



Osaamista
ja oivallusta
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Environmental Impacts of Ball Valves

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<p>Tämän insinööriyön tavoitteena oli tutkia, millaisia ympäristövaikutuksia rakennusten lämmitysjärjestelmien palloventtiileillä on ja miten vaikutukset näkyvät taloudellisissa kustannuksissa.</p> <p>Työssä perehdyttiin palloventtiilien koko elinkaaren ympäristövaikutuksiin. Näitä vaikutuksia ovat raakamateriaalin valmistus, venttiilien valmistus ja kuljetus asennuskohteeseen, venttiilien aiheuttamat paine- ja lämpöhäviöt, sekä tuotteen elinkaaren lopussa materiaalien kierätys ja loppusijoitus. Työssä käytettiin olemassa olevaa asuinkerrostaloa esimerkkinä venttiilien vaikutuksesta rakennuksen hiilijalanjälkeen ja käyttökustannuksiin.</p> <p>Tutkimukset todistavat, että palloventtiileihin liittyy merkittäviä ympäristö- ja taloudellisia vaikutuksia, jotka rakennushankkeen osapuolten tulisi tiedostaa. Täysaukkoisen venttiilin valitsemisella supistettuaukkoisen sijaan ja venttiilin eristämällä on suuri vaikutus venttiilin hiilijalanjälkeen. Projekti todistaa, että ympäristöystävällisempi vaihtoehto voi olla myös taloudellisesti edullisempi.</p> <p>Projektin tuloksia voidaan käyttää myös palloventtiilien markkinoinnissa osoittamaan eri venttiilivaihtoehtojen eroavaisuuksia.</p>	
Avainsanat	palloventtiili, täysaukkoisen, eristys

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<p>The goal of this final year project was to study what environmental impacts are associated with ball valves in a building's heating system, and how those impacts translate to financial costs.</p> <p>The project studied the environmental impacts of ball valves during their whole lifecycle. The impacts studied were the production of the raw material, production and transportation of the valves, pressure and heat loss related to the valves, and the end-of-life recycling of the valves. To demonstrate the impacts on a building level, an existing apartment building was used as an example for both the environmental and financial costs.</p> <p>The project proved that there are significant environmental and financial impacts related to ball valves, and that the parties involved in a building project should acknowledge this. It was shown that choosing a full-bore valve over a reduced bore one, and insulating the valve has a big impact on the valve's carbon footprint. The project showed that choosing an environmentally more sustainable solution would also be the financially cheaper one.</p> <p>The results of the project can be used in the marketing of ball valves to demonstrate the differences between different choices.</p>	
Keywords	ball valve, full-bore, insulation

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1 Introduction

Global warming and climate change are forcing us to find ways to use fewer natural resources for building materials, change the way we use them, and how we dispose of them. While the carbon footprint of a ball valve is insignificant in comparison to some other building materials, it still causes significant environmental impacts.

The idea for the thesis came from Broen A/S. Initially the idea was to study Environmental Product Declarations (EPDs) and establish whether it was possible to obtain them for Broen's new valve line. It soon became obvious that, even if EPDs are useful for a lot of building materials, the financial costs and the amount of work related to the process are not justifiable. The aim was then changed to study the environmental impacts of ball valves throughout their entire life cycle.

In this thesis I will present the main environmental impacts of ball valves and the differences there are between various types of ball valves in material, manufacturing location, energy consumption during both the use, and end-of-life recycling of the valve. The data for the valves comes mainly from Broen A/S, but also from publicly available sources.

Broen A/S is a Danish valve manufacturer whose most well-known product is the Ballofix mini ball valve that the company has been manufacturing since 1960. The brand Ballofix has become a synonym for mini ball valves in general in the Nordic countries. Broen has recently extended the brand to include other types of ball valves as well, and it is these new types of valves that are studied in this thesis. [1.]

Today Broen A/S is a part of Aalberts Industries, a Dutch corporation, along with many other HVAC manufacturers [1]. Aalberts Industries' Integrated Piping Systems business area has a press fitting brand called VSH Xpress [2], and that is where Broen gets their press connection technology from.

2 Lifecycle Assessment and Carbon Footprint

A product's carbon footprint demonstrates its climate warming potential and it is usually reported as carbon dioxide equivalent in kilograms (kg CO₂e), or, for example for building materials, in kg CO₂e per one kilogram of material produced (kg CO₂e/kg) [3, p. 43]. This is an easily comparable value with which manufacturers can show their products' carbon footprint.

2.1 Lifecycle Assessment

Like the name suggests, lifecycle assessment (LCA) assesses the environmental impacts associated with a product during all stages of its lifecycle (also called cradle-to-grave). The analysis is divided into different modules and product life stages described in standard SFS-EN 15978 [3, p. 21]:

A1	raw material supply
A2	transport
A3	manufacturing
A4	transport
A5	construction/installation process
B1	use
B2	maintenance
B3	repair
B4	replacement
B5	refurbishment
B6	operational energy use
B7	operational water use
C1	deconstruction, demolition
C2	transport
C3	waste processing
C4	disposal
D	reuse, recovery, recycling potential.

Module D, reuse, recovery, recycling potential, is considered to be outside the scope of a common LCA analysis, but it is a mandatory module for construction material EPDs. Modules A1–3 deal with emissions from raw material production, the transport of raw material to the product manufacturing site, and the manufacturing of the product. Modules A4–5 deal with the product’s transportation to the installation site and the installation process. Module B covers the operational or usage time of the product, and module C is the end-of-life stage. [3, p.21.]

2.2 Environmental Product Declaration

An Environmental Product Declaration is a voluntary document for building materials which presents the environmental effects of the building material during its entire life cycle. Verified EPDs are becoming the industry standard in selecting energy-saving and low-carbon building products for new buildings and renovating older ones. [4.]

EN standard 15804 provides the guidelines and rules for EPDs. In Finland, the Building Information Foundation RTS maintains a database for EPDs. There are currently no EPDs in their database for HVAC products. [4.]

3 Environmental Impacts

Most HVAC fittings are produced in a similar process as ball valves and have a similar environmental impact. This thesis focuses on ball valves with the main focus on Broen valves. The common LCA modules (see chapter 2.1) covered in this thesis are A1–4, B6, C1–4, and D. The module A5 and most modules in stage B are not applicable to ball valves as they are usually maintenance free for at least a 25-year lifespan, and a ball valve in a heating system does not consume water in itself. Installing a ball valve uses little to no energy.

3.1 Production of Raw Material

The production of the raw material for ball valves uses a lot of energy, and therefore the carbon dioxide emissions depend heavily on the energy production methods. Swerea SWECAST AB's 2016 report on climate impact of metal-casting concludes that the energy mix in the production country of the raw material has a bigger impact on the material's carbon footprint than what material is being melted. According to the report melting brass uses significantly less energy than melting iron or steel, but different energy mixes in different countries have greater role in the overall carbon emissions. Figure 1 shows the differences in carbon emissions from electricity generation in different countries. [5.]

