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Breaking down the energy use into energy applications for Dutch retail buildings

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Acronyms

BAG	Basisregistratie Adressen en Gebouwen
CF	Capacity factor
ECU	Energy check-up
EPA	Energie Prestatie Advies
HP	Heat pump
HW	Hot water
kWh	Kilowatt-hour
LHV	Lower Heating Value (natural gas=31.65 MJ/ m^3)
N	Number of cases
NF	Shops non-food
NG	Natural gas
NTA	Nederlandse Technische Afspraak
PV	Photovoltaic

Preface

This report sprang of the internship of Hanna Jonker at TNO energy transition studies, in context of the master Energy Science at Utrecht University. The work forms part of the TNO project “Verrijking BAG utiliteitsbouw voor energetische vraagstukken”. The aim of this project is to provide energy use data of buildings to the Dutch registration of addresses and buildings (BAG). Using the results of this study, the energy use of retail buildings- split between user related and building related - can be integrated into the BAG, which helps to support energy transition decision making. The author likes to thank INNAX and energy audit companies for the interviews and their useful input. Quality assurance of the report is on the basis of reviews by TNO supervisor (Robin Niessink) and the TNO research department (Marijke Menkveld, Jeffrey Sipma). While several parties shared insights and provided data, final responsibility for this report lies with the author.

1 Introduction

To contribute to the *Paris 1.5 ºC target* it is needed to aim for a climate neutral built environment coming decades. Besides a transition from fossil fuels to renewable energy, it is important to stress the need for increased *energy efficiency.* To make something more *energy efficient* means using less energy to perform the same task or produce the same result. Energy savings causes less demand for fossil fuels, which translates to reduced greenhouse gas emissions, or less demand for renewable energy. To establish effective policy for energy efficiency knowledge on potential savings is needed. To assess energy saving potential it is therefore crucial to gain understanding of the constitutes of energy consumption. An energy consumption breakdown by energy application is used to provide these insights. For example, to indicate the share of electricity consumption that goes to ventilation, or the amount of natural gas (NG) used for space heating. The service sector in the Netherlands is a field where only a limited amount of research is performed on this subject, mostly due to the lack of publicly available and representative data. For the Dutch services sector the most recent research that provides a full energy breakdown with differentiation per building type originates from 2009 (Meijer, 2009). However, by “state of the art” this report is already outdated and urgently needs an update. This report will follow up on this need. Due to time limitations, only one sub-sector within the non-residential sector was investigated in this study.

Goal of this study is to update the energy breakdown of different types of shops. The sector shops was chosen due to its significant share in consumption and floor area within the services sector. In terms of floor area, it is the third largest sector in the non-residential sector, see Figure 1 (CBS, 2022). In this report, first the approach is described, then the reference buildings and sub-sectors are discussed. Then, a literature study is performed to gain insight in building related versus user related energy consumption. The theoretical consumption is analysed. The bottom-up method is proposed, and the results are presented. The research is finalized by validation, discussion and a conclusion.

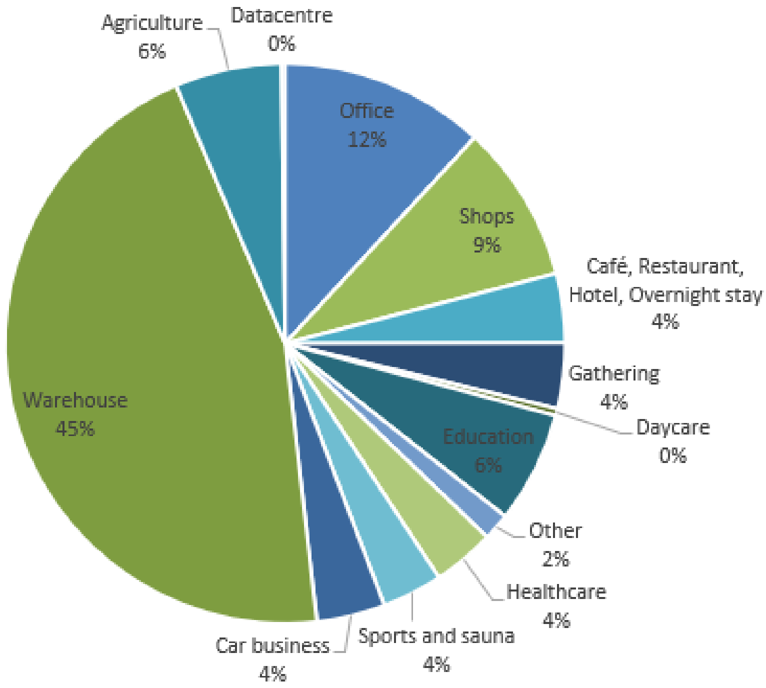


Figure 1. Share of floor area (m^2) in non-residential sector in 2021 (based on CBS, 2022). Non-residential means that buildings in agriculture and industry sectors are included in this picture.

2 Approach

To arrive at the energy consumption per application various steps were performed as shown in Figure 2. First the average energy use per building type was determined. The energy use intensity (EI) defined here represents the energy consumption divided by the floor area of a building. The EI is determined per energy carrier. For example, m^3 natural gas per m^2 floor area, or, for electricity in kWh per m^2. It was needed to first determine the average EI per shop subsector following steps 1 until 4 in Figure 2. Steps 5 until 9 in Figure 2 were taken to approximate the energy consumption per application. The steps and data sources used for this are further described below.

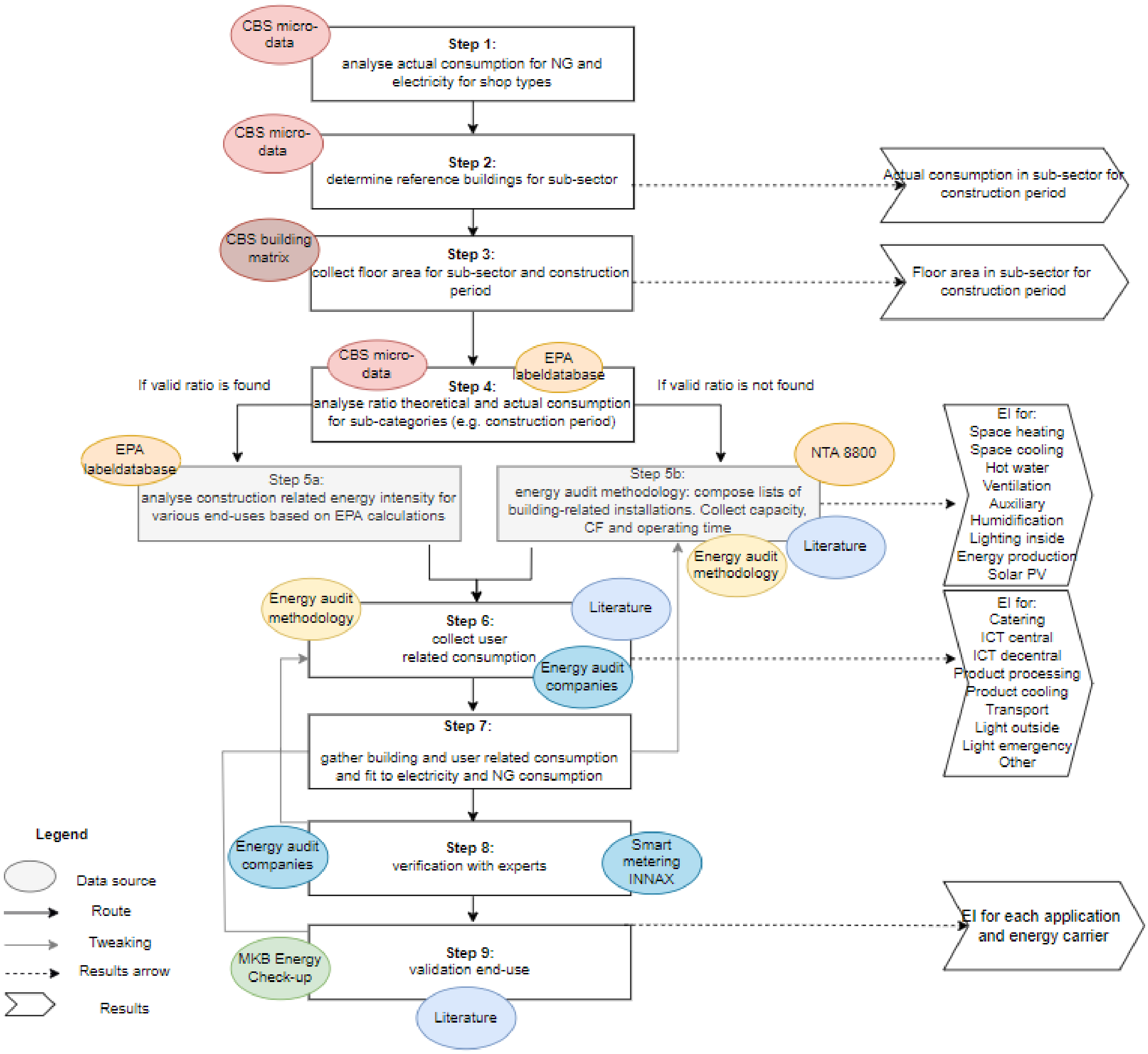


Figure 2. Route to establish sub-sectoral energy consumption by energy application with data sources in ovals

Step 1: The analysis of total electricity and natural gas consumption in the sub-sector. The data was checked for valid datapoints and it was chosen to omit the extreme values (outliers). In this step the CBS microdata on metered energy consumption of shop buildings in the Netherlands was used. The dataset provides annual energy consumption of gas and electricity from 2010 to 2019. The data preparation was performed by Hanna Jonker.

Step 2: Determine reference buildings for each sub-sector. This is based on the energy consumption of the shop types within the shop sector.

Step 3: Collect floor area for sub-sectors and construction periods. Step 1 and 2 combined yield the average energy intensity for shops in the sub-sector.

Step 4: Analyse ratio theoretical and actual consumption for various selections of groups and for the whole sub-sector and construction periods. The theoretical and actual consumption are both available in the CBS microdata and can be compared. An analysis based on literature, can verify the validity of the energy consumption for the end-uses. Research by the Dutch MKB energy check-up (2017) was used in the comparison.

Step 5

Based on own assessment if a valid ratio is found in step 4, either path 5a or b is taken.

5a: When a valid ratio is found, the database of the research by Nuiten (2020) on energy labels will be used. This database was last updated on 12-04-2021. The database consists of results of energy performance calculations (using EPA software), and includes the calculated building related energy consumption per application. This dataset is available through TNO, and consists of more than 31 thousand energy labelled shops in the Netherlands. The dataset also contains the energy performance characteristics of the buildings and the building related installations which are input in the calculation. It only concerns the installations which belong to the building. For instance, mobile ventilators are not included.

5b: If no valid ratio is found in step 4a, the Energy Audit methodology is applied. Based on interviews with energy audit experts, insight in the “usual procedure” of an energy audit is obtained. Energy audit companies estimate the power/capacity, operating time and capacity/load factor of the installed technologies based on an in-house visit and available data. The energy label dataset (see 5a) was analysed to come with assumptions on the type and number of installations for each sub-sector. Based on that, average capacities of the installations are approximated. Using other information sources as shown in Figure 2, the operating time can be approximated. Those are inputs to equation 1.

Equation 1.

$$E = P * t$$

Based on Blok & Nieuwlaar (2017)

E	Energy consumption (kWh/year)
P	Power/Capacity (kW/m^2)
t	Operating time (h/year)

The following building related applications are approximated this way:

- Space heating
- Hot water
- Space cooling
- Ventilation

- Auxiliary equipment
- Humidification
- Lighting inside
- Energy production with solar PV panels.

Step 6: The user-related consumption is determined. The user-related consumption follows from the total energy consumption minus the building related consumption. The user-related consumption can be calculated with equation 2. In this research the energy audit methodology was applied to estimate the consumption per application as in Equation 1. The assumptions for capacities are based on literature, like Freitas (2007), and interviews with energy audit companies.

Equation 2.

$$EI_{user} = EI_{actual} - EI_{building}$$

The following end use categories are distinguished: (aggregation was necessary in case data limitations appeared.)

- Product processing
- Product cooling
- ICT centralized
- ICT decentralized
- Transport
- Light outside
- Light emergency
- Food and drink facility
- Other.

Step 7: In this step the building and user-related consumption are combined and compared to the actual consumption, and tweaked, based on insights from steps 8 and 9. This tweaking is often applied in energy audits, as quick fix to inaccuracies in the method, when data and time are limitedly available (Anonymous1, 2022). During the research, it must be established which side of the consumption should be tweaked, the capacity, the capacity factor (CF) or operating time. Elkhuizen (2022) pointed out that the operating time in the service sector brings along much uncertainty, since it is, among others, strongly depends on the effectiveness of building management.

Step 8: Experts in the field were consulted to establish the final values for energy intensity per end use category and energy carrier for each construction period. For the verification of results, semi structured interviews were held. At least two experts in the field were asked to review the results. Interviewees were selected from the contacts of TNO, they received the results beforehand, and the limitations and uncertainties were discussed during the interviews.

Step 9: In the last step, the results were validated though cross comparison to other sources. To do so INNAX, a smart metering company was approached, energy audit companies were asked for their input, and the previous research by Meijer (2009), and other literature was consulted. Finally, the MKB energy check-up was approached to share insight in the method they use for their energy breakdown.

3 Determining the final energy consumption

In the microdataset of CBS, the energy intensity is presented as the energy consumption over the floor area, per independent unit of use (Dutch: “verblijfsobject” [1]). The most recent data is the energy consumption for 2019. Other data like floor area, construction period is from at the end of 2018.

The mean energy intensity for each category is calculated as the unweighted mean of the sample. This means, that the mean is not weighted for the floor area of objects, which is referred to as the weighted mean. An weighted mean, does result in larger buildings weighting more heavily in the average. Due to the application of reference buildings, the differences between these methods are expected to be marginal. Earlier research by Sipma (2019), discusses both methods and presents the unweighted values for energy intensities, since it enables comparison with other research. Several filters and categorizations have been applied to the CBS microdata as described below.

Filter steps:

1. The CBS itself performs a validation for the gas and electricity consumption. Shops with invalid consumption are excluded from the data. A filter which checks for valid electricity and NG consumption and for electricity consumption only (all-electric) are applied.
2. The district heating consumption is not known by the CBS, therefore, shops attached to a DH network are excluded from the analysis.
3. Select category “shop” as usage function. To exclude other building usage functions such as industrial ones (e.g., cooled warehouse of a supermarket which has a light industrial function).
4. For the figures based on the microdata - unrelated to energy consumption- presented in this report, these are filtered for a valid energy consumption in 2019 (e.g., Figure 8 and Figure 9).

