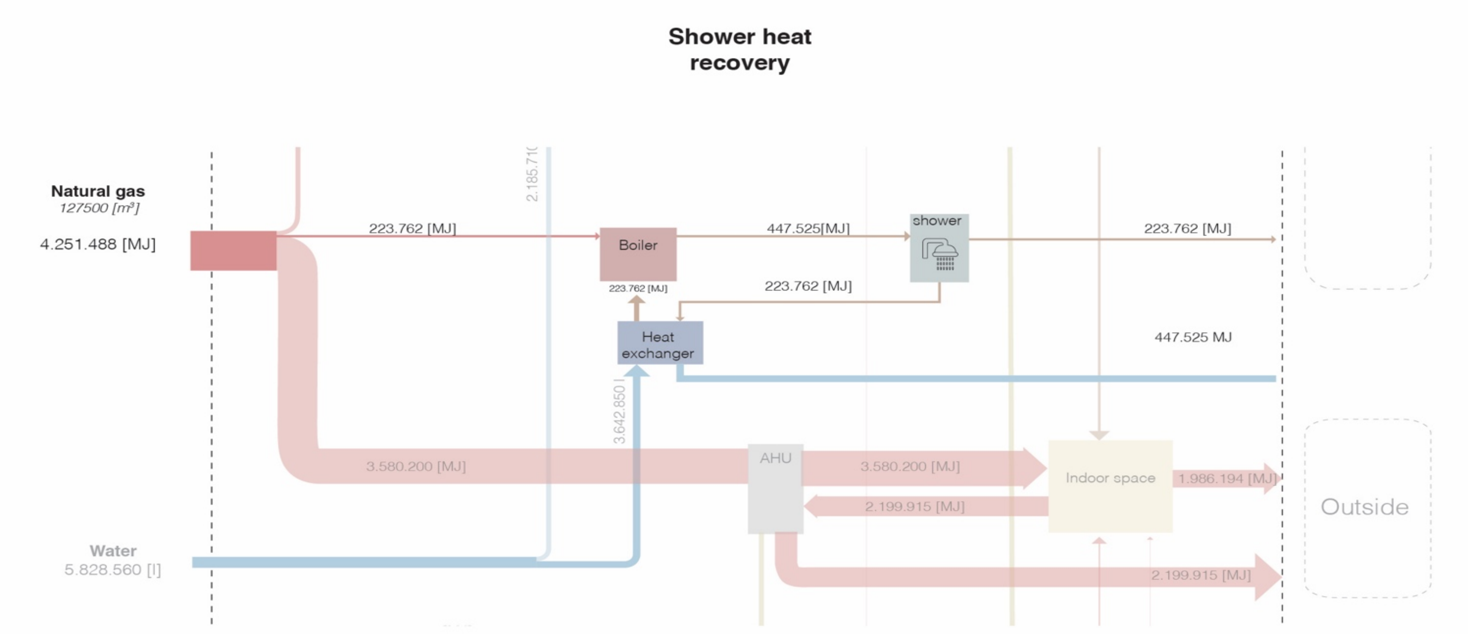
15 x 3642850 [l] x 1,2 x 10^{-4} [m^3] = **6557m3 = 229495 MJ / 3,6 = 63749 kWh = 223762 [MJ]**
This comes down to a saving of 50% on the shower heat.

This means the overall gas consumption is reduced to 4251488 [MJ], which is an overall reduction of **5%**

When this is led to an air-water heat pump with the COP of 3,5, this means that
223762 [MJ] / 3,5 = **65570 [MJ]**

	[MJ]	Difference	
Total natural gas	4475250	447525	-10%
Total electricity	1224000	65570	+7%
Total people	78681		
Total	5777931	381955	- 7%

The effect of the shower heat recovery and heat pump on the flows is depicted in Figure 10.2.3.1.