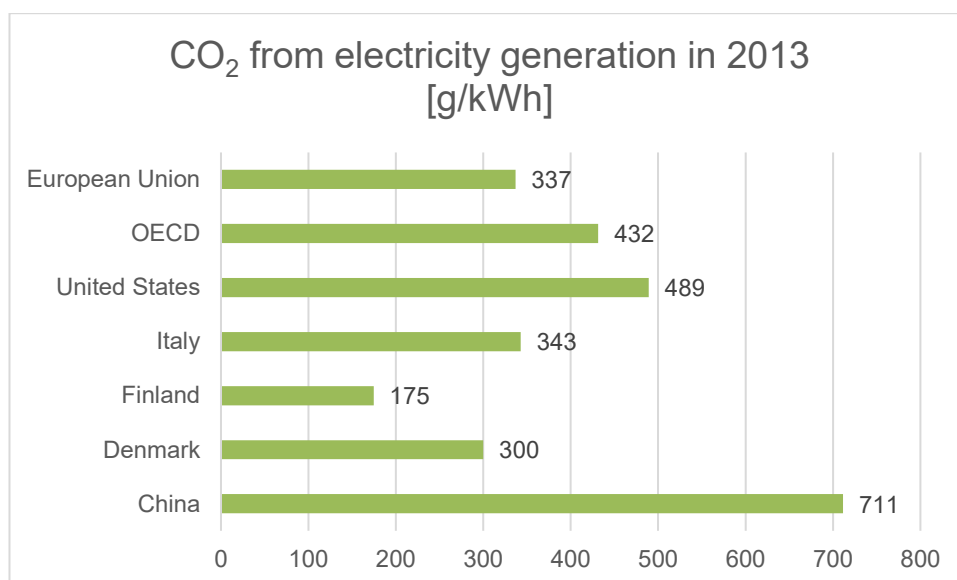


Figure 1. OECD data for electricity generation [6].

According to Supply Chain Specialist Haider Saied from Broen, the carbon footprint of the raw material used in Broen valves on average per one kilogram of finished product is

- 3.61 kg CO₂e for brass
- 5.58 kg CO₂e for stainless steel
- 2.40 kg CO₂e for structural steel [7].

Different materials can only be compared directly if they are used in the same application, like brass and structural steel in closed heating systems. In this case, if the comparison is purely about raw material use, a Broen structural steel valve is a greener choice than a Broen brass valve. Although producing brass uses a lot less energy than producing structural steel, a bigger percentage of the raw material is scrapped in the production of brass than in the production of structural steel. [7.]

3.2 Production of Fittings

A major part of the carbon footprint of a building product comes from its production. For most HVAC fittings the environmental impacts in the production phase include

- transportation of raw material to the production site
- raw material used
- machining
- recycling scrapped material
- transportation of parts to the assembly location
- assembling the product
- surface treatment of the product
- packaging the product. [7.]

For ball valves, the first five steps in the list above apply to each part of the finished product. The production of a Broen Ballofix brass valve body starts with the transportation of the raw material, or brass rods, to the production site, and scrapped material is then transported back to the supplier for recycling after machining. Similar steps are taken in the production of other parts of a Ballofix: the ball, retainer rings, O-rings, spindle, screw, and handle. [7.]

The production of the fittings is also an energy-consuming process, and the differences between energy mixes in the manufacturing countries have a major role in the carbon footprint of the finished product [5, p.5]. The Nordics in general use a lot of nuclear and renewable energy, so their carbon footprint in valve production is significantly smaller than that in competing countries like China (figure 1). [7.]

The average carbon footprint per one kilogram of finished product in the production of Broen valves is

- 0.37 kg CO₂e for brass
- 1.45 kg CO₂e for stainless steel
- 1.53 kg CO₂e for structural steel [7].

It is the relatively small amount of energy required for machining brass that makes producing brass valves the most environmentally friendly option of the three listed above [7].

3.3 Transportation of Fittings to Installation Site

The carbon footprint of the transportation of a single fitting is small, especially in the final leg of the journey from a wholesaler warehouse to the installation site. Since the different products are being transported in a similar fashion, there are no differences in this phase. Like any industrially manufactured product, HVAC fittings are manufactured in different locations and transported elsewhere. Therefore, the focus should be on the transportation of the fittings from the manufacturing site to the wholesaler

warehouse. This thesis focuses on Denmark, Italy, and China as the manufacturing locations, and Hyvinkää as the wholesaler warehouse location.

VTT, the Technical Research Centre of Finland has compiled the LIPASTO service for emissions of transportation. This service is used to calculate the carbon footprint of transporting the fittings from the manufacturing site to the wholesaler warehouse. The carbon emissions (g CO₂e) per 1 kg of freight used for the calculations are

- Road transport: fully loaded 25-ton semi-trailer: 0.038 g/km
- Baltic Sea transportation: roro 200 trailer capacity: 0.143 g/km
- Ocean shipping: container ship 2000 TEU: 0.028 g/km. [8.]

3.3.1 Manufacturing Locations

To reach the Hyvinkää warehouse, Broen valves are transported on trailers from Assens, Denmark to Kapellskär, Sweden (900 km), shipped on a ferry to Naantali (130 nautical miles or 240 kilometers), and on a trailer to Hyvinkää (200 km) [7]. The distance of the Baltic Sea transportation is less than 20 percent of the total distance, but it makes up for almost half of the carbon emissions of the transportation from Denmark. The carbon emissions of each leg of the transportation of fittings from Denmark calculated in this final year project are listed in table 1. Total emissions are 0.0761 kg CO₂e/kg, or 76.1 g CO₂e/kg.

Table 1. Carbon emissions of transportation from Denmark.

Denmark	leg	km	CO ₂ e (kg/kgkm)	CO ₂ e (kg/kg)
road	1	900	0.000038	0.0342
ferry	2	240	0.000143	0.0343
road	3	200	0.000038	0.0076
total emissions				0.0761

There are several HVAC manufacturing companies in Northern Italy, Milan with surroundings. Thus, Milan is used as an alternative point of departure for Assens in this thesis. Because a lot of freight from Central and Southern Europe is transported to Finland via the Travemünde port, it is used as a waypoint. From Milan, the goods to the Hyvinkää warehouse are transported on trailers to Travemünde, Germany (1,200 km), shipped on a ferry to Helsinki (750 nm or 1,400 km), and transported on trailers to Hyvinkää (70 km). According to the calculations in the final year project, the ferry ride from Germany to Finland causes about 80 % of the carbon emissions of the transportation from Italy to Finland. The carbon emissions caused by the transportation of the fittings from Italy are listed in table 2. The total emissions for this route are 0.2485 kg CO₂e/kg, or 248.5 g CO₂e/kg.