Categories analysed:

1. Shops speciality food, supermarkets and non-food.
2. Reference building small and large
3. Construction period ‘before and including 2010’ and ‘after 2010’
4. New variable: Als/Ag. Heat loss area compared to (total) usable floor area.

[1] Definition in the BAG: “The smallest unit of use located within one or more buildings which is suitable for residential, commercial or recreational purposes, and which is accessed via its own lockable access from the public road, a yard or a shared traffic space. It can be the subject of legal acts under property law and in functional terms.”

Check for normal distribution

See figures 3 and 4. To perform statistical analysis, a normal distribution is often required. The analysis showed a right skewed distribution. The Smirnov normality test did not give normality, for any type of shop and energy source. Adjusting the data with log, cube, square root, did not change this result. Therefore, it needs to be noted that while performing and presenting the results, they are not evenly distributed. However, Glass et al (1972) stated that for larger sample sizes, results can be used without the normality condition.

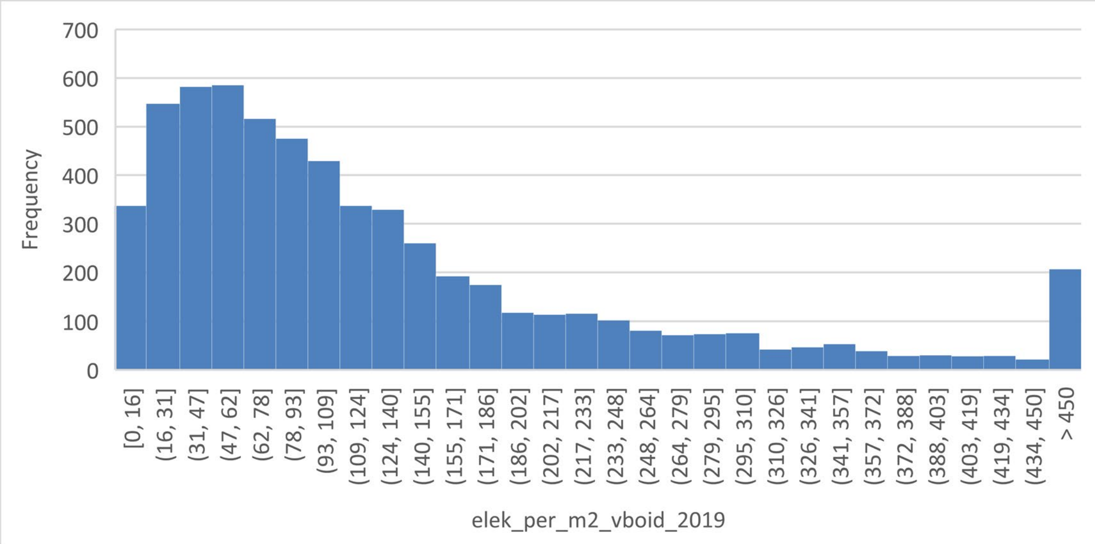


Figure 3. Frequency table of electricity consumption of shops (CBS microdata, 2022)

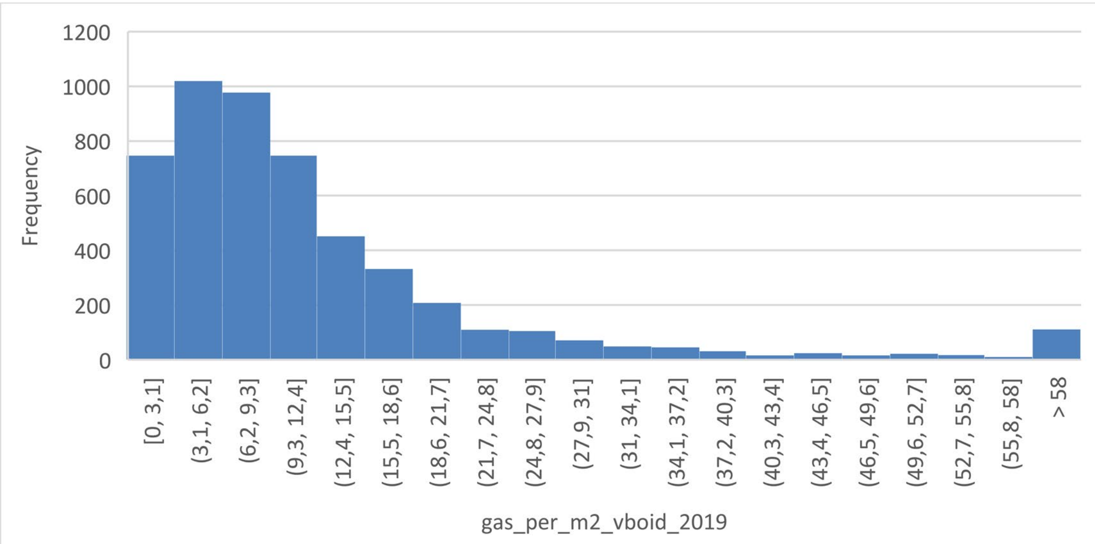


Figure 4. Frequency table of NG consumption of shops (CBS microdata, 2022)

4 Reference buildings

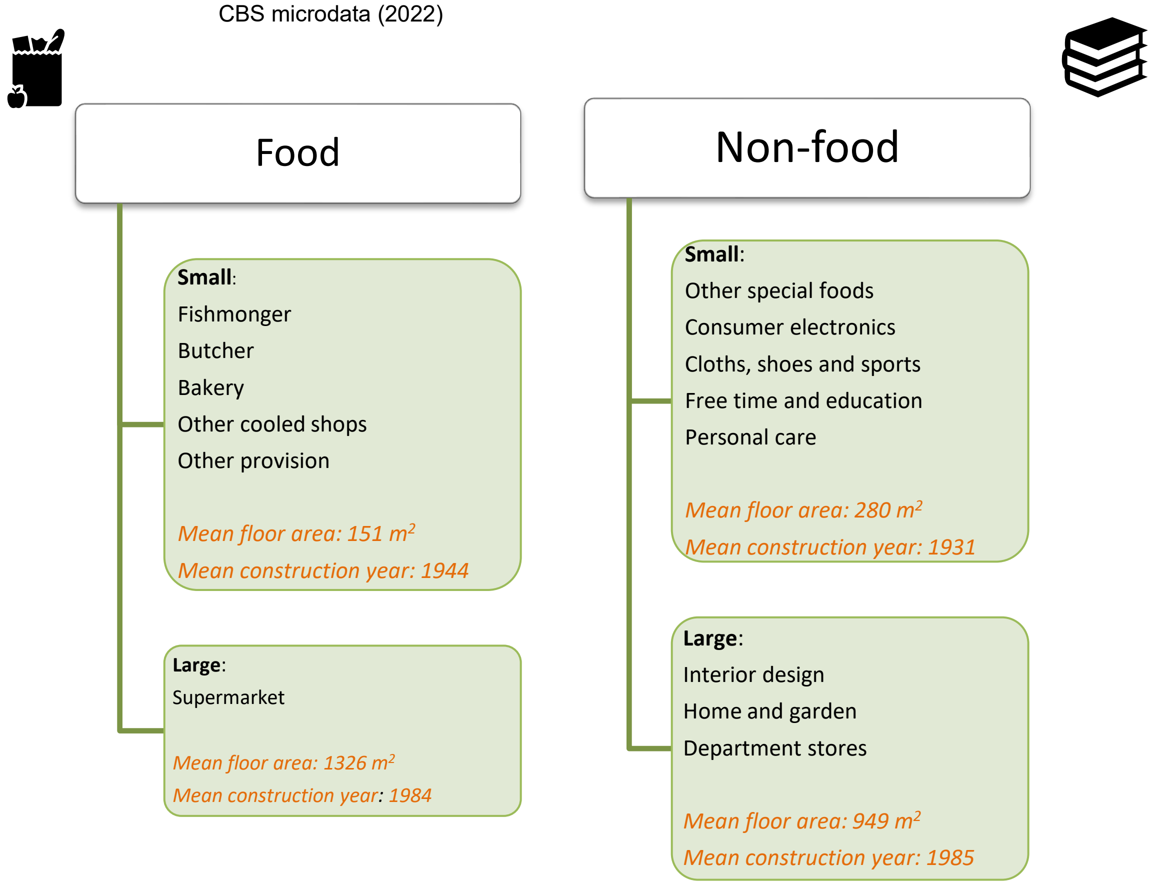
4.1 Determining the reference buildings

Shops are present in various types, sizes and type of commodities. A first distinction can be made between food and non-food shops based on their energy consumption, where food shops have a higher energy intensity due to food preparation and product cooling (refrigeration). Within the category food shops, supermarkets and speciality food shops were analysed independently, due to their differentiating floor area, resulting in incomparable energy intensity. Examples of speciality food shops are bakeries or butchers. A further distinction in reference buildings can be made to account for the difference of number of appliances per shop type. It was chosen to categorize 'small' and 'large' shops, based on the floor area. Dutch shops are commonly located in a type of shopping street, a so called 'outdoor shopping mall' (winkelplint). These are characterized by a street with multiple shops next to each other and apartments on top, see Figure 5. This mostly applies to smaller shops. Larger shops are often detached, like garden or furniture shops, see Figure 6. Therefore, for shops non-food, a small reference building in a mall and a large, detached building are chosen as reference buildings. For supermarkets a large, detached shop is taken as reference building. In Figure 7, the categorization is visualized.

Figure 5. Shop in an outdoor mall (Huispedia, n.d.)

Figure 6. Detached shop (Tuincentrumdenieuwestad, n,d,)

Figure 7. Food and non-food categorization with mean floor area and construction year from CBS microdata (2022)



From the CBS microdata, the number of shops and mean floor area per shop type were determined, these are shown in Table 1. The bottom of the table (gray) shows the number of shops representative for the reference buildings.

Figure 8 presents the floor area distribution for the sample of Dutch shops. Figure 10 gives this division of floor area for the reference building categories.

Table 1. Categorisation of shop types (CBS microdata, 2022)

	Category	Number of shops	Mean floor area [m^2]	Reference building
Fishmonger	food	91	135	Small
Bakery	food	260	186	Small
Butcher	food	170	137	Small
Supermarket	supermarket	651	1326	Large
Other cooled	food	169	128	Small
Other provisions	food	214	139	Small
Special food other	non-food	309	136	Small
Personal care	non-food	1221	241	Small
Consumer electronics	non-food	411	277	Small
Clothing, shoes and sports	non-food	2976	316	Small
Department store	non-food	108	1777	Large
Free time and education	non-food	691	255	Small
Home and garden	non-food	1067	874	Large
Furniture and interior design	non-food	853	930	Large
Food	Small	904		
Food	Large	651		
Non-food	**Sub-total**	**7636**		
Non-food	Small	5608		
Non-food	Large	2028		
	Total	**10095**		

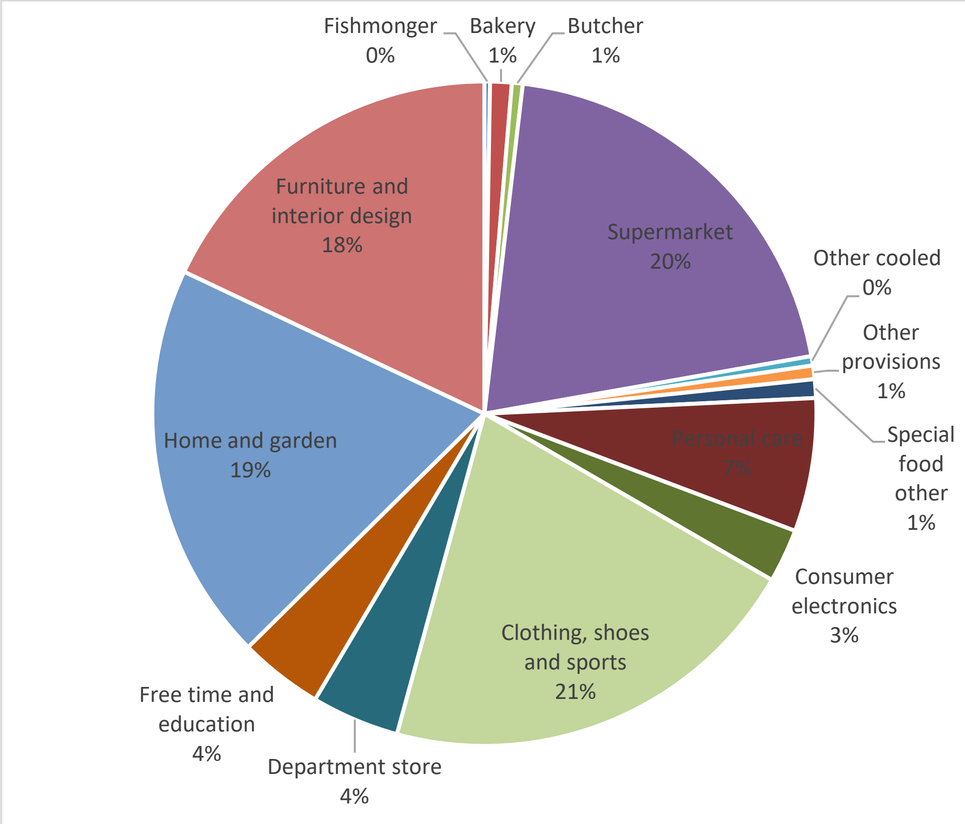


Figure 8. Floor area distribution for sample Dutch shops (CBS microdata, 2022)

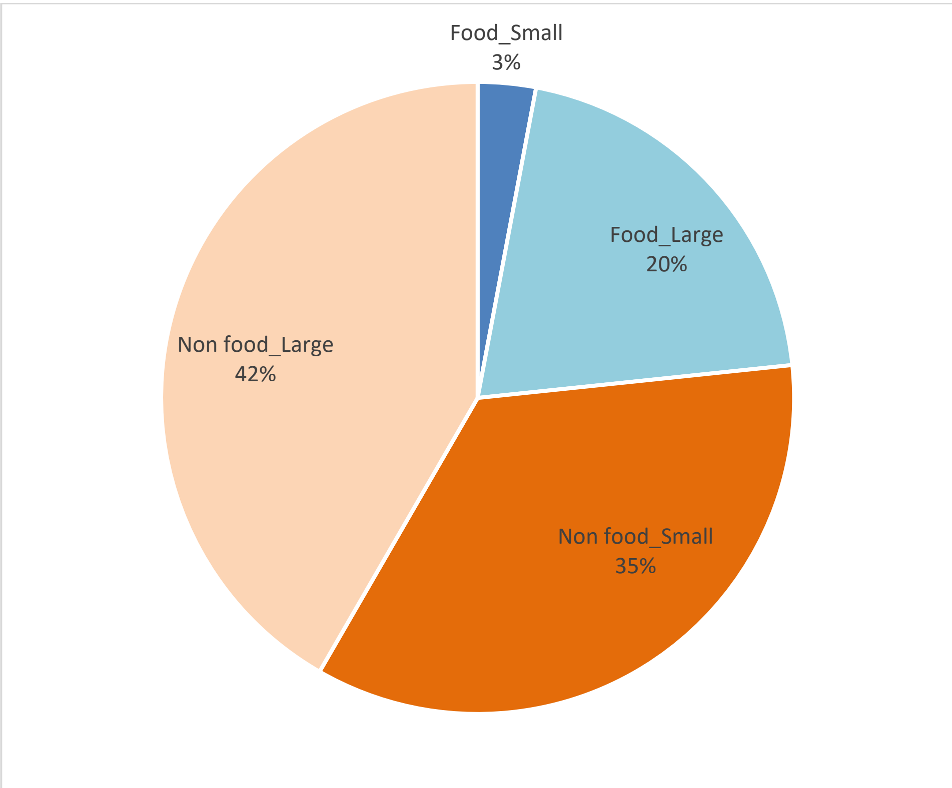


Figure 9. Floor area distribution for sample reference buildings (CBS Microdata, 2022)

4.2 Sample compared to population

This sample of buildings originates from the CBS microdata with verified energy consumption. The sample consists of 9.258 shops, and the non-food shops dominate the sample, see Figure 9. The Dutch population of shops is according to the CBS at 125 thousands shops without product cooling and 900 supermarkets (CBS, 2022). It has to be noted that these definitions of shops without product cooling differ from the categorization made in this research. The dataset of the Energy labels contains 35 thousand shops in the Netherlands. This dataset only recognizes shops in general.