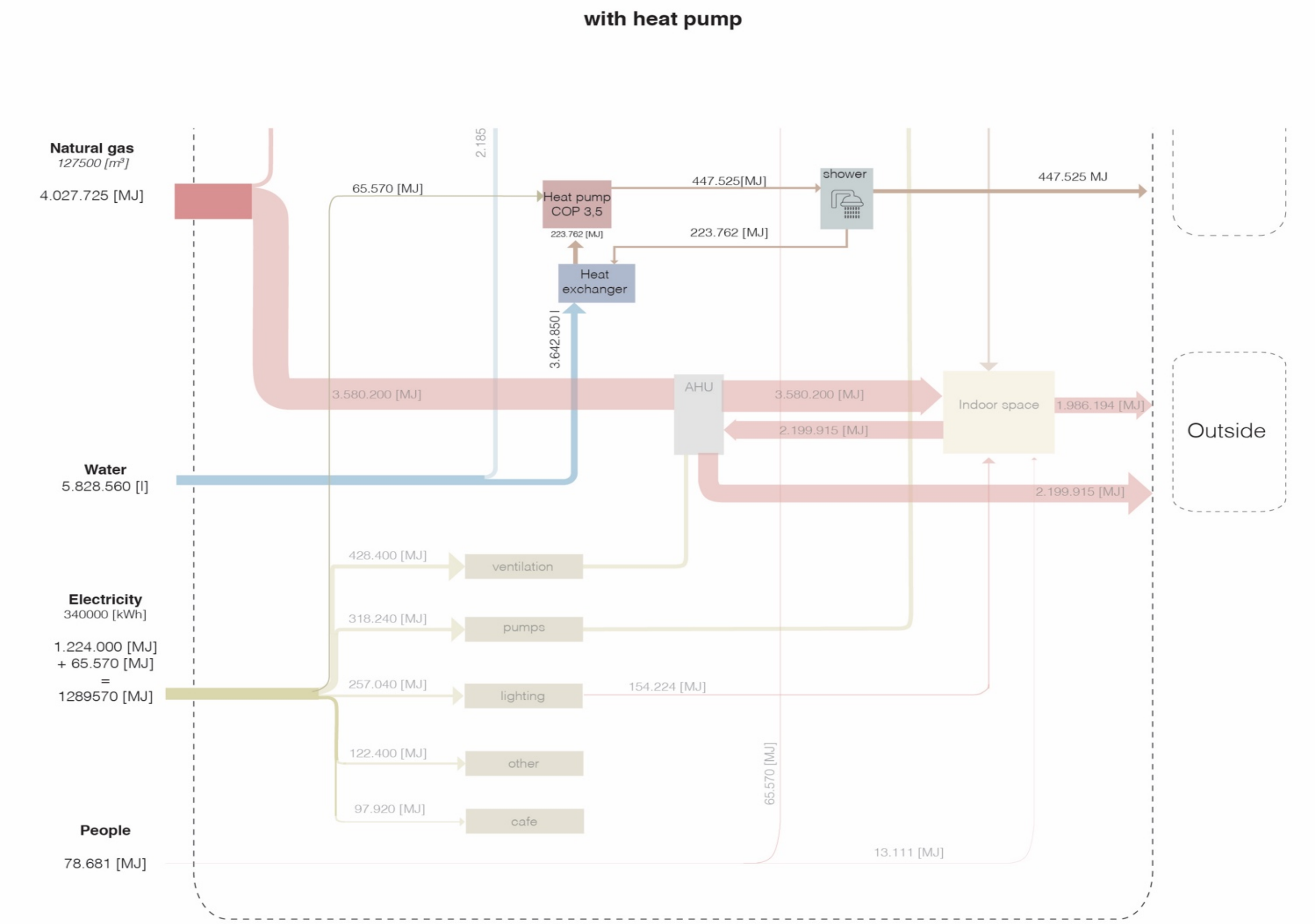


Figure 10.2.3.1. Effect of shower heat recovery and heat pump on the flows

10.2.4. Pool Water Heat Recovery

The fresh supplied water enters the system at 10 °C half of this amount is evaporated and the other half ends up in the sewage system. Heat of the water that goes into the sewage system has an average heat of 30°C. This heat can therefore be used to heat up the fresh water.