Table 2. Carbon emissions of transportation from Italy.

Italy	leg	km	CO ₂ e (kg/kgkm)	CO ₂ e (kg/kg)
road	1	1,200	0.000038	0.0456
ferry	2	1,400	0.000143	0.2002
road	3	70	0.000038	0.0027
total emissions				0.2485

Most freight from China is shipped from Shanghai on container ships to European cargo ports like Rotterdam or Hamburg. In this thesis, an estimate of 500 km is accounted for the road transport in China to the Port of Shanghai to demonstrate the scale of the carbon emissions on the first leg of the journey. The sea route from Shanghai to Hamburg is approximately 12,300 nm or 22,800 km. In the calculations of this thesis, the containers are transported on trailers to Travemünde (50 km), shipped to the Vuosaari port in Helsinki (750 nm or 1,400 km), and transported on trailers to the Hyvinkää warehouse (70 km). As can be seen on table 3, the long sea voyage from China to Germany causes three fourths of the carbon emissions of the transportation from China to Finland. The total emissions calculated for this route are 0.8622 kg CO₂e/kg, or 862.2 g CO₂e/kg.

Table 3. Carbon emissions of transportation from China.

China	leg	km	CO ₂ e (kg/kgkm)	CO ₂ e (kg/kg)
road	1	500	0.000038	0.0190
ship	2	22,800	0.000028	0.6384
road	3	50	0.000038	0.0019
ferry	4	1,400	0.000143	0.2002
road	5	70	0.000038	0.0027
total emissions				0.8622

While the carbon emissions for transporting one valve seem insignificant, millions of valves are transported each year. As can be seen from the calculation results, transporting fittings from Italy to Finland causes roughly three times the carbon emissions than transporting them from Denmark. The carbon emissions for transporting fittings from China are greater than the emissions from the machining of the product itself.

3.4 Usage Time

The operation of a ball valve does not use any energy or natural resources in itself. However, when they are used in a closed circulation system, the system will lose energy. The main carbon emissions due to the use of a ball valve in a closed circulation system are caused by pressure and heat loss. The emissions caused by pressure and heat losses are discussed below. [7.]

3.4.1 Pressure Loss

All fittings in a HVAC system cause drop of pressure, or pressure loss, which in general is an unwanted phenomenon. Ball valves are manufactured as full or reduced bore. A reduced bore is one nominal pipe size, or DN (diamètre nominal/nominal diameter) size, smaller than a full-bore valve's bore with the same connection size. A reduced bore causes higher pressure drop across the valve than a full bore with the same flow due to the smaller diameter of the valve bore.

Each valve has its specific K_V value which is the flow coefficient of the valve. The K_V value is defined as the flow rate of water in cubic meters per hour [m^3/h] with a pressure drop of one bar across the valve. If the flow rate and pressure drop across the valve are known, the K_V value can be calculated with the formula:

$$K_V = q_V \sqrt{\frac{\rho}{\Delta p}} \quad (1)$$

where

- q_V is flow rate of water in m^3/h
- ρ is density of water = $1 \text{ kg}/\text{dm}^3$
- Δp is pressure drop across the valve in bars.

From formula (1), if the flow rate and the flow coefficient are known, the pressure drop across the valve can be calculated with the formula:

$$\Delta p = \rho \left(\frac{q_v}{K_v} \right)^2 \quad (2)$$

Pressure loss can also be expressed as hydraulic power, or the amount of energy needed to counter the pressure drop with the formula

$$P = q_v \Delta p \quad (3)$$

where

- P is hydraulic power (W)
- q_v is flow rate of water (m^3/s)
- Δp is pressure drop across the valve (Pa).

The flow rate in the formula (3) is the flow rate of the pump, or the combined flows of the ball valves in the system. When the hydraulic power is multiplied by the overall efficiency of the pump the result is the power consumed by the pump to counter the pressure drop. In the calculations in this thesis, 70 % is used as the overall efficiency of the pump.

The power consumed by the pump multiplied by the hours in a year (8,760 h) results in the amount of electricity used (in watt hours, Wh) to counteract the pressure drop over the course of one year. This amount of electricity can then be multiplied by the carbon emissions of power production per Wh to show the annual environmental impact of the pressure loss of a system. If it is estimated that a ball valve is used for 25 years, the carbon emissions must be multiplied by 25 to get the total carbon emissions of the pressure drop across a ball valve.

In order to compare the environmental impacts of a ball valve, the carbon footprint of the pressure drop across a valve must be comparable to the carbon footprints discussed in chapters 3.1–3.3. Valves in DN sizes 10, 15, 20, 25, 32, 40, and 50 will be used for the calculations. The flow rate for each size will match a pressure drop of 50 Pa/m for the valve's connection sized steel tube. The flow rate for the hydraulic power calculation will be the combined flows of the seven valves. The combined carbon footprint is then divided

by the combined weight of the valves to show the average carbon footprint per one kilogram of valve.

The flow coefficients for the Broen valves can be found in the technical handbook for the Ballofix Full Flow valves [9, p. 10], but the flow coefficients for brass valves are nearly impossible to find. The flow coefficients used for brass valves in this thesis are taken from A-collection ball valves [10].

Table 4. Flow rates and pressure drops for valves.

50 Pa/m			Generic brass valve		
Size	Flow		K _v	Δp (kPa)	m (kg)
DN10	0.021	l/s	5.2	0.0219	0.131
DN15	0.042	l/s	8.3	0.0327	0.205
DN20	0.097	l/s	15.2	0.0530	0.357
DN25	0.175	l/s	24.4	0.0667	0.547
DN32	0.389	l/s	40.3	0.1207	0.841
DN40	0.569	l/s	86.8	0.0558	1.178
DN50	1.125	l/s	122	0.1102	1.715

50 Pa/m			Ballofix Full Flow		
Size	Flow		K _v	Δp (kPa)	m (kg)
DN10	0.021	l/s	13	0.0035	0.240
DN15	0.042	l/s	21.1	0.0051	0.276
DN20	0.097	l/s	37.1	0.0089	0.501
DN25	0.175	l/s	65.5	0.0093	0.696
DN32	0.389	l/s	90.7	0.0238	1.099
DN40	0.569	l/s	141.5	0.0210	1.690
DN50	1.125	l/s	308.4	0.0172	2.850

Table 4 shows the flow rates and the flow coefficients for generic brass ball valves and the Broen Ballofix Full Flow valves. The pressure drops were calculated using the formula (2) above.