4.3 Energy consumption reference buildings

4.3.1 Energy consumption per shop type

The energy consumption per shop type is visualized in Figure 10 and Figure 11. The distribution is shown by the boxes with the 25^{th} percentile, median and 75^{th} percentile in boxes. The whiskers represent the 5 and 95% range. When whiskers are missing, the number of cases was too low. In purple the mean is shown. In the coloured boxes the categorization for the reference buildings is shown, dark blue is food speciality, red is supermarkets, dark green is shops non-food small, light green is large shops non-food. The largest variation in electricity intensity is found in shops food. For NG the largest variation is shown for fish monger and bakeries. The unweighted mean and the median deviate for most shop types, and the mean is in most cases higher, which is also a sign of right skewed distribution.

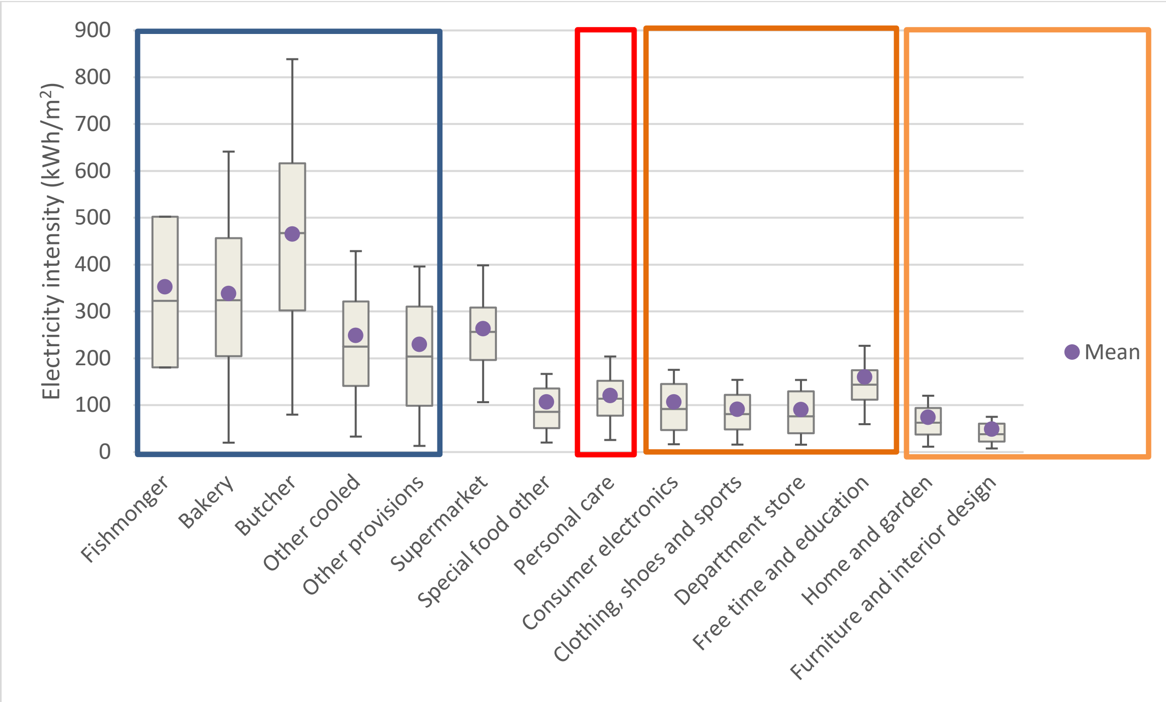


Figure 10. Electricity intensity distribution for shop types (CBS microdata, 2022)

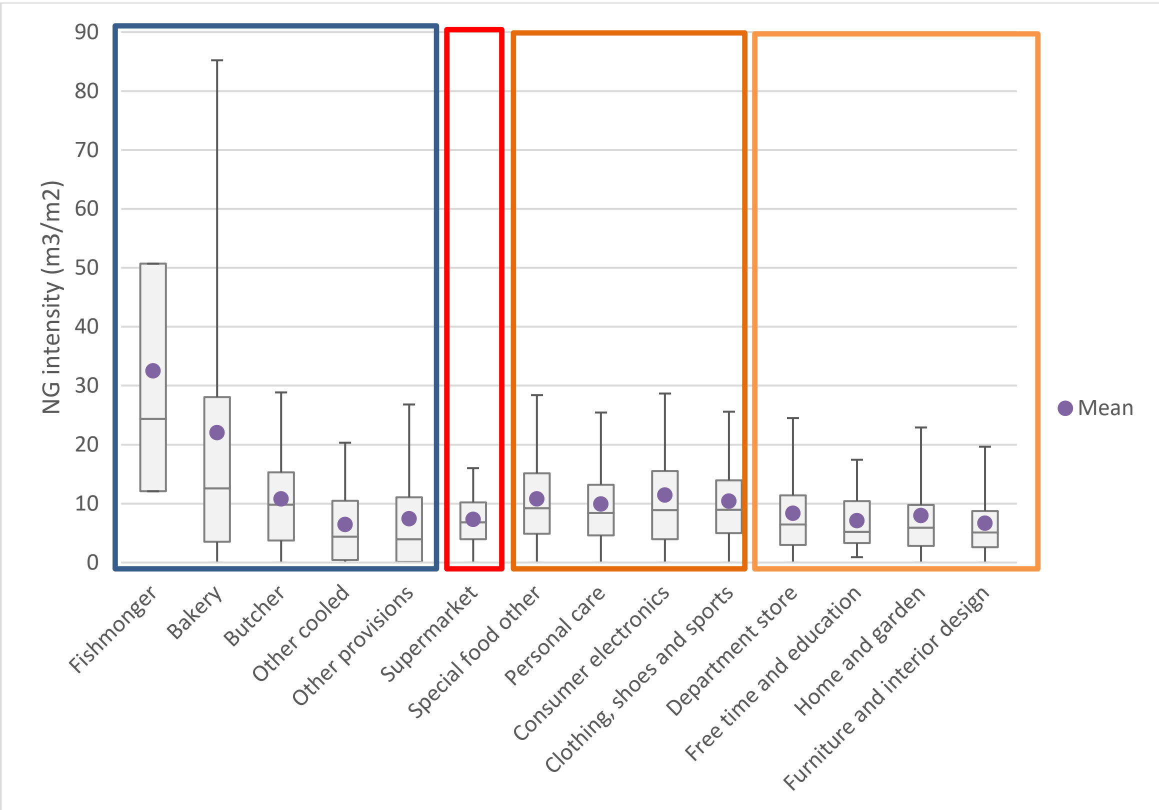


Figure 11. NG intensity distribution for shop types (CBS microdata, 2022)

4.3.2 *Distribution from the mean*

It needs to be noted that the shop sector shows large variety from the mean, as shown in Figure 12 and Figure 13. When interpreting the 25 until 75th percentile variation, it is clear that there exist large variation around the mean, especially the smaller shops show more variation, regarding electricity and NG. The small food shops show the largest variety. When breaking down the energy consumption for energy applications, this should be borne in mind. Also, the weighted mean for floor area is for some reference buildings quite different from the unweighted mean. These differences are large for the non-food sub-sector. The calculations are performed for the unweighted mean with reason that is makes comparison with other sources easier.

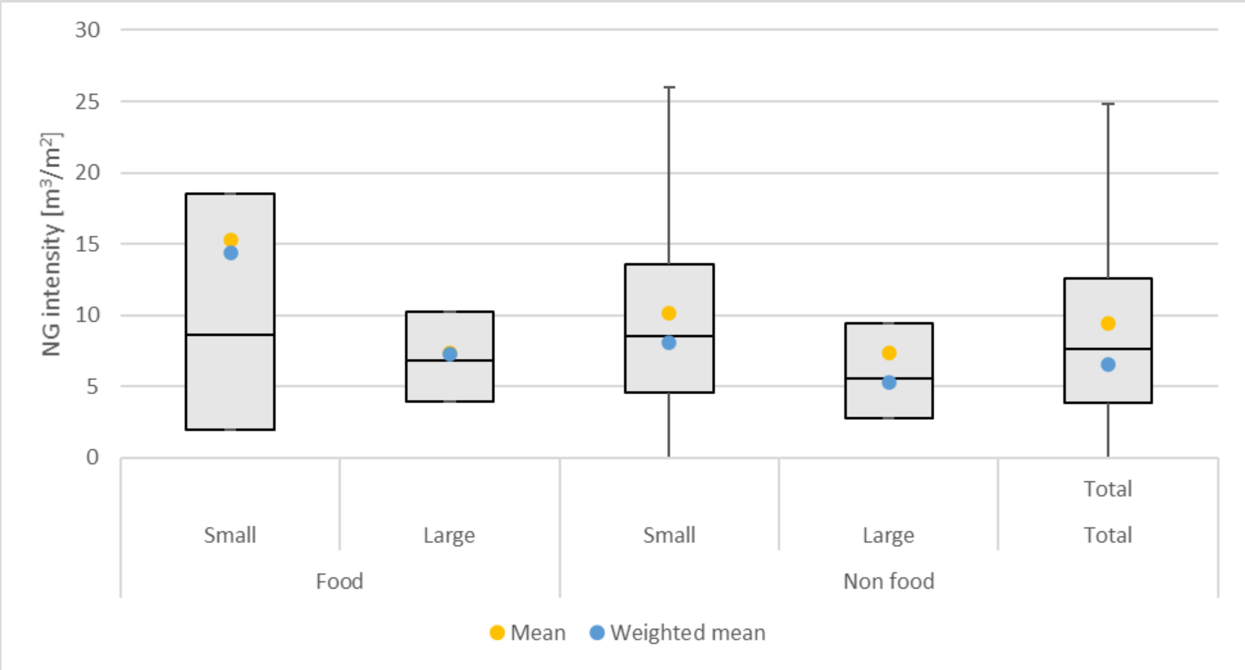


Figure 12. NG intensity distribution for reference buildings with median, 25th, 75th percentile and whiskers for 5 and 95% (CBS microdata, 2022)

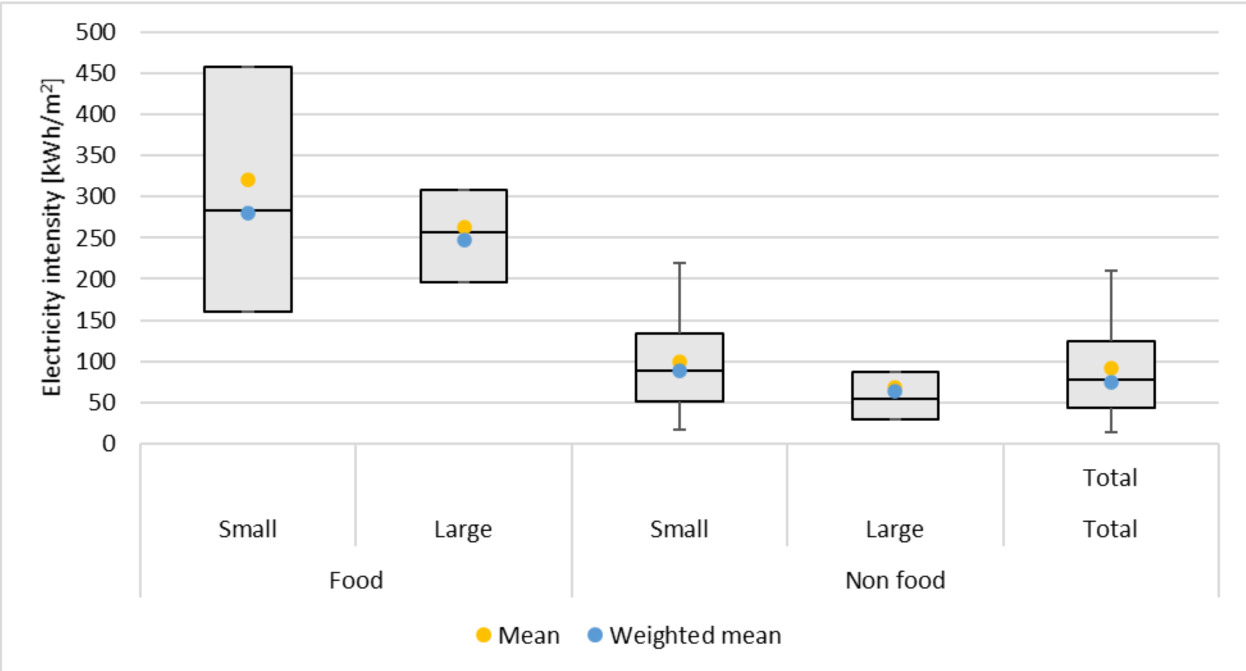


Figure 13. Electricity intensity distribution for reference buildings with median, 25th, 75th percentile and whiskers for 5 and 95% (CBS microdata, 2022)

4.3.3 *Result*

The mean energy intensity for the reference buildings is shown in Table 2. An additional filter for the NG consumption for gas heated shops is applied. This will be used later in the research. This filter excludes about half the cases.