447.525 [MJ] comes into the system to heat up fresh pool water. Half of this ends up in the sewer. This means 223762 [MJ] goes into the sewer. 60% of this heat can be recovered with an heat exchanger = 134.257 [MJ].
→ 447.525 [MJ] - 134.257 [MJ] = **313268 [MJ]** is still needed for the fresh water supply = reduction of
30% on heating fresh water supply for the pool

2.5 With heat pump:
When a heat pump is used with a COP of 3,5 than the total energy 313268 [MJ] / 3,5 = **89.505 [MJ]** electricity.
This is a **total energy saving of 80% for pool water** compared to the initial 447.525 [MJ]

	[MJ]	Difference	
Total natural gas	4475250	447525	-10%
Total electricity	1224000	89.505	+7%
Total people	78681		
Total	5777931	358.020	-6%

The effect of the pool water heat recovery and heat pump on the flows is depicted in Figure 10.2.4.1.

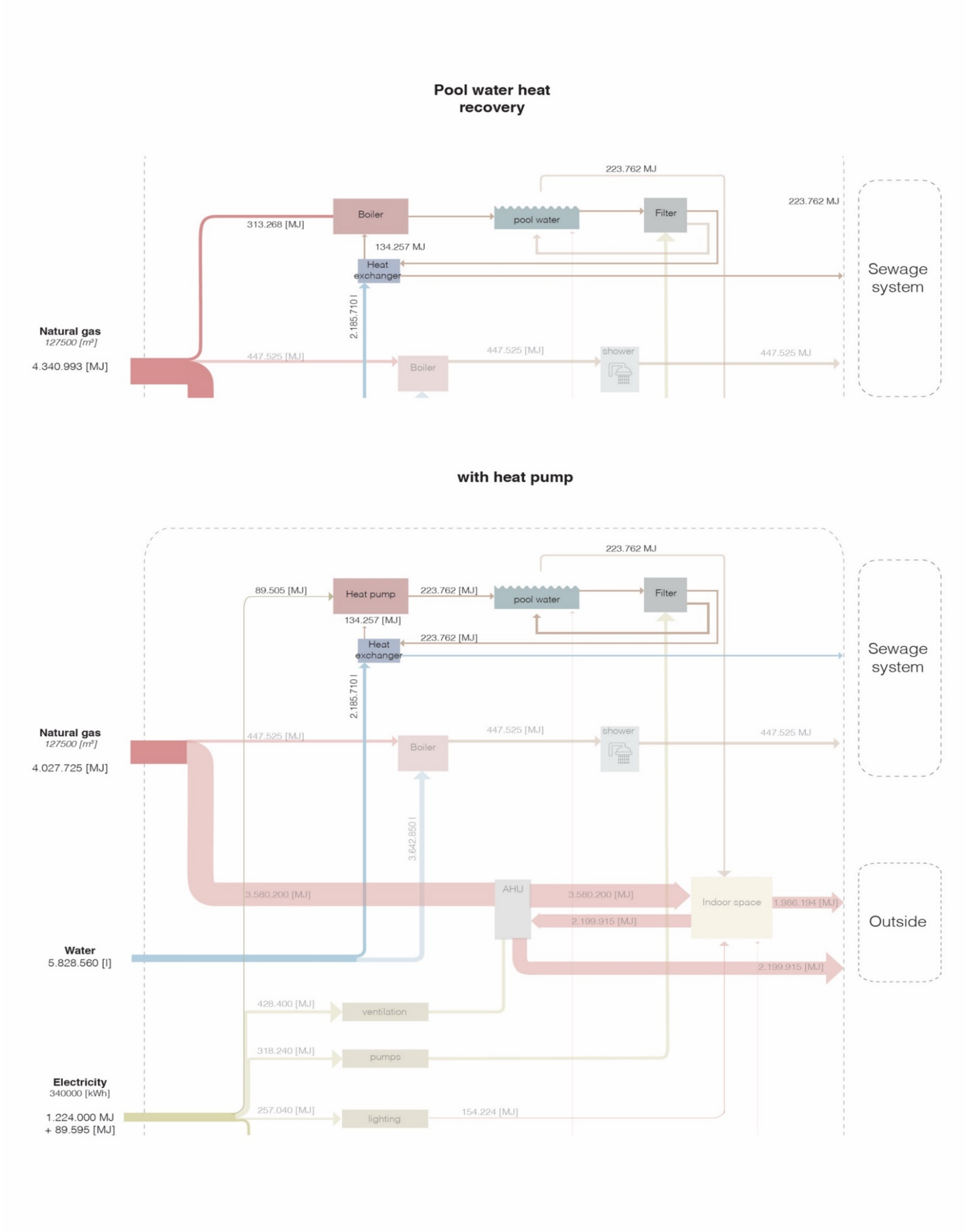


Figure 10.2.4.1. Effect of pool water heat recovery and heat pump on the flows

10.2.5. Sewer and Geothermal Heat Recovery

Ground water and sewer water have a temperature around 16 °C. This is 6°C higher than the average fresh water inflow. It means that these sources can be used to pre-heat through heat exchangers water before it enters the pool/shower. There is assumed that this is used in combination with a heat pump. In the current situation 447.525 [MJ] is needed to heat up 30 °C. This means that a saving of 6°C can be reached.
For shower water at 40°C: (6/30) * 447.525 = **89.505 [MJ]** for the shower savings.
For Pool water at 30°C: (6/20) * 447.525 = **134.258 [MJ]** for pool water savings.

When this is used in combination with a heat pump with a COP of 3,5:
For shower water: 447.525 - **89.505 =** 358.020 [MJ] / 3,5 = 102.291 [MJ]
For Pool water : 447.525 - **134.258 =** 313.267 [MJ] / 3,5 = 89.505 [MJ]

Pool water:

	[MJ]	Difference	
Total natural gas	4475250	447525	-10%
Total electricity	1224000	89.505	+7%
Total people	78681		
Total	5777931	358.020	-6%

For shower:

	[MJ]	Difference	
Total natural gas	4475250	447.525	-10%
Total electricity	1224000	102.291	+8%
Total people	78681		
Total	5777931	345.234	-6%

Because this intervention has a similar effect in the system of the pool as the previous two described intervention (pool water heat recovery, shower heat recovery) no system diagram is made of this intervention.

10.2.6. Pool Cover

Latent heat reduction:
223.762 [MJ] * 0,75 = 167.821 [MJ] = **55.941 [MJ] Saving on heat for pool water (25%)**
50% of the fresh water supplied for the pool is to cover evaporation losses. When this is reduced with 25% it means that the total fresh water supply for the pool is reduced with 50% *25% = 12,5% = **273.214 [l] savings**

Ventilation reduction:
the 25% less latent heat, means 25% less ventilation due to the decrease in moist air.
Saving is: 428400 * 0,25 = **107100 [MJ] = saving on vent. Electricity = 13% savings**
This means new ventilation energy consumption = 428.400 [MJ – 107.100 [MJ] = 321300 [MJ]

Due to the ventilation reduction of 25%, the heat loss through ventilation can also be reduced with 25%.
(1.985.103 [MJ] - 55.941 [MJ]) * 0,75 = 1.446.872 [MJ] = **538.231 [MJ] = Saving on heat for air heating = 15%** of the total space heating 3.580.200

Total reduction of the pool cover:

Natural gas: 552.217 [MJ]
Electricity: 107.100 [MJ]
Total savings of energy = **659.316 [MJ] = 11% of total initial energy consumption** (5.777.931 [MJ])

Savings Pool cover			
	[MJ]	Savings pool	%
Total natural gas	4475250	650.112	-12%
Total electricity	1224000	107100	-9%
Total people	78681		
Total	5777931	757.212	-13%

The effect of the pool cover on the flows is depicted in Figure 10.2.6.1.