3.4.2 Heat Loss

Because the pipes in a heating system have a higher temperature than the surrounding air in a building there will be heat loss in the system. While this heat loss is not necessarily wasted, it is still unwanted in spaces like the building basement where radiators might not have thermostats to keep the space at a steady temperature. In Finland the pipes of heating systems are usually insulated to prevent or minimize heat loss, but valves are in most cases left uninsulated.

The importance of insulating a valve is shown in the thesis using Broen full bore valves as an example. The Broen Full Flow valves are available with a high spindle so they can be insulated with regular pipe insulation sections without a need for specific insulation boxes. This lowers the costs of insulation significantly. Generic brass valves are usually left uninsulated, because the most widely used low-cost brass ball valves are only available with a low spindle and the valve body is bulkier than that of a Broen Full Flow valve. Brass has higher thermal conductivity than steel, but brass valves are shorter, so their heat loss is close to that of the steel valves. Therefore, heat loss calculations are only done for the Broen valves in this thesis. [7.]

Because heat loss depends on both the temperature of the medium in the system, and the temperature of the surrounding air, it is not constant. In the thesis, a primary heating system with design temperature of 70 degrees centigrade for the supply pipe and 40 degrees centigrade for the return pipe, and a supply air heating system with design temperature of 60 degrees centigrade for the supply pipe and 40 degrees centigrade for the return pipe are used as examples for valves sized DN10–50. To simulate real-life supply water temperatures, the long-time (1981–2010) monthly average temperatures for Helsinki-Malmi airport by the Finnish Meteorological Institute are used [11], and together with the control curves for the supply water temperatures (figure 2) in a building for each month. These control curves are typical for most older apartment buildings in Southern Finland.

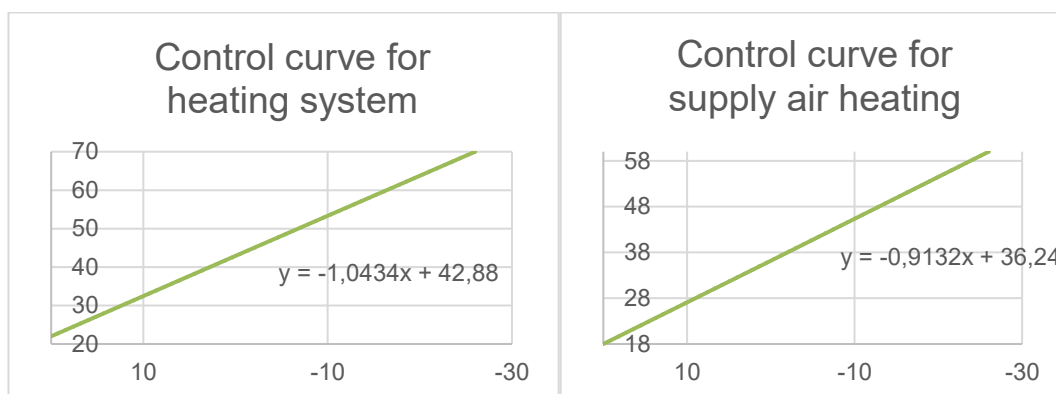


Figure 2. Typical control curves for primary heating and supply air heating systems.

By using the long-time monthly averages in Helsinki and the control curves, the average monthly supply water temperatures for the heating systems can be calculated. The calculated average monthly supply water temperatures for the primary heating system are listed in table 5. When the design supply water temperature for the heating system is 70 degrees centigrade, the monthly averages are between 24 and 50 degrees centigrade.

Table 5. Average supply water temperatures in primary heating system.

Month	Days	Hours	Avg temp.	t_{supply}	t_{room}	Δt
1	31	744	-5,1	48,20	21	27,20
2	28	672	-5,9	49,04	21	28,04
3	31	744	-2,0	44,97	21	23,97
4	30	720	3,9	38,81	21	17,81
5	31	744	10,4	32,03	21	11,03
6	30	720	14,6	27,65	21	6,65
7	31	744	17,5	24,62	21	3,62
8	31	744	15,5	26,71	21	5,71
9	30	720	10,4	32,03	21	11,03
10	31	744	5,4	37,25	21	16,25
11	30	720	0,3	42,57	21	21,57
12	31	744	-3,3	46,32	21	25,32

The calculated average monthly supply water temperatures for the supply air heating system are listed in table 6. When the design supply temperature is 60 degrees centigrade, the calculated monthly average temperatures are between 20 and 42 degrees centigrade.

Table 6. Average supply water temperatures in supply air heating system.

Month	Days	Hours	Avg temp.	t_{supply}	t_{room}	Δt
1	31	744	-5,1	40,90	21	19,90
2	28	672	-5,9	41,63	21	20,63
3	31	744	-2,0	38,07	21	17,07
4	30	720	3,9	32,68	21	11,68
5	31	744	10,4	26,74	21	5,74
6	30	720	14,6	22,91	21	1,91
7	31	744	17,5	20,26	21	-0,74
8	31	744	15,5	22,09	21	1,09
9	30	720	10,4	26,74	21	5,74
10	31	744	5,4	31,31	21	10,31
11	30	720	0,3	35,97	21	14,97
12	31	744	-3,3	39,25	21	18,25

Heat loss is heat flowing through a material and each material has its own specific thermal resistance, or thermal resistivity R in kelvin meters per watt (Km/W). For an uninsulated pipe there are three different thermal resistivities that must be calculated: the inner surface, the pipe material, and the outer surface. The thermal resistivity of the inner surface is calculated with the formula

$$R_i = \frac{1}{\alpha_{is}\pi d_i} \quad (4)$$

where

- R_i is thermal resistivity of the inner surface (Km/W)
- α_{is} is heat transfer coefficient for the inner surface (W/m²K)
- d_i is inner diameter of the pipe (m).

The result from formula (4) is the pipe's inner surface's ability to resist the flow of heat through it. The heat transfer coefficient is different for insulated and uninsulated pipes, but the thermal resistivity of the outer surface is calculated for both with the formula

$$R_o = \frac{1}{\alpha_{os}\pi d_o} \quad (5)$$

where

- R_o is thermal resistivity of the outer surface (Km/W)
 α_{os} is heat transfer coefficient for the outer surface (W/m²K)
 d_o is outer diameter of the pipe or insulation (m).

The pipe material has its own specific thermal conductivity that determines how much heat flows through it. When the inner and outer diameters of the pipe, and the thermal conductivity of the material are known, the thermal resistivity of the pipe can be calculated with the formula

$$R_1 = \frac{1}{2\pi\lambda_p} \times \ln \frac{d_o}{d_i} \quad (6)$$

where

- R_1 is thermal resistivity of the pipe (Km/W)
 λ_p is thermal conductivity of the pipe (W/Km)
 d_i is inner diameter of the pipe (m)
 d_o is outer diameter of the pipe (m).