Table 2. Unweighted mean energy consumption for shops in 2019 (CBS microdata, 2022)

Reference building	Electricity consumption [kWh/m^2]	N_{elek}	NG consumption [m^3/m^2]	N_{NG}	NG consumption for gas heated [m^3/m^2]	$N_{NG\ only}$
Food	321.3	904	15.27	745		
Supermarket	263.1	651	7.33	484	7.45	280
Non-food	91.3	7636	9.40	5065	9.47	4281
NF small	99.6	5608	10.15	1877	10.15	3064
NF large	68.4	2028	7.39	9642	7.77	1217

5 Building versus user related consumption

5.1 Literature study

To first approximate and then validate the building related energy consumption, a literature study is performed.

Energy check-up
The Energy check-up has presented the most recent and comparable benchmark of energy consumption for shops in the Netherlands. This aggregated data is based on energy audits, those audits were performed at companies with more than 250 employees (fte), or an annual turnover of 50 million (RVO , n.d.). However, due to low transparency in acquiring more details about the method, it is unknown where the data originates from and how large the investigated sample is.

The results from the Energy check-up are split by shops with food and without food. In Table 3, the electricity consumption for shops is broken down. It is also calculated what the share of construction related energy consumption is. In the breakdown presented lighting is completely taken into account as building related, however, it should be noted that this also includes product lighting. The shares of the breakdown can be used to validate the results which are presented later on in this report. To make a comparison possible, the shares are multiplied with the energy consumption from the CBS for food and non-food, since the energy consumption in the Energy check-up is not split for food and non-food.

Table 3. Breakdown electricity consumption in shops (Energy check-up, 2018)

Breakdown	Non-food	Food	Building related
Lighting	65%	20%	Yes
Ventilation	3%	1%	Yes
Airconditioning	14%	6%	Yes
Space heating	3%	3%	Yes
Production appliances	10%	10%	No
Other	5%		No
Product cooling		60%	No
Building related	85%	30%	

Other literature
A literature study was performed to verify energy breakdown and construction related consumption in shops in different countries. The construction related consumption is calculated by interpretation of the breakdown of the consumption. To this mean, the indoor lighting is included in the building related consumption. The results are presented below. In the Annex the breakdown of energy consumption is presented.

The literature review shows large variations in construction related consumption. For the Dutch shop sector, the electricity intensity for supermarkets varies between 30 and 35%. In Europe, this varies by 26 to 40%. For the Dutch non-food retail sector, the building related consumption was 68 to 85%. In Europe, this varies by

92-96%. Food driven retail Some of this variation can be explained by the difference in climate, influencing the heating and cooling demand. For that reason, the US and Canada are shown in Table 4 (only for reference) not taken into account in the comparison.

Table 4. Literature study of energy consumption in shops

(Source, year), data availability	**Shop type and country**	**Electricity [kWh/ m^2]**	**Non-electric energy consumption**	**Building related***
(Energy check-up, 2018) Method: energy audits	Food, Netherlands	81	18 [m^3/ m^2] natural gas	30% of electricity
	Non-food, Netherlands			85% of electricity
(Meijer, 2007) Method: theoretical and sample buildings	Supermarket Netherlands	401	16 [m^3/ m^2] natural gas	35% of total
	Retail Netherlands	70	14 [m^3/ m^2] natural gas	68% of total
(EC, 2009)	European Food driven retail			55% of total (visual approximation)
	European Non-food retail			92% of total (visual approximation)
(Gov UK, 2016) Method: survey	Retail UK	192	50 kWh/m^2 non-electric	96% of total
(Mairet, 2009) Method: survey Data from 2001	French wholesale/retail trade			55% of total (visual approximation)
(Kauffeld, 2007)	German supermarket			26%
(Supersmart, 2016) Data from 2000	Eco friendly Supermarket Sweden			40% of total
(CSIRO and Griffith University, 2007) Data from 2003	Australia grocery and food			41% of total
(E Source Companies LLC, 2010). Data from the U.S. Energy Information Administration	Grocery store in the US			36% of electricity
(Gov Canada, 2018) Data from 2009 Method: survey	Canadian food and beverage stores	2.8 GJ/m^2 =778 kWh/m^2		63% of total
(Esource ,2020)https://esource.bizenergyadvisor.com/article/retail-buildings data from US Energy Information Administration, 2012	US retail	197		57% of electricity
(Esource ,2020)https://esource.bizenergyadvisor.com/article/retail-buildings data from US Energy Information Administration, 2012	US grocery store	565		13% of electricity

* Calculations based on Annex A: Literature study of energy consumption for energy

Theoretical energy consumption
The theoretical consumption breakdown of shops can possibly provide insight in the building versus user related consumption. An energy label, represents the energy performance of a building. Which is based on the building code (BRIS, 2021; NEN 2020). The label denotes the theoretical consumption and energy performance classification. Formerly, this classification was presented as an energy label, according to the EPA methodology. It was replaced in 2021 by the NTA8800 method which results in three BENG indicator scores (BENG means “near energy neutral buildings”) (Jansen & Spruit, 2021). Theoretical building related electricity and natural gas consumption is calculated with EPA or NTA software. Both calculation methodologies only consider the building related consumption. The extent to which theoretical consumption predicts actual consumptions is widely debated (Pels et al., 2018). The CBS microdata provides both the actual and theoretical consumption (EPA and NTA) for labelled shops.

5.2 Expected results theoretical building related consumption

Previous research can provide some insight in expected results for building related energy consumption share for shops non-food and supermarkets. In Table 5 it is shown that for non-food the electricity consumption for building related purposes varies between 79 and 85%. For supermarkets it is much lower, namely between 20 and 30%.

Table 5. Building related share of consumption of shops

	(Meijer, 2009)			(Energy check-up, 2017)
	Final energy	**NG**	**Electricity**	**Electricity**
Shops non-food				
building related	92%	100%	79%	85%
user related	8%	0%	21%	15%
Supermarkets				
building related	45%	100%	20%	30%
user related	55%	0%	80%	70%

5.3 Results theoretical building related consumption

In the figures below the energy consumption is shown for non-food shops, since they show a lower and more homogenous pattern compared to food shops. The shops non-food are split by size, small, large and average, and further differentiated by building period. The building period after 2010 resembles relatively newer buildings which can also be assumed to have a better energy label than the ‘older’ buildings.

The NTA method overestimates the actual electricity consumption largely, see Figure 14. The EPA method results in a much lower consumption and is lower than the total, which seems plausible. It was chosen to estimate electricity consumption bottom-up in order to take into account differences in the reference buildings. Based on previous research by Meijer (2009), 79% building related is expected for electricity, and the Energy check-up (2017) estimated 85%. A difference in electricity consumption between small and large can be observed.

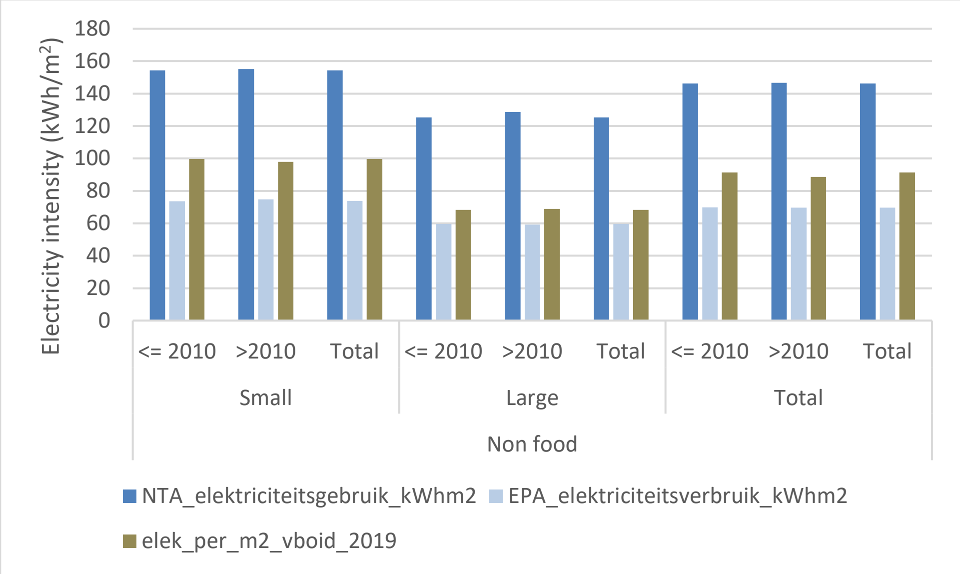


Figure 14. Theoretical and actual electricity consumption of shops non-food in 2019 (CBS microdata, 2022)

For natural gas both the EPA and NTA method (with few exceptions aside) yield an overestimation of the consumption, see Figure 15. Meijer (2007) indicates that the NG consumption is building related. Again, a difference between small and large shops is observed. Smaller buildings having a higher natural gas and electricity intensity compared to larger buildings. For NG also a clear difference between newer and older buildings can be observed.

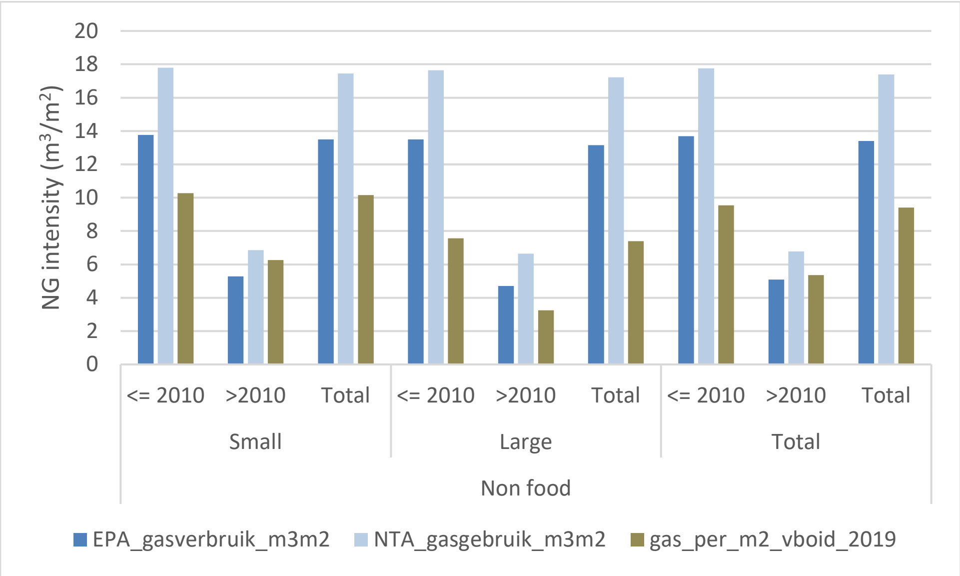


Figure 15. Theoretical and actual natural gas consumption of shops non-food in 2019 (not temperature corrected) (CBS microdata, 2022)

Performing a temperature correction yields the building related fit factors shown in Table 6. The EPA accounts for 3125 HDD, the NTA for 2725 HDD and 2019 there were 2648 HDD (corrected for the density of NG in the Netherlands) (Sipma, 2022; KWA, 2022).

Table 6. Theoretical building related fit to actual consumption for shops non-food. Temperature corrected (HDD=2648).

Construction period	NTA elec	NTA gas	EPA elec	EPA gas
<= 2010	160%	115%	76%	121%
>2010	166%	62%	79%	81%
Total	160%	114%	76%	121%

5.4 Conclusion

Since the results for theoretical calculations for both methods do not yield an accurate building related consumption, the route 4B is taken, requiring a bottom-up approach for building- and theoretical related consumption.

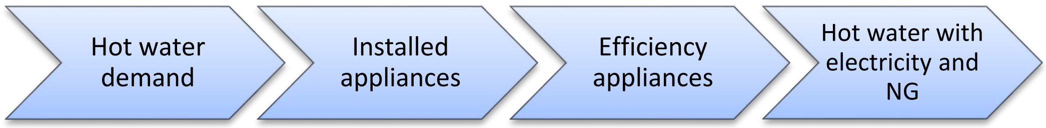
6 Breakdown energy consumption

6.1 Building related

The building related bottom-up approximation of energy use by application is explained in the following paragraphs.

6.1.1 Hot water

The following approach is used to calculate the hot water demand.



The hot water demand is calculated in accordance to the NTA 8800. Which assumes a net hot water demand of 1,4 kWh/m^2 (NTA 8800, 2020). For hot water, a correction for heat losses in the storage tank needs to be included. A heat loss of 25% is associated to storage tank of 30 L (CE, 2021). This represents a one-person household. For commercial uses, it can be expected that the losses are slightly lower, since showers require the largest storage, however, no data was found on this. The resulting heat demand is then 1.75 kWh/m^2.

Based on the efficiency of installed tap water boilers, it can be calculated what the required energy demand from NG or electricity is.

For simplicity, only a differentiation between gas and electrical boilers is made. This results in a division in hot water production in which 73% with an electric boiler and 27% with a gas boiler (EPA Input W/E, 2019). From the EPA dataset it is known that 20% is provided by high efficiency boilers (HR/CW). Therefore, the efficiency of high efficiency boilers is taken as representative for all gas boilers. The efficiency of boilers is used to calculate the energy requirement, using Equation 3. The efficiencies are shown in Table 7.

Equation 3

$$\eta = \frac{E_{useful}}{E_{total}}$$

able 7. Efficiency and share of hot water installations

Type boiler	Efficiency (η) (CE, n.d.)	Share shops (S)
Electrical boiler	95%	73%
HR gas boiler	90%	27%

The electricity and NG consumption can then be calculated with Equation 4, which is shown for electricity. For the purpose of unit transformation, the lower heating value (LHV) of 31.65 MJ/m^3 NG is used.