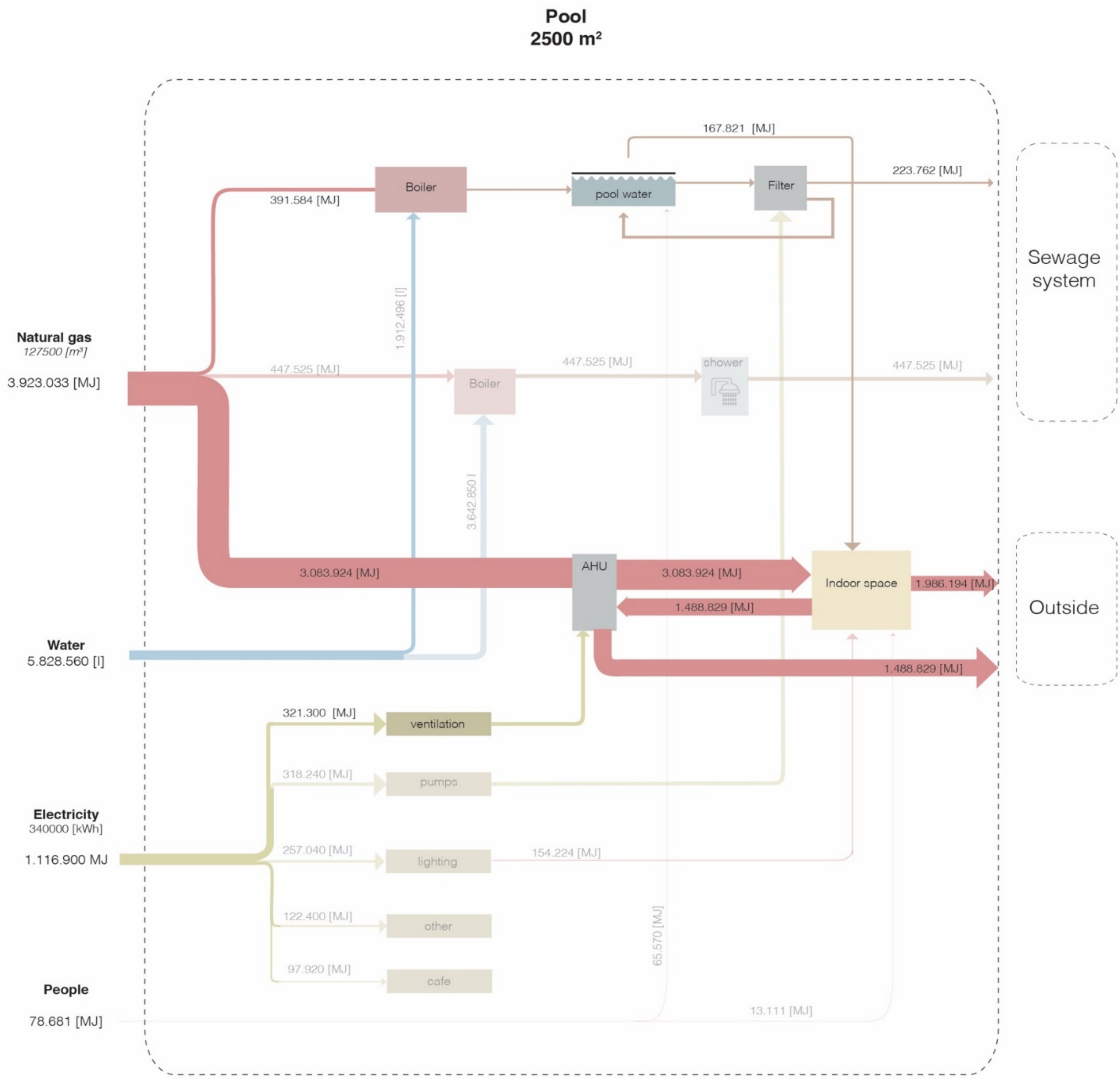


Figure 10.2.6.1. Effect of pool cover on the flows

10.2.7. LED Light

Assumed is that the reference pool has halogen lighting. This means that the amount of kWh can be decreased by **85%.**
0,15 * 257.040= **38.556 [MJ]**