If the pipe is insulated, the thermal resistivity for the insulation must be calculated with the formula

$$R_2 = \frac{1}{2\pi\lambda_i} \times \ln \frac{D_o}{d_o} \quad (7)$$

where

- R_2 is thermal resistivity of the insulation (Km/W)
 λ_i is thermal conductivity of the insulation (W/Km)

- D_o is outer diameter of the insulation (m)
 d_o is outer diameter of the pipe (m).

The values used for the constants α_{is} , α_{os} , λ_i , and λ_p in this thesis are

- $\alpha_{is} = 2,500 \text{ W/Km}$
- $\alpha_{os} = 8 \text{ W/Km}^2$ for insulated pipe, 14 W/Km^2 for uninsulated pipe
- $\lambda_i = 0.037 \text{ W/Km}$
- $\lambda_p = 45 \text{ W/Km}$.

The sum of these three or four resulting R-values is the total thermal resistivity of the pipe

$$\sum R = R_i + R_1(+R_2) + R_o \quad (8)$$

The reciprocal of the thermal resistivity of the pipe is the thermal transmittance of the pipe per meter (watts per kelvin meters). Thermal transmittance is often referred to as U-value and its SI unit is watts per meter squared kelvin. This is not a useful unit for pipes which are measured rather in length than area. The thermal transmittance per meter is referred to as the U'-value. Multiplying the U'-value by the temperature differential of the medium and the surrounding air gives the heat loss in watts per meter.

To simplify the calculations, union fittings are not used on either side of the valve. Due to the possible leaks and for maintenance purposes, the union fitting is left uninsulated and taking it into account here would serve no purpose. The length of uninsulated pipe before and after a valve is estimated to be

- 20 mm for DN10–20
- 25 mm for DN25–32
- 30 mm for DN40–50.

The heat loss for an uninsulated valve consists of three sections: the uninsulated pipe before the valve, the valve, and the uninsulated pipe after the valve. For an insulated valve R_2 value will be added. 40 mm will be used as the thickness of the insulation.

Multiplying the calculated heat loss in watts by the number of hours in each month gives the heat loss in Wh per month. The sum of the results gives the annual heat loss. These results can then be converted to the carbon footprint of heat loss with the Finnish average carbon emissions for district heating per Wh.

To get the total carbon emissions of the heat loss of a valve, the carbon emissions must be multiplied by the estimated 25 years of use in the same way as for pressure drop.

While the valve spindle and handle contribute to heat loss as well, the calculations for them are more complex and would only have a small effect on the results, so they are left out. The valve body is not a straight cylinder with a consistent thickness, but the calculations for the valve body part are simplified as well, and the outer diameter is an estimated average for the length of the valve body.

3.5 End-of-life Recycling of Fittings

Different ball valves are constructed in a similar way and they use similar parts, so it is easy to compare their recycling. The average carbon footprint for the end-of-life recycling of Broen valves is

- 0.98 kg CO₂e/kg for brass
- 1.30 kg CO₂e/kg for stainless steel
- 0.58 kg CO₂e/kg for structural steel [7].

As seen of the list above, structural steel has the smallest recycling carbon footprint; therefore, it is the most environmentally friendly option in this respect when comparing per kilogram of material. It should be noted that, with the same connection sizes, brass valves are usually lighter than structural steel valves, so a comparison of single valves would yield different results.

4 Comparison of Different Valves

An apartment building (figure 3) is used in the thesis to demonstrate the carbon footprint of the ball valves of the heating systems in a building. The building is in the Tapuli-kaupunki area of Helsinki, Finland, built in 1981. There are 30 apartments and four business spaces in the building. The business spaces have supply air heating in their ventilation systems.



Figure 3. The sample building.

The valves discussed in the thesis are on the supply pipes for branches where balancing valves are installed on the return pipes. In the building, there are 19 such ball valves in the heating system and six in the supply air heating system. The flow for the pump in the primary heating system is 1.1 l/s, and 1.9 l/s in the supply air heating system. (appendix 1.)

4.1 Broen Valves

The Broen valves used in the calculations in the thesis are the new Ballofix Full Flow valves with threaded and press connections, both in DN10–50. Both versions use the same patented valve design, and are manufactured in Assens, Denmark. Broen Ballofix Full Flow valves come in sizes DN10–50 and the connection options are threaded, swivel nut, press connection, and combinations of these (figure 4). The Ballofix Full Flow valves have a pressure class of PN16. [9.]



Figure 4. Selection of Broen Ballofix Full Flow valves [12].

Broen Ballofix Full Flow valves are manufactured with a high or a low spindle depending on whether the valve is to be insulated or not. Ballofix Full Flow valves are manufactured in two different materials: electrogalvanized pressure vessel grade steel, and stainless steel. [9.]

4.2 Valve Materials and Production

According to Haider Saied, the carbon footprint of the raw material used per one kilogram of Broen valves produced is

- 3.61 kg CO₂e for brass
- 2.40 kg CO₂e for structural steel [7].

Comparing these figures directly gives the generic brass valve an unfair advantage, because the carbon footprint for brass in the Broen valves is extremely low. The reason for this is that the brass used in Broen brass valves comes from Sweden, and the carbon emissions per one kWh of electricity in Sweden is 13 g, whereas, for example, in China the emissions are 711 g/kWh, more than 50 times as much [6]. Melting one kilogram of brass uses 0.3 kWh of energy [5, p. 5] and for one kilogram of valve five kilograms of raw material is used [7]. Thus, it is safe to assume that the carbon footprint of a Chinese brass valve is at least 1.05 kg more than that of a Broen brass valve. The Chinese brass valve has a carbon footprint of at least 4.66 kg CO₂e for raw material per one kilogram of valves.

The carbon footprint of the valve production of Broen valves per one kilogram of finished product is

- 0.37 kg CO₂e for brass
- 1.53 kg CO₂e for structural steel [7].

The carbon footprint of the valve production comes from the energy use in the machining and assembly processes. The difference in the carbon footprints of electricity generation in Denmark (300 g/kWh) and China (711 g/kWh) is 411 g/kWh [6]. Thus, the carbon footprint of producing brass valves in China is 0.88 kg CO₂e/kg.

The carbon footprint of the finished product, the ball valve, before it leaves the factory is the sum of the carbon footprints of the raw material used, and of the valve production. The carbon emissions for the ball valve options in the primary heating and supply air heating systems of the sample building are in table 7.

Table 7. Carbon emissions of valves in sample building.

	Primary heating system	Supply air heating	Total carbon emissions	
Generic brass valves	28.5	22.6	51.1	kg CO ₂ e
Ballofix Full Flow threaded	28.2	21.2	49.4	kg CO ₂ e
Ballofix Full Flow press	17.3	15.2	32.5	kg CO ₂ e

In the heating systems of the sample building, the Broen Ballofix Full Flow valves are the most sustainable solution, and in the whole building the difference between the press version of the Ballofix Full Flow valves and generic brass valves is 18.6 kg CO₂e.