Equation 4

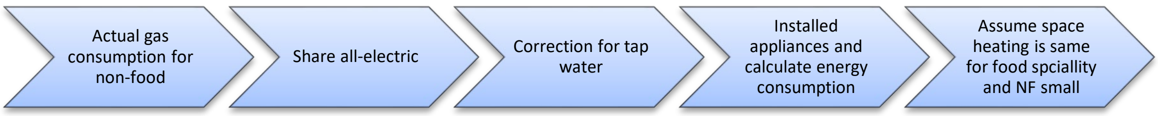
$$Q_{electric} = (Q_{total} * S_{el.boiler}) \;/\; \eta_{el.boiler}$$

This results in the following energy consumption, which is assumed to be constant for all reference buildings. There might be differences in shop types though. For instance, it could be argued that food shops consume more hot water for production and cleaning. Due to missing data, this is not accounted for.

	Net heat demand [kWh/m²]	Including losses [kWh/ m²]	Electricity [kWh/ m²]	NG [kWh/ m²]	NG [m³/m²]	Energy consumption [kWh/m²]
Shop	1.4	1.75	1.34	0.53	0.06	1.87

6.1.2 *Space heating*

The space heating is calculated based on the actual NG consumption for shops non-food, which are connected to the NG grid. It is assumed that all shops with a NG connection use NG for space heating. A correction for the hot water production with NG is made. Since food speciality shops have a considerably higher NG consumption, it is assumed that this is due to the product processing, like ovens and cooking. Therefore, the heat demand of smalls shops non-food is transferred to food speciality shops. The supermarkets were found to have a lower NG consumption compared to non-food shops, and are therefore expected to do no product processing with NG.



The share of all-electric shops is calculated from the sample for each reference building category.

Equation 5

$$S_{all-electric} = 1 - \frac{Valid\ N_{NG\ in\ 2019}}{Valid\ N_{electricity\ in\ 2019}}$$

This yields the table below.

Table 8. Share all-electric

Shop type	Share all-electric
NF small	9,68%
NF large	7,45%
NF average	9,09%
Supermarket	25,65%
Food speciality	17,59%

The NG consumption for space heating is calculated by subtracting the tap water NG demand from the NG intensity. To determine the space heating electricity demand, it is assumed that all-electric shops are heated with a heat pump. The efficiency of the gas boiler needs to be determined to estimate the heat demand for the all-electric shops.

Since it is unknown which type of gas boiler is installed, the efficiency needs to be calculated, to determine the heat demand for the HP.

Equation 6.

$$\eta_{gasboilerl,j} = \left(Q_{NG,j} - Q_{NG,TW}\right) * \left(\frac{1 - S_{all-electric,j}}{Q_{NG,j} - Q_{NG,HW}}\right)$$

$\eta_{gasboiler}$	Efficiency reference building, *j*
S_i	Share of all-electric *i*
Q_{NG}	NG intensity for NG connected shops
$Q_{gas,HW}$	Gas intensity for hot water

This is needed to determine the gross energy requirement for heating with a boiler or a heat pump.

Equation 7.

$$Q_{boiler} = Q_{NG,j} - Q_{NG,HW}$$

Equation 8.

$$Q_{HP} = \frac{Q_{boiler}}{\eta_{gas\ boiler,j} * S_{boiler}} * \frac{S_{all-electric}}{\eta_{HP}}$$

This yields an average efficiency for the gas boilers of:

Table 9. Calculated efficiencies for gas boilers

Reference building	Calculated efficiency NG boiler
Non-food Small	90%
Non-food Large	93%
Non-food Average	91%
Supermarket	74%
Food speciality	82%

Which is in line with expected efficiencies:

Table 10. Efficiency heating systems (NTA, 2019, p. 303_305; Milieucentraal, n.d.)

Type	Efficiency	Assumption
conventional boiler	75%	
VR (improved efficiency)	80%	
HR 107 (high efficiency)	95%	
Heat pump	2.3	Supply temperature between 35 and 55 C. Heat pump on outside air. Average COP is 2,3. From table 9.27 NTA 8800 2019

The gross heat demand for boilers and HP is then calculated with Equation 7. In the table below the results are presented. The space heating for small shops is assumed equal for non-food and food shops. The total NG consumption for shops with NG connection is corrected for all the shops, including the all-electric ones, as calculated above. The space heating demand is expressed in NG and electricity, which are both needed to heat an 'average' shop.

Table 11. Energy requirement for space heating

	NG connected	NG average all shops	Elec (kWh/m²)	
			Boiler	HP
Non-food small	10.15	9.16	80.04	3.73
Non-food large	7.39	6.84	59.63	2.09
Non-food average	9.40	8.55	74.62	3.24
Supermarket	7.33	5.45	47.41	7.11
Food speciality	15.27		72,98	6,77

6.1.3 *Auxiliary equipment*

Auxiliary energy is needed for the heating and cooling systems in a building. For heating and cooling these values are estimated separately and corrected for the number of shops with space cooling. The intensities for offices are assumed to resemble the intensities of shops. All shops are assumed to have the same intensity.

Table 12. Auxiliary equipment (INNAX, 2022)

Circulator type	Electricity intensity [kWh/m²]	Share cooling
Heating	1.5	
Cooling	1.1	45%
All shops	1.99	

6.1.4 *Ventilation*

The ventilation requirements are dependent on the type of building and related to energetic performance. The requirement is dependent on the heating, cooling, seams and cracks in the building. Since this is complicated to model, and data availability is limited, a standardized formula is used here as approximation, which is:

Equation 9.

$$P_{shaft} = \frac{U_{v,min} * c_{sys} * A_i}{1000}$$

(NEN 2916, 2004 p.80)

With (NEN 2916, p. 80)

P_{eff}	Standard effective capacity [kW]
c_{sys}	Dependent on the installed appliances [(W.s)/dm³]
$u_{v;m}$	Air supply by mechanical ventilation [dm³/(s.m²)]
A_i	Floor area [m²]

The effective standard capacity is calculated by

Equation 10.

$$P_{eff} = rf * \frac{f_{time} * P_{shaft}}{\eta}$$

(NEN 2916, 2004, p. 82)

The energy consumption for ventilation is calculated with

Equation 11.

$$E = f_v * 8760 * \frac{P_{eff}}{A_i}$$

Table 13. Other input values ventilation

Variable	Value	Assumption	*Source*
f_time	1	Reduction factor for type of ventilator. Assumed is no time management.	*NEN2916, 2004, p. 83*
rf	0.8	Reduction factor for over dimensioning of ventilator	*NEN2916, 2004*
f_fraction	0.3	Fraction of time the ventilator is in operation	*NEN2916, 2004 p. 51*
$u_{v;m}$	0.35	Ventilation air flow rate as prescribed in Building Order for a shop (Bouwbesluit) 2012	*NTA 8800, 2020 p. 449*

Table 14. Efficiency shaft motor, installed after 2004 (NTA 8800, p.493)

Shaft power (kW)	Efficiency
<1	70%
1 to 2	75%
2 to 4	80%
4 to 10	85%
10 to 30	87.25%
30 to 60	90%
60 to 120	92.5%
≥120	95%

Table 15. Constant values for c_sys

		c_{sys} [W.s/dm^3] (NEN 2916, 2004)	Share of shops with ventilation (W/E, 2022)
A1	**Natural ventilation**		**73%**
C1	Mechanical exhaust	1.2	62%
B1	Mechanical supply	2	4%
D1 and D2	Other	3	34%
Weighted average		1.85	

For each reference shop type, it is estimated whether they have installed ventilation, which results in the table below. It should be noted that by just using the building code values as input to the calculations yields a lower energy intensity when compared to literature. The values are lower than the intensities (2,3 kWh/m2) as found by Meijer (2009).

Table 16. Energy intensity of ventilation

Reference building	Share of shops with ventilation system	EI (kWh/m^2)
Food Small	0%	0
Supermarket	100%	1.94
tot non-food	18%	0.35
Non-food Small	7%	0.14
Non-food Large	47%	0.92

6.1.5 *Space cooling*

For the reference buildings, the theoretical calculations as presented in the document ‘Uniforme Maatlat’ by the ECW (2021) are used. For that purpose, the floor area, construction period, heat loss area and the window area need to be assigned to the reference buildings. The floor area, construction period and heat loss are taken from the CBS. The window area is based on the BENG reference buildings, shop size S (DGMR, 2018). Assumptions for the ventilation type per reference buildings are based on expert insight at TNO, for the small shops natural ventilation (A) is assumed. For the large shops the C1, mechanical exhaust fan is assumed. The shape factor and the cooling demand are then calculated in the ‘Uniforme maatlat’ for a shop.

Table 17. Space cooling input (DGMR, 2018; ECW, 2021; CBS microdata, 2022)

Reference building	Area [m^2]	Window ratio	A_{loss} /Area	Construction period	Shape factor [W/m^2 K]	Assumption	Cooling demand [kWh/m^2]
Food speciality	151	16%	0.69	1951	2.65	A	10.5
Supermarket	1326		0.70	1986	0.95	C1	19.7
Non-food average	459		0.78	1941	2.65	C1	13.2
Non-food small	280		0.79	1934	2.65	A	12.7
Non-food large	949		0.75	1960	2.65	C1	14.4

Since it is known that not all shops full the cooling demand, a correction is performed for the share of cooled shops. This is based on the theoretical dataset, which states that 45% of the shops has no installation for space cooling. In this dataset, mobile air conditioners are not included.

Table 18. Space cooling appliances (W/E adviseurs, 2022)

Adjusted categories	Share of total
None, unknown, negligible	45%
Compression cooling	52.8%
Free cooling	2.6%
Total	**100%**

Table 19. Assumed efficiency space cooling

Type	COP	Assumptions	Source
Compression	3.75	Average of 3 and 4.5	Israëls, Stofberg & Kuijpers-van Gaalen (2020)
Free cooling	13	Average of groundwater and ground heat exchange	Israëls, Stofberg & Kuijpers-van Gaalen (2020).

It is assumed that the space cooling is applicable to the large shops and the small shops do not have installed cooling appliances, as shown in Table 18. When cooling is assumed present, the shares of Table 19 are applied. This yields the following table with results.

Table 20. Energy intensity space cooling

	Energy consumption cooling [kWh/m^2]				
	Food speciality	Supermarket	Small NF	Large NF	NF
Compression		5.01		3.66	0.89
Free cooling		0.07		0.05	0.01
Total		**5.08**		**3.71**	**0.09**

6.1.6 *Humidification*

It is assumed that humidification is not applicable for shops. This is also assumed in Meijer (2009).

6.1.7 *Indoor lighting*

Indoor lighting in shops is used for product lighting and ‘head lighting’ (also called, horizontal lighting or loopverlichting). The lighting in the refrigerators is not included in indoor lighting but is counted towards product cooling.
In the annual monitoring research by Panteia (2020), a survey among shops results in a sample size of about 190 shops. This research shows that 62% of the shops has efficient (e.g. LED) lighting and 38% uses regular (e.g.) TI lighting (Panteia, 2020). Based on the capacity and the operating time, the energy consumption is calculated, see Equation 11 below and Table 22, assumptions for the capacity of indoor lighting are shown.

Equation 12.

$$E = P * t * cf$$

E	Energy consumption [kWh]
P	Capacity [kW]
t	Operating time [h]
cf	Capacity factor [0-1]

Table 21. Indoor lighting capacity and assumptions

	Capacity [W/m²]	Assumptions	Source
Food & supermarket			
Low efficiency	30	Standard is 30 W/m^2	NTA 8800, 2020
High efficiency	17.5	High efficiency lighting with LED for shops is between 15 – 20 W/m^2. Average value taken in calculations.	Neprom, 2014
Non-food			
Low efficiency	27.5	Values found in practice for buildings with higher roofs, average of 20 to 35 W/m^2. Average value taken in calculations.	Neprom, 2014
High efficiency	17.5	High efficiency lighting with LED for shops is between 15 – 20 W/m^2. Average value taken in calculations.	
Garden shops	6	Garden shops with additional daylight	

The operating time is based on the standard value for shops of ISSO (2010), which are 2400 hours. The NTA 8800 (2020), assumes a considerably higher figure, namely maximum 3100 hours per year. For the reference buildings it seems that this number is relatively high, assuming 6 opening days a week, it comes down to 10 hours per day. Therefore, the 2400 hours are assumed. Only for supermarkets, longer opening times are assumed, namely 10 hours opened from Monday to Saturday, and on Sunday 6 hours. This results in 3441 hours per year. However, due to higher application of smart technologies in supermarkets, a correction for a lower capacity factor is incorporated (Anonymous, 2022). The correction factor is adjusted according to the daylight, 60% by dusk, and 30% after sunset (Interact, 2018). Overall, an 80% CF is taken for supermarkets (Stimular, 2022). For garden shops, significantly less lighting is used due to the large windows. The lighting intensity for shops non-food is therefore corrected for the share of garden shops. Which yield the table below.

Table 22. Energy intensity for indoor lighting

	Energy intensity [kWh/m²]				
	Food speciality	Supermarket	NF	NF small	Large NF
Total	53	61	48	51	41

6.1.8 *Emergency lighting*

Emergency lighting energy consumption is published by ECT ISSO (2022), for shops. It includes escape route lighting and indication. This is in total 0.6 kWh/m^2 and assumed for all shop types.

6.1.9 *Solar PV*

The electricity intensity only includes the electricity taken from the grid. The self-consumption of electricity should be added to the electricity consumption as known by the CBS, to determine the total electricity consumption of the building. However, this data is not available. Only the feed-in and theoretical production are known. The theoretical production is the average for all shops, being 0.12 kWh/m^2 calculated with the NTA methodology (based on Nuiten, 2020). Which implies a peak capacity based on the material and installation year (NTA 8800, 2020). The CBS provides the feed-in electricity, but emphasizes that this is only accurate for large electricity consumers, due to challenges in the electricity bill registration for small consumers, experienced by electricity companies (Sipma, 2021).

If is found that the average theoretical production is lower than feed-in electricity for supermarkets and is therefore not representative. Therefore, the assumption is made that the feed-in electricity equals the self-consumption. This self-consumption is added to the electricity consumption.

Table 23. Feed-in or self-consumption of solar PV electricity for each reference building (CBS microdata, 2022)

Category	Feed in solar PV kWh/m^2
Food speciality	0
supermarket	0.23
Non-food average	0.02
NF small	0
NF large	0.08

6.2 User related

User or process related energy is calculated with the bottom-up methodology. To take into account the presence of each energy application the table below is developed, where for each shop type a share is indicated. For each shop type it is estimated in what share of the shops an energy application is present. The table is based on the *number* of shops in each category. The shares are based on expert opinion. Literature on this topic, which has to be representative of the Netherlands, is lacking. For the calculation of the energy application the basic approach is to first calculate the energy consumption of the application and multiply this with the share which is calculated in Table 24.