From these lights, 50% is converted to heat 19.268 [MJ] . Consequently the reduction in heat for the space heating is **154.224 [MJ]** – 19.268 [MJ] **= 134.956 [MJ]** which needs to be replaced with another heat source

Heat source increases with **134.956 [MJ]**
Electricity for light is reduced with **218.484 [MJ]**

The effect of LED lights on the flows is depicted in Figure 10.2.7.1

Saving light based on 75 Watt				
	Halogen	**Led light**	**Difference**	Heat Loss
Energy	257.040	38.556	218.484	
Heat	154.224	19.268	134.956	
	[MJ]	Savings LED	Total savings	
Total natural gas	4475250	-134.956	+3%	
Total electricity	1224000	218.484	-18%	
Total people	78681			
Total	5777931	83.528	-1%	

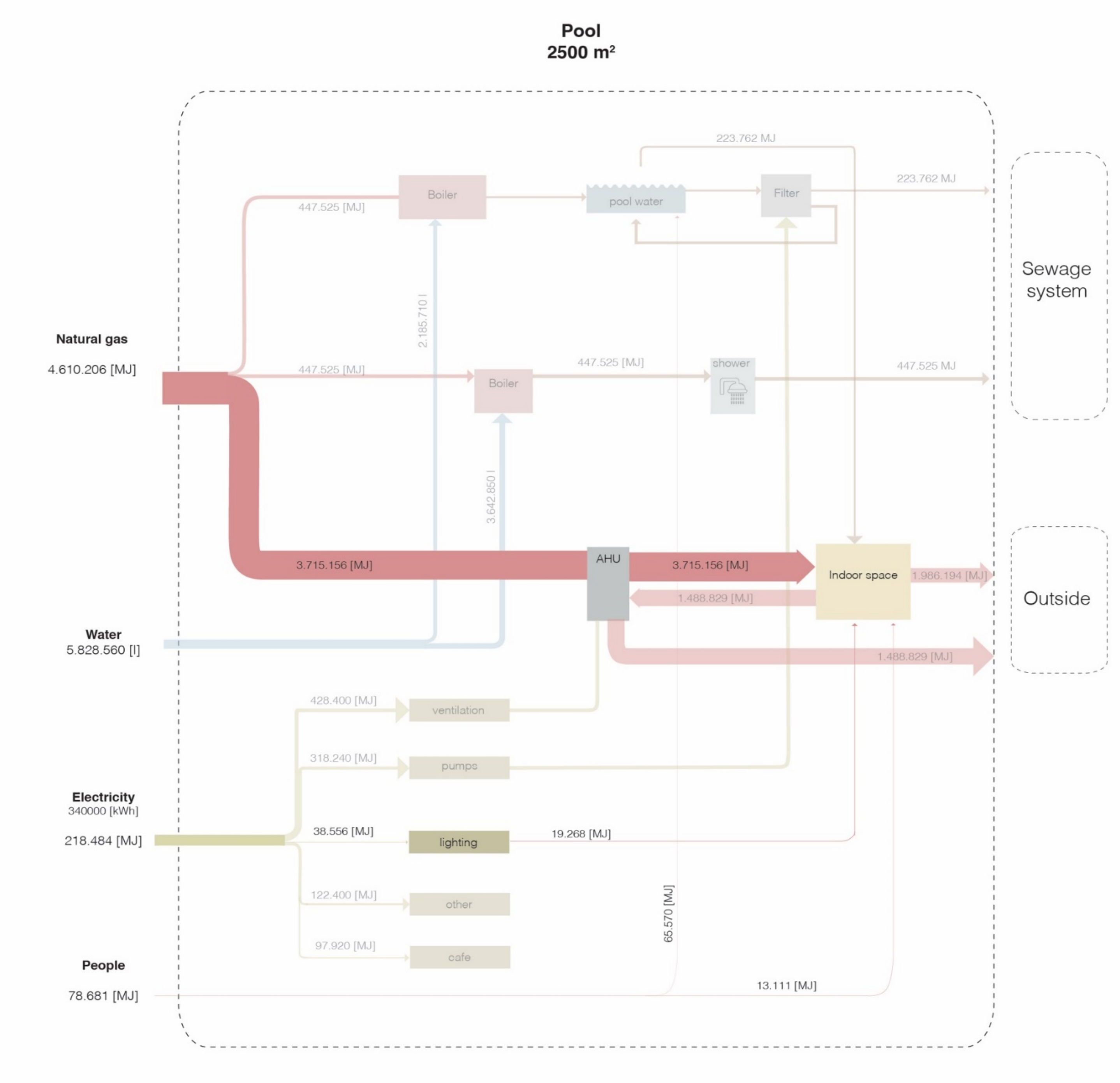


Figure 10.2.7.1. Effect of LED light on the flows

10.2.8. Frequency Pumps

Frequency pumps for pool water can reduce the electricity consumption with 20000 kWh (=72000 [MJ]) this is a reduction of 72000/318.240 = **23 %** on the electricity consumption of these pumps.

	[MJ]	[MJ]	
Total natural gas	4475250		
Total electricity	1224000	72000	6%
Total people	78681		
Total	5777931	72000	1%

10.3. Combinations of Interventions

Step 1 insulation:
Gas input: reduced with 1.410.198 [MJ]. From 3580200 [MJ] natural gas for space heating to 2.170.002 [MJ].
1985103 [MJ] is still needed to cover the ventilation losses. This can be reduced with 90 %= 1.786.593 [MJ]
2.170.002 [MJ] - 1.786.593 [MJ] = 383.408 [MJ]
Divided by a COP of 3,5 air heat pump: 383.408 [MJ] / 3,5 = 109.545 [MJ] electricity for the heat pump.

Insulation + Heat Pump:

	NEW [MJ]	OLD [MJ]	%	
Total natural gas	895.050	4475250	- 80%	3.580.200
Total electricity	1.333.545	1.224.000		-109.545
Total people	78.681	78681		0
Total	2.307.276	5777931	- 60%	3.470.655

With shower and pool water heat recovery + heat pump:

	NEW [MJ]	OLD [MJ]	%	Savings
Total natural gas	0	4475250	- 100%	4.475.250
Total electricity	1.488.620	1224000		-264.620
Total people	78.681	78681		
Total	1.567.301	5.777.931	- 73%	4.210.636

10.4. Case Study Swimming Pools