4.3 Manufacturing Locations

The location where a ball valve is manufactured has a major impact on its carbon footprint. The carbon emissions for transporting ball valves to Hyvinkää, Finland is 76 g/kg from Denmark, and 862 g/kg from China. The carbon emissions for the different valve options in the building used as an example in this thesis are

- 8.0 kg CO₂e for generic brass valves
- 1.0 kg CO₂e for Ballofix Full Flow threaded valves
- 0.6 kg CO₂e for Ballofix Full Flow press valves.

The difference between the Broen Ballofix Full Flow press version and generic brass valve is 7.4 kg CO₂e.

4.4 Usage Time

Because the variables for the calculations are unique to each building and no manufacturer is able to provide universal results, the calculations for the carbon footprint of the use of the valves are only relevant to that particular case. To get comparable results for

different valve options, the carbon emissions from pressure and heat losses have to be calculated using the same reference building for all of the valve options.

4.4.1 Pressure Loss

The calculated pressure losses in the ball valves of the sample building in primary heating and supply air heating are in table 8.

Table 8. Pressure losses of valves in sample building.

	Primary heating system	Supply air heating	Total pressure loss	
Generic brass valves	623.1	822.5	1445.6	Pa
Ballofix Full Flow valves	98.2	154.0	252.2	Pa

The calculations for converting the total pressure loss to the amount of electricity used to counter the pressure loss are explained in chapter 3.4.1. The amount of electricity needed to counter the pressure loss is

- 3.18 W for generic brass valves
- 0.56 W for Ballofix Full Flow valves.

Using the average emission factor for electricity generation in Finland (141 g CO_{2e}/kWh) from Motiva [13] in the calculations, the annual carbon emissions caused by the pressure loss of different valve options are listed in table 9.

Table 9. Carbon emissions from pressure loss per one kilogram of valves.

	1 year	25 years	
Generic brass valves	0.426	10.7	kg CO _{2e} /kg
Ballofix Full Flow threaded	0.056	1.4	kg CO _{2e} /kg
Ballofix Full Flow press	0.085	2.1	kg CO _{2e} /kg

The threaded version of the Ballofix Full Flow valve has the smallest emissions per kilogram of valve because it is significantly heavier than the two other options. The emissions per valve are the same as those of the press version of the valve.

For the 25-year usage life of the valves, the carbon emissions from the pressure loss in the ball valves of the sample building are

- 98.3 kg CO₂e for generic brass valves
- 17.5 kg CO₂e for Ballofix Full Flow valves.

This shows how big an impact the bore size has on the carbon footprint of a valve.

4.4.2 Heat Loss

Not enough reliable data could be found for the outer diameters of generic brass valves, and because the heat loss for an uninsulated brass valve is close to that of a structural steel valve (see chapter 3.4.2), only calculations for the Broen valves were made. To compare different valve types, the results for uninsulated threaded version of the Ballofix Full Flow valve was used for generic brass valves. Threaded and press versions of the Ballofix Full Flow valve were compared to establish how big the difference between them is. The inner diameters of the threadable pipes and the galvanized pipes for the press fittings are almost the same, but the outer diameters are different. This influences the heat loss through the pipe section that is left uninsulated. The measurements used in the calculations for the valves, insulation thickness, and uninsulated pipe sections are listed in table 10.

Table 10. Valve and pipe measurements in millimeters.

Ballofix Full Flow threaded

s	DN	L _{valve}	L _{pipe}	d _{valve,outer}	d _{valve,inner}	d _{pipe,outer}	d _{pipe,inner}
40	10	88	40	27.0	16.7	17.2	12.5
40	15	94	40	30.0	21.0	21.3	16.1
40	20	104	40	40.0	26.4	26.9	21.7
40	25	112	50	45.0	33.3	33.7	27.3
40	32	140	50	55.0	41.9	42.4	35.9
40	40	156	60	59.3	47.8	48.3	40.2
40	50	192	60	76.1	59.6	60.3	51.3

Ballofix Full Flow press

s	DN	L _{valve}	L _{pipe}	d _{valve,outer}	d _{valve,inner}	d _{pipe,outer}	d _{pipe,inner}
40	10	54	80	23	15	15	12.6
40	15	64	80	27	18	18	15.6
40	20	80	80	32	22	22	19.0
40	25	96	100	38	28	28	25.0
40	32	120	100	45	35	35	32.0
40	40	158	120	54	42	42	39.0
40	50	186	120	65	54	54	51.0

The data for the supply water temperature in the primary heating system of the sample building was used to calculate the carbon emissions for the annual heat loss in kWh for each valve size (table 11).

Table 11. Heat loss in kWh per year.

Size	Uninsulated			Insulated	
	generic brass	Ballofix threaded	Ballofix press	Ballofix threaded	Ballofix press
DN10	19.21	19.21	15.34	3.99	3.56
DN15	23.05	23.05	19.90	4.54	4.26
DN20	32.83	32.83	27.13	5.85	5.37
DN25	42.22	42.22	40.52	7.21	7.46
DN32	61.65	61.65	55.94	9.87	9.62
DN40	76.31	76.31	85.29	11.94	13.87
DN50	114.40	114.40	116.75	16.82	17.89

These results translate to carbon emissions (table 12) with the average carbon emissions for district heating production in Finland from Motiva (154 g CO₂e/kWh) [13]. The Ballofix Full Flow press valve has the smallest carbon footprint in sizes DN10–32. In sizes DN40 and DN50 the generic brass valve and the threaded version of the Ballofix Full Flow valve have smaller carbon footprints than the Ballofix Full Flow press valve.

Table 12. Carbon emissions for heat loss per year (kg CO₂e).

Size	Uninsulated			Insulated	
	generic brass	Ballofix threaded	Ballofix press	Ballofix threaded	Ballofix press
DN10	2.96	2.96	2.36	0.61	0.55
DN15	3.55	3.55	3.06	0.70	0.66
DN20	5.06	5.06	4.18	0.90	0.83
DN25	6.50	6.50	6.24	1.11	1.15
DN32	9.49	9.49	8.62	1.52	1.48
DN40	11.75	11.75	13.13	1.84	2.14
DN50	17.62	17.62	17.98	2.59	2.76

Dividing the results for heat loss per year with the weight of each valve shows the carbon emissions for heat loss per one kilogram of valve. The average carbon emissions from heat loss are listed in table 13.

Table 13. Average carbon emissions from heat loss of valves.