Table 24. Presence of user related energy applications

Shop	Nr. of shops	Product cooling	Product process	Restaurant	ICT central	Coffee machine	Snack/soda machine	Mechanical ventilation	Space cooling
Food	904	86%	100%	0%	0%	0%	0%	0%	
Supermarket	651	100%	100%	0%	100%	100%	0%	100%	
Non-food	7636	0%	0%	9%	6%	22%	10%	18%	27%
Small	5608	0%	0%	3%	7%	1%	0%	7%	0%
Large	2028	1%	0%	26%	3%	82%	39%	47%	100%

6.2.1 *Outdoor lighting*

Outdoor lighting is based on assumptions for the number of lamps and operating time. A lamp is assumed to have the following characteristics, see Table 26. For each reference building, an assumption is made for the number of lamps, see Table 27. With the basic energy intensity equation, the consumption is calculated.

A remark here is that lighting for marketing purposes is not included, due to data availability. This implies that in reality the outdoor lighting intensity might be higher.

Table 25. Assumptions outdoor lighting

	Value	Assumption	Source
Capacity	65 W	Outdoor lamp	Bedrijfsverlichting, 2022
Operating time	4100 hours	Equal to public outdoor lighting	Ledlichtnederland, 2021
Yearly energy consumption	267 kWh		

Equation 13

$$EI = \frac{E}{A}$$

E	*Energy consumption [kWh]*
A	*Floor area for each reference building [m²]*
EI	*Energy intensity in [kWh/m²]*

Table 26. Energy consumption outdoor lighting

	Food speciality	Supermarket	NF	Non-food small	Non-food large
Number of lamps	3	10	4.9	10	3
Energy consumption [kWh/ m²]	5.55	1.95	2.94	2.92	2.96

6.2.2 *ICT decentralized*

This category covers various types of electronic devices like computers. First a collection of various devices and their energy consumption is presented. Afterwards, for each category it is determined how many are present in each reference building.

NF is calculated as weighted average based on number of shops for large and small NF shops.

Table 27. ICT energy consumption

	Energy consumption [kwh/year]	Assumption	Source
Computer	123.5	Includes computer, monitor, mouse and keyboard	Maya-Drysdale et al., 2018
Laptop	27.7	Notebook	Maya-Drysdale et al., 2018
Monitor	86.52	Tco 2005 Data 17-inch LCD	IVF, 2007
Cash register	27.7	Assume same as laptop	
Copy machine	780	Running 430 hours, 'stand-by' 1.900 hours; 'off 6.400 hours from 2007	Freitas, 2007

Table 28. Number of ICT devices per reference building and resulting energy intensity

Appliances per reference building			Energy intensity (kWh/m²)				
	Small	Large	Food speciality	Supermarket	NF	Small NF	Large NF
Computer	1	4	0	0	0	0	1
Laptop	5	10	0	0	0	0	0
Monitor	4	4	0	0	1	1	0
Cash register	2	10	0	0	0	0	0
Copying machine	1	1	1	1	2	2	1
Total			1.1	1.6	3.1	3.3	2.4

6.2.3 *ICT centralized*

Shops can have servers to offer a Wi-Fi connection to their customers, run a webshop, the cash register (ITbases, n.d.). These servers runs during day and nighttime, i.e. 8760 hours (SenterNovem, 2007). For a shop smaller than 10 thousand m², the capacity of a patch room is measured at 1.5 W/m² (Tebodin, 2007). Based on estimations to which an ICT server room applies, the following energy intensity is calculated.

Table 29. ICT centralized energy intensity

	Share of shops with ICT centralized	Energy intensity [kWh/m²]
Food speciality	0%	0
Supermarket	100%	13.14
NF	6%	0.8
NF small	7%	1.0
NF large	3%	0.3

6.2.4 *Food and drink facility*

For food and facilities in stores three types of energy consumption are recognized. Firstly, machines for soda, snacks and coffee. Secondly, a basic kitchen for the staff. Thirdly, appliances needed to run a lunchroom. It is assumed that every shop has a staff kitchen. For soda machines and the restaurant area it is determined per shop type whether it is applicable, see Table 25.

Vending machines

The energy consumption for vending machines is approximated for 3 different types and allocated per shop type.

Table 30. Vending machine energy consumption

	Energy consumption [kWh/year]	Assumption	Source
Coffee machine	1100	machine installed after 2005	Stimular, 2005
Soda machine	1547	7 °C temperature and best available technology	EC, 2019
Snack machine	2070	3 °C temperature and best available technology	EC, 2019

Table 31. Vending machines energy intensity

	Energy intensity [kWh/m^2]				
Coffee machine	Food speciality	Supermarket	NF	NF small	NF large
Soda machine		7.64	0.56	0.01	1.00
Snack machine			0.86		1.58
Total machines		**7.64**	**1.42**	**0.01**	**2.58**

Basic kitchen

For a small kitchen for the staff of a shop, the basic appliances considered are described below. One kitchen is assumed per shop type. The total energy is divided over the floor area of each shop type.

Table 32. Energy consumption for a basic staff kitchen

	Energy consumption [kWh/year]	Assumption	Source
Refrigerator	120	A refrigerator, including a freezer. With energy label B.	Milieucentraal, n.d.
Microwave	95		SenterNovem, 2007
Dishwasher	305	Data from 2000	SenterNovem, 2007
Coffee machine	79	Applicable to hospitality. Data from 2000	SenterNovem, 2007
Kettle	33	Applicable to hospitality. Data from 2000	SenterNovem, 2007
Total	**632**		

Lunch corner

A lunch corner includes the energy consumption as described in Table 34.

Table 33. Lunch corner energy consumption

Energy application	Capacity [kW]	In operation (h/day)	Capacity factor	Energy consumption	Assumption	Source
Stove	3.5	0.4	0.6	307	Average of minimum and maximum capacity. Electricity fuelled.	SenterNovem, 2007
Oven	8	0.4	0.9	1051	Average of minimum and maximum capacity	SenterNovem, 2007
Hot plate			0.75	0	Average of minimum and maximum capacity	SenterNovem, 2007
Dishwasher	3.5	5	0.275	1757	New dishwasher with 230 V connection and 3.5 kW capacity. Other values from SenterNovem.	HKL horeca, n.d.; SenterNovem, 2007
Display fridge				1643	Self-service cooled counter-island. Cooling refrigerant R290. For temperature between -1 and +1 °C. and energy label C.	Carrier, 2022
Refrigerator	0.2	24	0.6	1051	Average of minimum and maximum capacity	SenterNovem, 2007
Cold storage	1.7	24	0.4	5957	Average of minimum and maximum capacity	SenterNovem, 2007
Extraction hood				15	Extraction hood for a household	Keukenloods (n.d.)
Total lunch corner				**12900**	With a correction for opening 6 instead of 7 days a week	

The reference table is used to estimate the applicability of the lunchroom, which yield the energy intensity.

Table 34. Energy intensity of a coffee/lunch corner

		Energy intensity [kwh/m^2]
Food speciality	0%	0
Supermarket	0%	0
NF	9%	2.67
Small	3%	1.37
Large	26%	3.77

The total food and drink (horeca) energy intensity is the sum of the three.

Table 35. Results of food and drink facility

	Food		Non-food		
	Speciality	supermarket	**non-food**	Small	Large
Total	**4.39**	8.10	5.52	3.69	7.05
Staff kitchen	4.39	0.46	1.43	2.31	0.70

6.2.5 *Transport*

For transport, elevators and escalators are considered. This only includes the inside transport within a shop. Based on a sample of 1500 shops, Table 37 is constructed. It is assumed that the shop has one elevator and/or escalator when applicable. The energy consumption for elevator and escalator is.

Table 36. Energy consumption for transport

	Energy consumption [kWh/jaar]	Assumption	Source
Elevator	550	Best practice elevator. An elevator for a small office or administrative building. With 50 operations per day.	Durand et al., 2019
Escalator	9426	Finnish elevator in a shop in December. Extrapolated to energy consumption for a year.	Semen, 2015

Table 37. Share of elevators and escalators (CBS microdata, 2022)

	Elevator	Escalator
Speciality food		
Supermarket	11%	6%
NF	24%	7%
Small NF	21%	8%
Large NF	26%	7%

Table 38. Energy consumption transport

	Elevator [kWh/ m^2]	Escalator [kWh/ m^2]	Total transport [kWh/ m^2]
Speciality food			
Supermarket	0.04	4.06	4.10
NF	0.29	4.65	4.94
Small NF	0.42	2.58	3.00
Large NF	0.16	0.74	0.90

6.2.6 *Product preparation*

Product processing is food preparation which can be done with NG and electricity. For NG, relevant energy application are ovens and stoves. And for electricity, it can include frying pans, and electric ovens.

NG

The NG demand for product preparation is calculated for the food speciality shops by assuming that it is the remainder of the total NG consumption, space heating and hot water, see Equation 13.

Equation 14.

$$Q_{product,NG} = Q_{NG,food} - Q_{NG,space\ heating.} - Q_{NG,HW}$$

This yields

Table 39. Energy intensity NG for product preparation

	Energy intensity [kWh/m^2]	NG [m^3/m^2]
Speciality food	37.12	4.22

Electric

For electric product processing, the consumption of food preparation in fish mongers and butchers is considered. Therefore, the consumption of a frying pan, oven and stove are evaluated. For a supermarket, only an oven is considered for bake-off.

Table 40. Electric product preparation

	Capacity [kW]	Operating time [h/yr]	CF	Energy consumption [kWh/yr]	Assumption	Source
Frying pan	5	183	0.6	548	Assume 2 pans per shop	SenterNovem, 2007
Ovens	8	Shop specific	0.9		Specialty food: Assume 1 oven operating 3h/day per. Supermarkets assume 4 ovens operating 4 h/day.	
Stove	3.5	146	0.6	307	Assume 1 per shop	

Based on the reference table, the following energy consumption results.

Table 41. Energy intensity electric product preparation

	Energy intensity [kWh/m²]
Speciality food	64.48
Supermarket	30.76

6.2.7 *Product cooling*

Freezers and cooling are considered separately. It is assumed that horizontal and vertical cooling are equally applicable. The estimated space in a shop is used to determine the cooling requirement. Per shop it is indicated how much cooling they require. The cooled warehouse of a supermarket is considered as an industrial function and is therefore not included in the shop's energy consumption. For the shops NF, the department stores require product cooling, and therefore are included in this category.

.

Type of cooling	Energy consumption (kWh/year)	Operating time	Assumption	Source
Vertical refrigerator	4526	8760	Best available technology. Area : 3.3 m²	EC, 2019
Horizontal refrigerator	2044	8760	Best available technology. Area : 2.2 m²	EC, 2019
Average refrigerator	**6570**	8760	Best available technology. Area: 5.5 m²	EC, 2019
Vertical freezer	9709	8760	Best available technology. Area : 3 m²	EC, 2019
Horizontal freezer	1606	8760	Best available technology. Area : 1.4 m²	EC, 2019
Average freezer	**11315**	8760	Best available technology. Area: 4.4 m²	EC, 2019
Self-service counter-island	1643	8760	Self-service cooled counter-island. Cooling refrigerant R290. For temperature between -1 and +1 °C. and energy label C.	INNAX and Carrier 2022

Based on the table for reference buildings the applicability of product cooling is determined. Then, an assumption on the share of area cooled is determined. With Equation 14 the energy intensity is calculated, as presented in Table 43.

Table 42. Share of area cooled

	Supermarket/large shops	Speciality food shop
Refrigerator C_r	4%	10%
Freezer (C_f)	2.8%	3%
Self-service counter island ($n_{counter\text{-}island}$)	5 pieces	n.a.

Equation 15.

$$E_{product\ cooling} = S_i * A_i * C_f * E_{freezer} + S_i * A_i * C_r * E_{refrigator} + E_{counter-island} * n_{counter-island}$$

Table 43. Energy intensity for product cooling

	Share of shops	Refrigeration [kWh/m²]	Freezer [kWh/m²]	Total [kWh/m²]
Speciality food	86%	102.28	66.05	**168**
Supermarket	100%	53.79	70.72	**125**
NF	0.3%	0.14	0.20	**0.3**
Small NF	0%			
Large NF	1%	0.51	0.75	**1.3**

6.2.8 Other

Other energy application which were not captured in the prior categories are included here. Some examples are “other” product preparation appliances, and security systems and air curtains (DGMR, 2021). The other category is considered a residual category, so for the final tweaking, energy can be allocated to this category.

7 Results

The resulting breakdowns per shop type of energy consumption per energy application are presented below.

7.1 Shops non-food

The bottom up method results in the following overview of energy breakdown, as shown in the table below, and in the figure below, the 'average' sized shop non-food is shown, which is the weighted average of small and large shops without cooling. It can be concluded that for shops without cooling, space heating and indoor lighting are dominant categories. To approximate the actual energy intensity, tweaking 'other' has taken place. For shops NF, about 9% is all-electric.