10.4.1 Welle in Drachten

Swimming pool de Welle in Drachten uses solar panels to reduce their primary energy consumption. 1182 PV panels, from which 864 were placed on the roof of the pool and 318 in the surrounding of the pool, are used to reduce the electricity use. This has led to a reduction of 420.000 kWh in electricity (Mager, 2017). Besides these panels, PVT panels are placed on the roof of the building. These panels are used to reduce both electricity and gas use and are also referred to as triple solar system panels. These panels are used for heating and hot tap water. The panels provide a saving of 60.000m^3 Natural gas (Groot, 2016). Part of this triple solar system is a heat pump. After one year they can conclude that the heat of the panels delivered 500.000 kWh heat, which was able to deliver 80% of heat for the indoor 50 meter pool (Mager, 2017). The panels where able to deliver heat for 90% of the time.

The heat from the PVT panels are guided to a heat pump, where electricity is used to increase the temperature to the desired temperature.

Zwembad de Welle in Drachten
- Recreation bath
- 50-meter bath

Active solutions

- PVT Panels
- PV Panels

10.4.2. Noorderparkbad Amsterdam

Details:
- 5600 m2
- 100.000 visitors a year

The energy consumption is 80% lower than in the previous Floraparkbad, which is now demolished and replaced with the Noorderparkbad. The warm air from the natatorium is guided through a high efficiency (82%) air handling unit with an integrated heat pump and HR-heat exchanger. Heat from the showers is recovered to reduce heat losses. The roof is an energy roof that combines PV-Panels, solar collectors and Bulb-collectors. The solar collectors on the roof are used to heat the outside pools. For the production of energy, an energy roof is build with 750 m^2 solar panels. The windows are constructed out of triple glazing. A shading system is used to prevent overheating. The lights that are used in the building are LED lights that reduces the electricity consumption (Erne, 2015).