	Uninsulated		
	1 year	25 years	
Generic brass valves	13.9	348.2	kg CO ₂ e/kg
Ballofix Full Flow threaded valves	9.5	237.1	kg CO ₂ e/kg
Ballofix Full Flow press valves	12.2	304.3	kg CO ₂ e/kg
	Insulated		
	1 year	25 years	
Ballofix Full Flow threaded valves	1.7	42.4	kg CO ₂ e/kg
Ballofix Full Flow press valves	2.4	58.8	kg CO ₂ e/kg

For the sample building, calculations for the primary heating and the supply air heating systems were made and the results were used to get comparable results for valves in general. Table 14 lists the carbon emissions caused by heat loss for the valves in the primary heating and the supply air heating systems of the sample building.

Table 14. Carbon emissions from heat loss in sample building.

Uninsulated			
	1 year	25 years	
Generic brass valves	110.4	2760.0	kg CO ₂ e
Ballofix Full Flow threaded valves	110.4	2760.0	kg CO ₂ e
Ballofix Full Flow press valves	95.1	2377.5	kg CO ₂ e
Insulated			
	1 year	25 years	
Ballofix Full Flow threaded valves	20.0	500.0	kg CO ₂ e
Ballofix Full Flow press valves	18.8	470.0	kg CO ₂ e

The difference between uninsulated generic brass valves and insulated Ballofix Full Flow threaded valves is 90.4 kg CO₂e per year, and 2,260 kg CO₂e in 25 years. As explained in chapter 3.4.2, not all of the heat loss from the ball valves goes to waste. In this thesis, it was estimated that 50 percent of the heat loss from ball valves goes to waste. The carbon emissions from heat loss still cause the biggest environmental impact during the lifecycle of a ball valve.

4.5 End-of-life Recycling

The end-of-life recycling of a valve is an energy consuming process. The data from Broen was used for the end-of-life recycling in this thesis, because reliable data for scrapping metals in Finland could not be found. Because the average carbon emissions for electricity generation in Finland are smaller than those in Denmark, the results would probably be lower. The carbon emissions caused by the end-of-life recycling are 0.98 kg CO₂e/kg for brass valves and 0.58 kg CO₂e/kg for structural steel valves in Denmark.

The carbon emissions for the ball valves in the primary heating and supply air heating systems of the sample building were also calculated. The carbon emissions caused by the recycling of the generic brass valves would be 9.0 kg CO_{2e}. The carbon emissions caused by the recycling of the threaded version of the Ballofix Full Flow valves would be 7.3 kg CO_{2e} and 4.8 kg CO_{2e} for the press versions of the Ballofix Full Flow valve.

4.6 Total Carbon Emissions

The total carbon emissions for the ball valves in the heating systems of the sample building comprise the emissions for raw material, valve production, transportation, pressure and heat loss, as well as the end-of-life recycling of the valves. The total carbon emissions of the valves in the sample building are listed in table 15.

Table 15. Total carbon emissions in sample building.

	uninsulated	insulated	
Generic brass valves	1550	-	kg CO _{2e}
Ballofix Full Flow threaded valves	1460	330	kg CO _{2e}
Ballofix Full Flow press valves	1240	290	kg CO _{2e}

The difference between insulated press versions of the Ballofix Full Flow valve and uninsulated generic brass valves is 1,260 kg CO_{2e} over the 25-year usage life of the ball valves. If the heating systems are poorly balanced and, for example, radiator valves are set to design settings rather than to keep the room temperature at a desired level, the difference would probably be a lot bigger.

Table 16. Environmental impacts (kg CO_{2e}/kg).

	Valve material	Valve production	Transport	Pressure loss ^(*)	Heat loss ^(**)	End-of-life	Total emissions
Generic brass threaded	4.7	0.9	0.9	10.6	174.1	1.0	192.1
Generic brass press	4.7	0.9	0.9	10.6	203.0	1.0	221.0
Ballofix Full Flow threaded	2.4	1.5	0.1	1.4	21.2	0.6	27.2
Ballofix Full Flow press	2.4	1.5	0.1	2.1	29.4	0.6	36.1

^(*) 25-year usage life

^(**) 50% of the total heat loss

Table 16 lists the total carbon emissions of the different ball valves studied in this thesis. The calculations in the thesis showed that the total carbon emissions from generic brass ball valves are more than six times those of the Ballofix Full Flow valves. The only stage in the lifecycle of a ball valve where a generic brass valve causes smaller carbon emissions is the production of the valve.

5 Financial Impacts

The financial costs caused by pressure and heat losses are caused by the cost of the electricity that is used for pumping to counter the pressure loss across the ball valves, and by district heat that is consumed to counter the heat loss from the ball valves of the system. The current energy price used in the thesis for electricity is 0.15 €/kWh and 0.06 €/kWh for district heating.

The prices of electricity and district heat are not constant and the average fluctuation of the prices was accounted for. According to the Energy Authority of Finland, the average increase in consumer prices of electricity is 1.1 % per year [14], and according to Finnish Energy, a branch organization for the Finnish energy industries, the average increase in consumer prices of district heat is 3 % per year [15].

The energy costs will be paid in intervals during the 25-year usage life of the ball valves. Therefore, inflation and interest must be accounted for. The value of money changes over time, and the average inflation rate of consumer prices in the EU between 2015 and 2020 was used [16]. The average inflation rate used in the thesis was 1.12 %. If the money used for the energy costs could have been saved or invested instead, there would be interest paid to the investment. Interest rates in the early 2000's have been exceptionally low, so the interest rate used in the calculations in this thesis is 1 %. Thus, the interest rate in the calculations is -0.12 %. [17.]

Discounted cash flow analysis method was used to calculate the net present values for the financial impacts. The cost of energy on the n^{th} year (number of years after present day) is calculated using the formula:

$$E_n = E_p(1 + e)^n \quad (9)$$

where

E_n	is energy cost on n^{th} year
E_p	is present energy cost
e	is average energy price increase per year [%]
n	is number of years after present day. [17.]

This energy cost is then discounted to net present value:

$$DPV_n = \frac{E_n}{(1+r)^n} \quad (10)$$

where

E_n	is energy cost on n^{th} year
n	is number of years after present day
DPV_n	is discounted present value for energy cost on n^{th} year
r	is interest or discount rate. [17.]

The energy costs for pressure loss were used in their entirety, but, as explained in chapter 3.4.2, not all the energy used to counter heat loss goes to waste, so only 50 % of the energy costs for heat loss were used in the calculations. The discounted present values for each year are summed and the result is the net present value. 25 years was used as usage time in the calculations. In reality the valves would be used for 30 or 35 years, so the costs for pressure and heat losses would in many cases be significantly higher.

5.1 Valve Prices

An online store was used to find out the prices of the generic brass valves and the press couplings for the valves [18]. The cheapest alternatives were chosen for the calculations in the thesis. The Ballofix Full Flow valves prices used in the calculations in the thesis were for versions with a high spindle and an estimated discount level for small to medium businesses. The low spindle versions are considerably cheaper, especially in smaller sizes, but for the sake of the comparison of an energy efficient choice, the pricing is for the more expensive versions.