Table 44. Energy intensity per energy application for average Dutch shop without cooling in 2019

Energy application	Energy carrier	Energy intensity [kWh/m²]			NG intensity (m³/m²)
		Small	Large	Average	Average
Space heating	Natural gas	80.04	59.63	74.62	8.49
	Electricity	3.73	6.24	3.24	
Space cooling	Electricity		3.71	0.90	
Hot water	Electricity	1.34	1.34	1.34	
	Natural gas	0.53	0.53	0.53	0.06
Humidification	Electricity				
Other	Electricity	24.50	0.50	17.50	
Food/drinks	Electricity	3.69	7.05	5.52	
ICT centralized	Electricity	0.96	0.35	0.80	
ICT decentralized	Electricity	3.34	2.41	3.09	
Auxiliary	Electricity	1.99	1.99	1.99	
Product preparation	Electricity				
Product cooling	Electricity				
Inside transport	Electricity	2.58	0.74	4.65	
Ventilation	Electricity	0.14	0.92	0.35	
Indoor lighting	Electricity	51.12	40.64	48.34	
Outdoor lighting	Electricity	0.60	0.60	0.60	
Emergency lighting	Electricity	5.55	1.95	2.94	
Solar PV	Electricity		0.08	0.02	
Total					
	NG [Nm³/m²]	9.16	6.84	8.55	
	NG [kWh/m²]	80.57	60.17	75.15	
	Electricity [kWh/m²]	99.50	68.44	91.25	

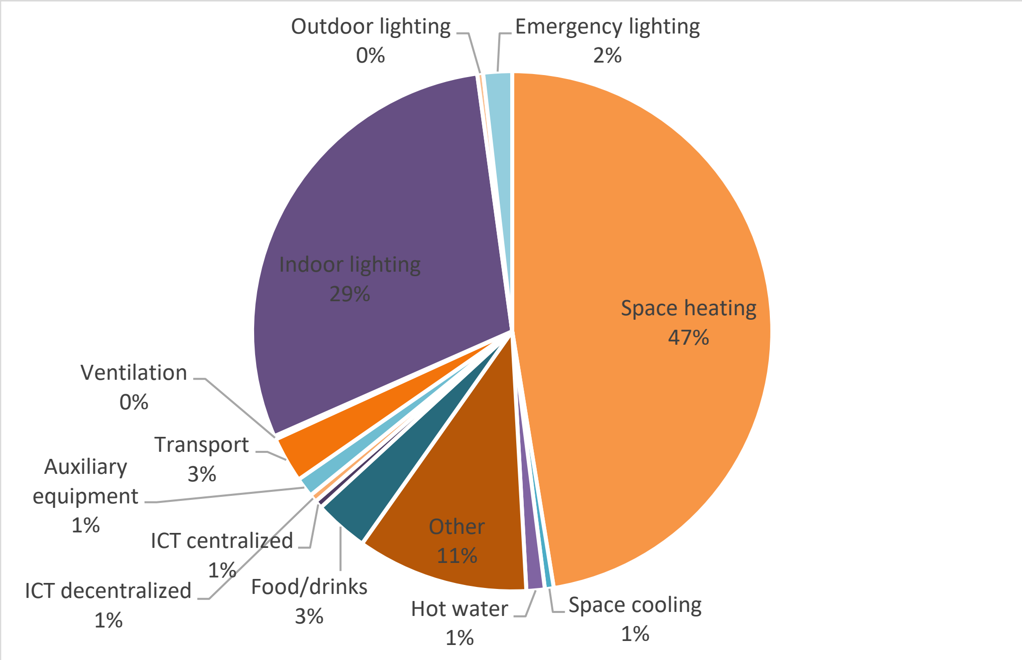


Figure 16. Energy breakdown of average Dutch shop without cooling in 2019

7.2 Food specialty shops

The bottom up method results in the following overview of energy breakdown, shown in the table and figure below. It can be concluded that for food speciality shops, space heating, indoor lighting, product preparation and product cooling are dominant categories. To approximate the actual energy intensity, tweaking of 'product cooling' and 'product preparation' has taken place. For product cooling, the shares of the floor area of the store cooled (Table 42) were tweaked. Initially 5 and 10% of refrigerated and cooled floor area was chosen, and the shares for frozen storage were tweaked down. For product preparation, the number of appliances was increased. Of the food speciality shops in the sample, 18% is all-electric.

Table 45. Energy intensity per energy application for food specialty shops in 2019

Energy application	Energy carrier	Energy intensity [kWh/m²]	NG intensity (m³/m²)
Space heating	Natural gas	72.98	8.33
	Electricity	6.77	
Space cooling	Electricity	0	
Hot water	Electricity	1.34	
	Natural gas	0.53	0.06
Humidification	Electricity		
Other	Electricity	16.00	
Food/drinks	Electricity	4.39	
ICT centralized	Electricity	0	
ICT decentralized	Electricity	1.09	
Auxiliary	Electricity	1.99	

Energy application	Energy carrier	Energy intensity [kWh/m²]	NG intensity (m³/m²)
Product preparation	Electricity	64.48	
Product preparation	Natural gas	37.12	4.22
Product cooling	Electricity	168.33	
Inside transport	Electricity	0	
Ventilation	Electricity	0	
Indoor lighting	Electricity	53.40	
Outdoor lighting	Electricity	0.60	
Emergency lighting	Electricity	2.96	
Solar PV		0	
Total			
	NG [Nm³/m²]	12.58	
	NG [kWh/m²]	110.64	
	Electricity [kWh/m²]	321.35	

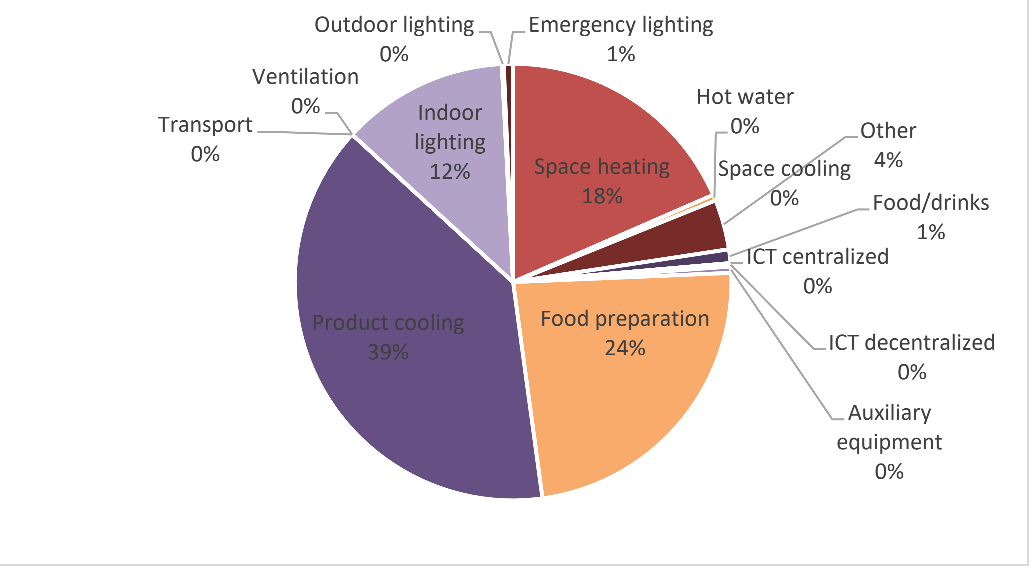


Figure 17. Energy breakdown of average Dutch food specialty shop in 2019

7.3 Supermarkets

It can be concluded that, indoor lighting, space heating, product cooling and ICT decentralized, followed by product preparation are dominant categories. Of the supermarkets in the sample, 26% is all-electric. To approximate the actual energy intensity, tweaking of ‘product cooling’ and ‘product preparation’ has taken place. For product cooling, the shares of the floor area of the store cooled (Table 42) and the number of open coolers (self-service counters) were tweaked. Initially 5 and 10% of frozen and cooled floor area was chosen, with insights from INNAX, the open coolers were added, and the shares were tweaked down. Product preparation refers to the bake-off, with insight from INNAX they operating time was intensified. Expert insight has also highlighted the penetration of heat exchangers in product cooling (WTW), the renovated or new build supermarkets make only use of waste heat from product cooling and ovens for space heating (Thijssen, 2017; INNAX, 2022). However, since quantification and allocation of these energy streams is challenging, this has not been taken into account.

Table 46. Energy intensity per energy application for average Dutch supermarket in 2019

Energy application	Energy carrier	Energy intensity [kWh/m²]	NG intensity (m³/m²)
Space heating	Natural gas	47.41	5.39
	Electricity	7.11	
Space cooling	Electricity	5.08	
Hot water	Electricity	1.34	
	Natural gas	0.53	0.06
Humidification	Electricity		
Other	Electricity	-	
Food/drinks	Electricity	8.10	
ICT centralized	Electricity	13.14	
ICT decentralized	Electricity	1.59	
Auxiliary	Electricity	1.99	
Product preparation	Electricity	30.76	
Product cooling	Electricity	124.5	
Inside transport	Electricity	4.06	
Ventilation	Electricity	1.94	
Indoor lighting	Electricity	61.26	
Outdoor lighting	Electricity	0.60	
Emergency lighting	Electricity	2.92	
Solar PV	Electricity	0.23	
Total			
	NG [Nm³/m²]	7.33	
	NG [kWh/m²]	64.48	
	Electricity [kWh/m²]	263.90	

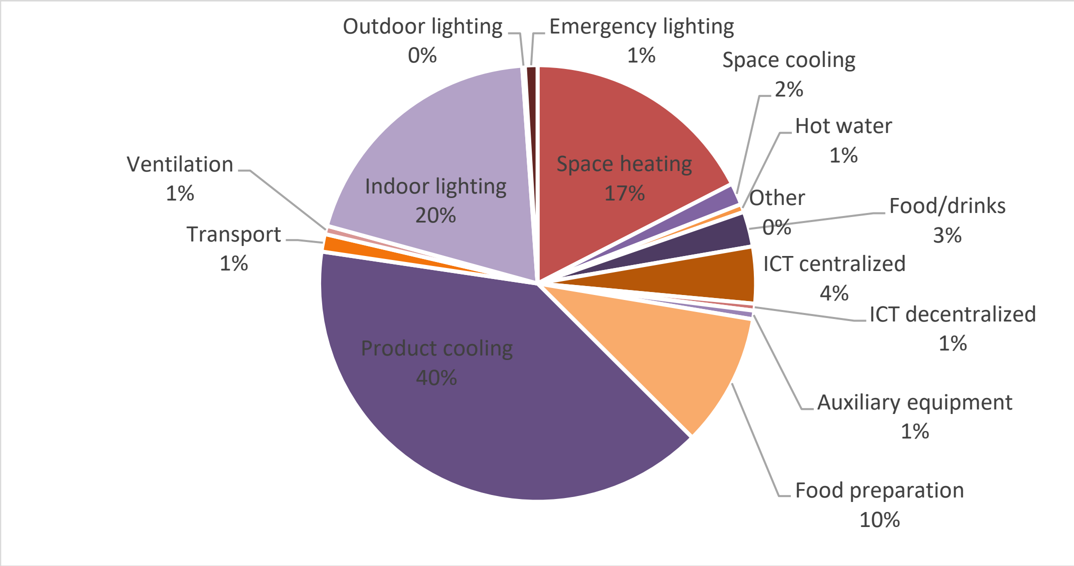


Figure 18. Energy breakdown of average Dutch supermarket in 2019

8 Validation

The validation of the bottom up approach needs to be done to assess the quality and reliability of the results. Validation is done in two ways, firstly, by comparing the results to the Energy Check-up (2018), and the results of Meijer (2009). Secondly, experts were asked to review the results, mostly providing qualitative validation. With both insights, adjustments have been made when necessary. Throughout the validation process, the results are fitted to the actual energy consumption.

8.1 Comparison with previous studies

Firstly, the building and user related consumption shares were compared. In Table 48 the results are shown. The validation could only be performed for non-food and supermarkets for Meijer, regarding the energy check-up, it is unclear what is included in the category ‘shops cooled’. Since most literature refer to supermarkets, this is assumed. In the table it is shown that the ‘bottom up’ shares are comparable to previous research.

Table 47. Validation building and user related energy

	2007	(Meijer, 2009)		2017 (Energy Check-up)	2019		
	energy	NG	electricity	electricity	energy	NG	electricity
Shops non-food							
building related	92%	100%	79%	85%	82%	100%	67%
user related	8%	0%	21%	15%	18%	0%	33%
Supermarkets				*shops cooled			
building related	45%	100%	20%	30%	43%	100%	23%
user related	55%	0%	80%	70%	57%	0%	77%

Energy check up

The MKB energy check-up (ECU) has limited insight due to its limited details on the method. The shares of electricity consumption can be directly compared to that of the energy check-up, for some electricity applications. It needs to be noted that the shops cooled is compared to supermarket even though it is unclear what is intended by the ECU. In Figure 19, the results from the Energy check-up over the bottom up results are visualized. They have been compared by applying the shares to the total electricity consumption of 2019, and categorizing the results from this research to the ECU energy applications. Since ECU did not share further insight, this was not straightforward for every category. Some insights are as follows. Summed consumption for lighting is comparable. Ventilation and air conditioning are much lower than ECU. Which could be due to the exclusion of mobile appliances. Production appliances is rather low, for non-food, even when the energy application ‘others’ is included. Product cooling is comparable but higher for ECU.

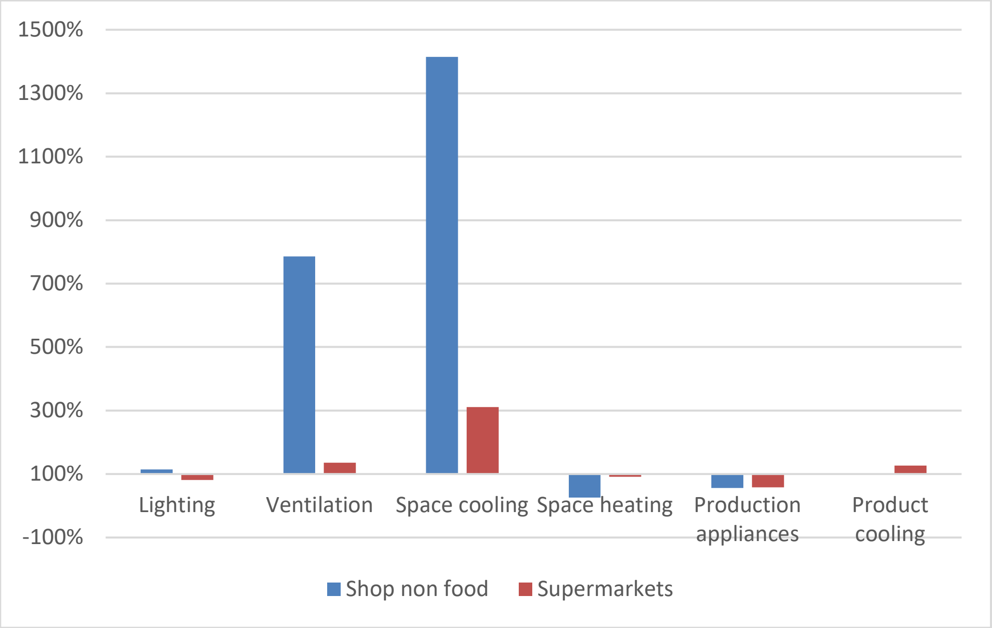


Figure 19. ECU divided by results found in this research

Meijer
The categories, supermarket and shops non-food can be compared to Meijer (2007). Comparison of results and discussing the largest deviations yields the following. For food and drink facilities, an increase due to more need for luxurious treatment of customers. For instance, more coffee is served to customers. Decreased lighting intensity, although there are more light hours for supermarkets and more marketing focused lighting, the efficiency improvement is dominant. Ventilation is lower for both shop types. Meijer did not correct for the number of shops with ventilation and assumes higher air flow rate. Transport has increased, but no clear explanation can be given for the discrepancy. The sample size could be unrepresentative, as the sample size is limited to 1600 shops. More validation on this using other data is necessary. Space cooling is decreasing for some shops non-food and increasing for supermarkets. Regarding the supermarkets, product processing has increased and product cooling has decreased. This can be explained by increased efficiency of product cooling and an increased bake-off of bread.