It seems that most energy in the interior of the building is saved due to the high insulation values and the new high efficiency air handling units.

- orientation
- organisation

- Heat pump
- Heat exchanger

- Shower heat recovery
- Solar collector (Outside pool)

- Rinse water recovery
- Led lightning

Consumption: Unknown
Reduction: 80%

10.4.3. Dijnselburg Zeist

Swimming pool Dijnselburg has applied some new interventions to reduce the energy consumption. Due to the new interventions, 50% of the energy is saved. The gas use used to be 400.000m^3 and is reduced to 200.000m^3. There all several small interventions applied to reduce the energy consumption of this pool. A new high efficiency boiler is installed. Heat pipes and sun discs are used to heat up the outdoor pool and shower water. The Sun discs provide enough heat for the outside pools, which lowers the overall gas consumption significantly. All pools are covered with a sheet when they are not used. Energy efficient lightning is installed. Furthermore are the pumps of the water controlled. Another bigger intervention is the Kantherm air handling unit with a 90% efficiency heat exchanger. To reduce the primary energy consumption a cogeneration plant is installed, which can save up to 20% of the primary energy use. Energy efficient lightning has been applied to reduce the

However the WKK plants often run on natural gas and do not achieve an reduction in the gas use. It saves exhaust greenhouse gasses when it is compared to a grey electricity production. A more sustainable solution could be to use biomass as a fuel, however, here too, you can discuss how sustainable that solution is.

Interventions:
- Pool covers
- Controlled water pumps

- Air handling unit with heat exchanger
- Cogeneration plant (gas use)
- High efficiency boiler (still gas use)

- Heat pipes for shower water

Electricity 1.2000000 kWh → 661.435 kWh = 45% reduction
Natural gas: 400.000m^3 → 200.000m^3 = 50 % reduction

In the next phase new interventions:
PV panels, increasing insulation, double/triple glass and possibly a biomass generator.

10.4.4. Geusseltbad Maastricht New pool by Koppert Koenis Architecten

The Geusseltbad is a **newly** built swimming pool in 2013. The design includes several passive techniques to reduce energy consumption of the pool. The orientation of the building and organization of the functions have played an important role in the design of the building. The second major energy saving intervention has been the high insulation values. Triple glazing is applied to reduce heat loss and the insulation values of the walls reach RC values of 8m2K/W. The heat is provided with the use of ground water. The main elements of this energy design are two big buffer barrels with water of 50 °C. This comes from ground water, which is upgraded by the use of a heat pump (electrical energy). This water is used to provide heat for the pools, showers, and hot tap water. The main heat supply in the building is through air, in addition floor heating is used in some parts of the building. There are also rinse water recycling systems used to reduce the energy demand. The outdoor pool is heeded by 300m^2 solar collectors (Hellebekers, 2014). The installation devices such as heat pumps and air handling units are placed in the cellar of the pool.

Interventions

- Orientation of the building
- Organization

- High insulation value

- Thermal ground energy (Combined with heat pump)

- Rinse water recycling

- PV panels
- Heat collectors (outside pool)

→ Electricity from the PV panels is used to provide energy for the swimming pool. This is supplemented with green energy that is produced in the direct surroundings.

10.4.5. Swimming pool Urk ’t Bun

Swimming pool ’t Bun in Urk is a **renovated** pool of more than 40 years old, that counts more than 120.000 visitors every year. First of all, improved insulation is applied to the building to reduce heat losses. Other elements are included such as heat pumps and pool covers (Kolkman, 2016). It seems that riothermia is used to heat the pool water, but does not provide heat for space hating. The efficiency of the air handling units are increased with 35-40% which means that the new efficiency of these units is around 85-90%. It is at this point not clear how much electricity is used to provide the right amount of energy needs of this pool.

- high insulation
- pool covers

- heat pumps
- heat exchangers

- Riothermia for pool heating
- Aquifer heat storage

Heat pump power: 180 kWh
Heat exchanger power: 120 kW