The cheapest option when looking only at the purchase price is the generic brass valve with threaded connections. In a press system the Ballofix Full Flow valve is slightly cheaper than a generic brass valve due to the added cost of press couplings for the brass valve. The purchase prices for the different options for the sample building in the thesis are in table 17.

Table 17. Purchase prices of different valve options.

	threaded	press	
Generic brass valves	235	578	€
Ballofix Full Flow valves	651	531	€

There is a significant price difference for threaded valves but it can be diminished if union fittings are used with each ball valve. There are also versions of Ballofix Full Flow valves with a swivel nut where only a male thread coupling is needed to replace a separate union fitting.

5.2 Installation and Insulation

The installation time for generic brass valves and for the threaded version of the Ballofix Full Flow valves is the same, but in a press system the installation of a generic brass valve takes more time per valve when all the extra work of adding the press couplings and handling the extra fittings is included. Five minutes was used as the extra time in the calculations in the thesis. This longer time increases the installation costs with 83 euros in the sample building if the cost is calculated using 40 euros per hour as the wage cost of the installer.

The material costs for insulating a valve with the same pipe sections and PVC foil as the pipe compared to cutting the insulation right before the valve and adding an aluminum end cap are roughly the same. For the calculations in the thesis, it was estimated that cutting the insulation and the foil and installing the end caps takes two minutes more time than insulating the valve. That amounts to 33 euros in the sample building.

The normal average installation and insulation costs were left out of the calculations, because they are the same for each option, and the goal of these calculations was to find if there are any noticeable differences between the different valve options.

5.3 Pressure Loss

The amount of electricity used to counter the pressure drop across the ball valves in the heating systems of the sample building per year, and the cost of electricity caused by pressure loss over the 25-year use of the valves are listed in table 18.

Table 18. Financial impact of pressure loss.

	kWh/a	€/25 a
Generic brass valves	27.9	123
Ballofix Full Flow valves	5.0	22

While the calculated costs are small, the difference is 4 euros per valve in the sample building. This should be taken into consideration when determining which valve is the cheapest choice in the construction phase of a building.

5.4 Heat Loss

The amounts of district heating energy wasted annually due to heat loss in the sample building are listed in table 19. If the ball valves are not insulated, the generic brass valve is the most sustainable option in systems using threadable steel pipes. If the ball valves are insulated, the Ballofix Full Flow valves are the better option.

Table 19. District energy used to counter heat loss.

Uninsulated			
	threaded	press	
Generic brass valves	359	411	kWh
Ballofix Full Flow valves	359	309	kWh
Insulated			
	threaded	press	
Generic brass valves	359	411	kWh
Ballofix Full Flow	65	61	kWh

The financial impact of heat loss for different valve options in the sample building over the 25-year usage time were calculated using the formulas (9) and (10). The results are listed in table 20.

Table 20. Financial impacts of heat loss.

Uninsulated			
	threaded	press	
Generic brass valves	822	942	€
Ballofix Full Flow	822	708	€
Insulated			
	threaded	press	
Generic brass valves	822	942	€
Ballofix Full Flow	149	140	€

By choosing Ballofix Full Flow valves and insulating them, the savings over 25 years are 673 euros using threaded connections, and 802 euros in a press system. These translate to 27 and 32 euros per valve for the sample building.

5.5 Total Financial Impacts

The total financial impacts of the different valve options, shown in table in the reference building consist of the material costs, installation and insulation costs, and costs for pressure and heat losses. The total financial impacts of the different valve options are listed in table 21.

Table 21. Financial impacts of different valve options.

	Threaded	
	Generic brass valve	Ballofix Full Flow valve
Valves	235	651
Insulation	33	-
Pressure loss	123	22
Heat loss	822	149
	1,213 €	822 €
	Press	
	Generic brass valve	Ballofix Full Flow valve
Valves	578	531
Installation	83	-
Insulation	33	-
Pressure loss	123	22
Heat loss	942	140
	1,759 €	693 €

When calculating the costs with a 25-year usage time, the Ballofix Full Flow valve is shown to be cheaper in both threaded connection and press systems. This difference in prices would be even greater with a usage time of 30 or 35 years.

6 Conclusions

The goal of this thesis was to study what, if any, effects the simple choice of ball valves for the heating systems of a building has on the carbon footprint of the building. The results were somewhat expected, but the effect of heat loss came as a surprise. The assumption was that pressure loss has the biggest impact on the carbon footprint of a valve, and while it certainly contributes to it, it is virtually irrelevant when compared to the carbon footprint caused by heat loss. Considering the carbon footprint of the construction phase of an apartment building like the building used as a sample in the thesis, the valve choice might seem insignificant. However, if a carbon-neutral future is sought, the smaller emissions must be looked into as well.

The ball valves are paired with balancing valves on the return pipe, and the emissions for the balancing valves should be recognized as well. The carbon emissions of the balancing valves are likely to be similar to those of the ball valves.

The financial impacts were included in the study because they are often the impacts a building owner cares about. In my experience, the HVAC designer has little interest in ball valves because the installer often chooses a cheaper solution or the kind they have always used. The installer often looks at the financial costs of the construction phase and chooses the lowest costing valves even when they might prove to be more expensive if all costs during installation were accounted for. If the lifecycle costs of valves are calculated, the cheapest solution in the construction phase can be the most expensive solution for the building owner. The environmentally more sustainable solution can be the financially cheaper solution as well for the building owner.

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Appendix 1. List of Ball Valves in Sample Building

Primary heating system:

Branch	Size	Flow	
L1	DN20	0.080	l/s
L2	DN15	0.014	l/s
L3	DN15	0.034	l/s
L4	DN20	0.075	l/s
L5	DN15	0.025	l/s
L6	DN15	0.047	l/s
L7	DN15	0.055	l/s
L8	DN20	0.059	l/s
L9	DN20	0.063	l/s
L10	DN15	0.053	l/s
L11	DN15	0.030	l/s
L12	DN20	0.078	l/s
L13	DN20	0.082	l/s
L14	DN15	0.039	l/s
L15	DN20	0.096	l/s
L16	DN25	0.210	l/s
L17	DN10	0.033	l/s
L18	DN10	0.011	l/s
L19	DN15	0.011	l/s

Supply air heating system:

Branch	Size	Flow	
IV1	DN32	0.360	l/s
IV2	DN32	0.240	l/s
IV3	DN32	0.580	l/s
IV4	DN32	0.390	l/s
IV5	DN20	0.190	l/s
IV6	DN20	0.120	l/s

Primary heating **1.095** **l/s**

Supply air heating **1.880** **l/s**