CBS retail dashboard
The CBS has constituted dashboards about energy consumption for various sectors. When comparing the final consumption per shop type in 2018 with the CBS retail dashboard it can be noticed that there is for some shops a rather large variation in the energy intensity, visualized in Figure 20 and Figure 21. Especially the food speciality shops show large variation in NG and electricity. This can partly be explained by the CBS dashboard's filter for minimum floor area of 50 m^2, which is not applied in this research. A difference in applied filters and imputation by the CBS is expected to explain the remaining difference in results.

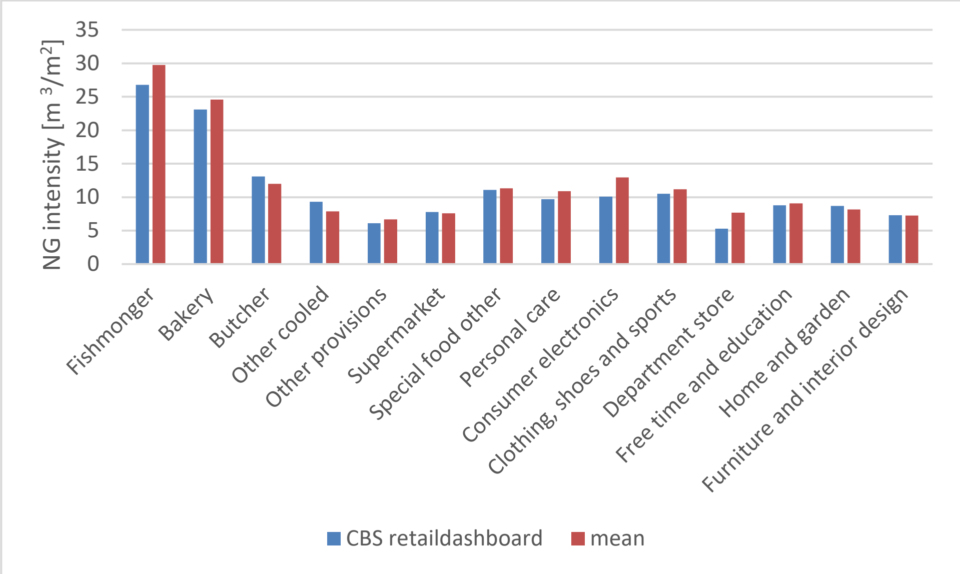


Figure 20. Comparison of NG intensity of 2018 from CBS retaildashboard and mean values of this dataset (CBS microdata, 2022; CBS, 2018)

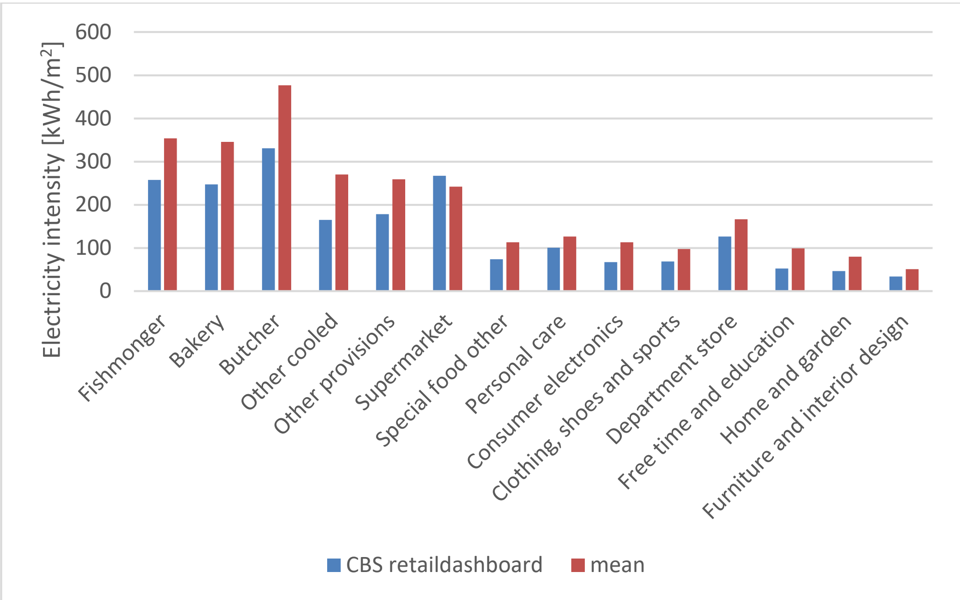


Figure 21. Comparison of electricity intensity of 2018 from CBS retail dashboard and mean values of this dataset (CBS microdata, 2022; CBS, 2018)

8.2 Expert validation

Expert validation was performed with an energy audit expert and a smart metering expert. INNAX is specialized in the smart energy metering in particular in non-residential buildings and developed tools for energy management. The results were discussed and for some energy applications the calculations were adjusted. The energy intensity of hot water and product cooling were adjusted based on shared insights. The use of ventilation was verified. Also, trends which are observed when comparing the research to Meijer were discussed. This resulted in the finding that the increase in intensity for transport is not in line with expectations. The change in intensity could be due to overestimation of the current numbers, or an unrepresentative sample or underestimation in the previous research. The estimations for ICT centralized are significantly higher, however, this is based on a small sample of supermarkets and has therefore not been extrapolated to the overall results.

Validation with Anonymous2, an energy audit expert for shops (2022) led to the following. They confirmed the methodology and the overall results. They also note that they normally consider less energy applications, due to the large uncertainty related to the small applications.

8.3 Overview

As can be concluded from the validation, the bottom-up results for shops non-food and supermarkets seem to represent the average situation. For the food speciality shops, little validation could be performed. Together with the large variety in energy intensity, and the small population size, it needs to be noted that more research - when more data is available- is recommendable to further validate the results.

In the table below, the validation for each energy application is listed.

Table 48. Validation for each energy application

Energy application	Validation
Space heating	Actual NG consumption CBS and shares of boilers from database.
Hot water	A validation with the energy check-up gives insight in this estimation. the comparison is made with offices, since NG consumption is not broken down for shops and they are assumed to be comparable. The hot water consumption for offices is 5% of the total NG consumption. For both shops it is 1%.
Space cooling	For supermarkets discussed that this can be negligible (INNAX, 2022)
Ventilation	Air flow rate is lower than Meijer (=0.5). Also ECU assumes more ventilation. This could be due to exclusion of mobile ventilators and the simplified method.
Auxiliary equipment	Not validated, but marginal
Humidification	N.a.
Lighting inside	Based on measured data and corrected for modern technologies. Neprom research is slightly outdated, from 2014. Large differences between supermarkets and other shops could be due to the frequent upgrades in supermarkets, for which is not accounted for.
Product processing	Qualitative validation with INNAX.
Product cooling	Fitted to the supermarket product cooling of INNAX
ICT centralized	Increase in efficiency but also increase in overall applicability. Numbers are somewhat outdated. INNAX assumes 5 W/m^2 for supermarkets.
ICT decentralized	No validation
Transport	Comparably lower numbers than Meijer (2009). No reason to assume change. Either underestimation in previous research or overestimation or unrepresentative sample.
Light outside	No validation
Light emergency	Shop specific number by ISSO
Food and drink facility	For appliances relatively outdated numbers are used, namely from 2007. Increase compared to Meijer (2007). Increase is validated with INNAX qualitatively.
Other	No validation
Solar PV	Low data availability, no national data collection.

9 Discussion and conclusion

9.1 Limitations

This research has several limitations, of which the most important ones are discussed here.

Firstly, the results are very sensitive to the assumptions made in the determination of each energy application. The assumptions and calculation methods have been reflected with experts in the field, however, the energy intensity of the applications need to interpreted while bearing in mind the assumptions. Finding the most representative/relevant and up to date data for each application was strived for. However, for some applications, recent data (later than from 2000) could not be found, for instance, the food and drink category. It can be expected that this yields a higher energy intensity than should be found, due to gradual average efficiency improvements over the years. Also, due to lack of data not all assumptions could be made specifically for shops, in that case, an office is chosen as most representative. This was applied to hot water for instance.

Secondly, in this research it is chosen to fit the energy consumption to the unweighted mean. For some of the reference buildings, it is shown that the median, weighted and unweighted mean can differ substantially. Depending on the type of research, one indicator is preferred over another. This is also relevant for the type of installations and the number of all-electric shops. This is based on the number of shops and not on the floor area of these shops.

Thirdly, validation of the final results is very challenging. Comparison with other countries is hard because of the influence of the energy carrier mix, differences in appliances, and climatic conditions. Furthermore, it was found that energy audit companies are mostly specified in assessing individual building consumption, and aggregation to an average energy consumption is not their main expertise.

Fourthly, the administrated installations as gathered for the ‘EPA energy label database’ of the shops was not differentiated to shop types. There is however no consensus on the estimate of the energetic condition of unlabeled shops, about 30% is labeled, and in the sample used for this research, 68% scores label B or better (based on EPA) (van Eijk et al., 2021; BZK, 2022). This could results in a bias towards assuming more efficient installations than actually present in the entire stock, or simultaneously, it could also lead to an overestimation of shops with installations for space cooling or ventilation.

Fifthly, the fit factor applied for total electricity consumption ranged between 80 and 105%, therefore tweaking with indoor lighting and ‘other’ has taken place. These tweaking are sensitive to interpretations.

Lastly, the penetration of heat exchangers in supermarket leads to changes in the energy balance, however, quantification was not possible due to data limitations. The utilization of waste heat of product cooling (e.g. heat recovery installations) and ovens requires a new allocation method to build an energy balance as presented in this research. This also relevant for space cooling which is not necessary in supermarkets due to the product cooling in the shop.

9.2 Knowledge gaps and future research

While defining the energy consumption for each energy application it is clear that some of the knowledge gaps remain. First of all, zooming out from shop type to four reference buildings, leaves a large and right skewed distribution in energy consumption, especially for food speciality stores. It could be assumed that this variation is dependent on the type of product preparation and the extend of product cooling. Also, the applied indoor lighting has a major influence on the electricity consumption, therefore, when zooming in, this is a key driver of the variation. For instance, a difference of 15 W/m^2 in installed capacity, representing LED vs TI lighting, makes a 36 kWh/m^2 impact on the final electricity consumption. For shops non-food, this would be about 1/3rd of the electricity consumption.

Secondly, data availability for some of the energy applications was rather low. This was especially the case for, firstly, space cooling, since only the installed appliances could be taken into account. Furthermore, product processing, since it is a mere estimation of the relevant appliances. Surveys or monitoring research could give more insight in the relevant applications. Thirdly, for solar PV, it was found that the theoretical electricity production and feed-in electricity did not match. Therefore, the gathered solar PV production determined for supermarkets and large shops non-food is most likely an underestimation.

Comparison with the research by Meijer (2009) gave some insight in changes in the sector over the past decade. Some striking results were an increase in transport and only partly an increase in space cooling. Future research could focus on data collection of these energy applications. For space cooling, more insight is needed in the penetration of air conditioners and the operation hours. For transport research can validate whether a representative sample was used in this study. Also, the validation for some of the energy applications could be improved, and focus on the food speciality stores. This is especially relevant due to the high NG consumption, which needs to be phased out quickly.

9.3 Conclusion

In this research a bottom-up method has been developed to estimate a breakdown of energy consumption of different shop types. The bottom-up method has proven to estimate the average final electricity consumption of shops with a fit factor varying between 80 and 105%. These were tweaked to 100% by adjusting the category other, indoor lighting and product cooling. For NG the method is top down using the actual consumption, which implies a 100% fit factor. It is concluded that these methods for gas and electricity yields a reasonable approximation. Validation of the results is challenging due to the lack of comparable research. Expert insights have provided some validation of assumptions for shops non-food and supermarkets. There is still room for improvement in the methodology for energy applications which face most uncertainty, like transport, outdoor lighting, product processing and ICT decentralized. Energy applications require periodical checking of the assumptions made especially the ones which are large contributors to the total, like indoor lighting. When interpreting the data, it should always be kept in mind that the retail sector is very heterogeneous and energy consumption per shop type and even within the shop types shows large variation and is skewed to the right. The assumptions made are adjustable to the relevant situation, but are intended to represent the ‘average situation’ in the stock. It should be stated that data availability is key for this type of research, and that with better data availability better methods can be developed. This in turn leads to more representative results.

In further research, a next step is to apply the same method and data sources (in a similar way) to other sectors, preferable a more homogenous sector where less variety occurs. The method developed in this research is intended as a first step in the development of a transparent method, which can be applied to other building types as well after slight modifications of the method and assumptions. Energy applications which are shared between building types can be estimated in the same way, only need to add new applications.

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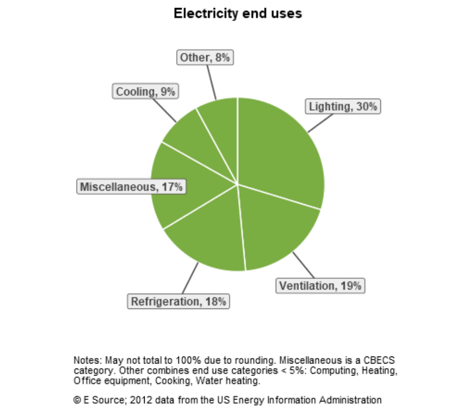
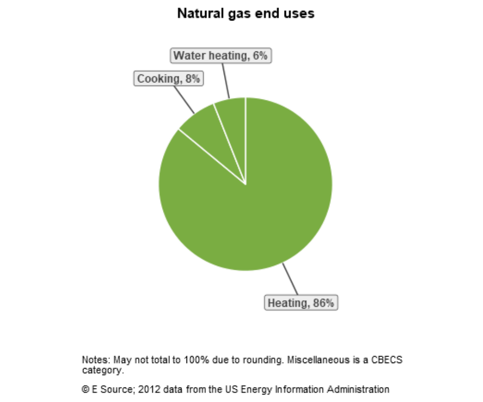
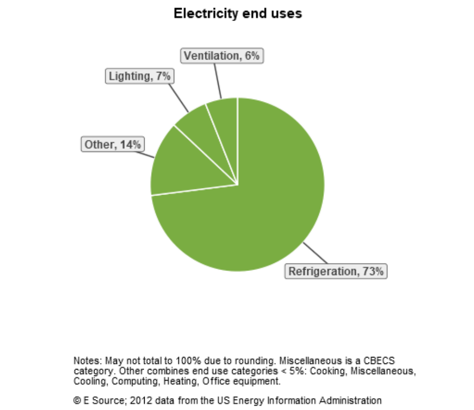
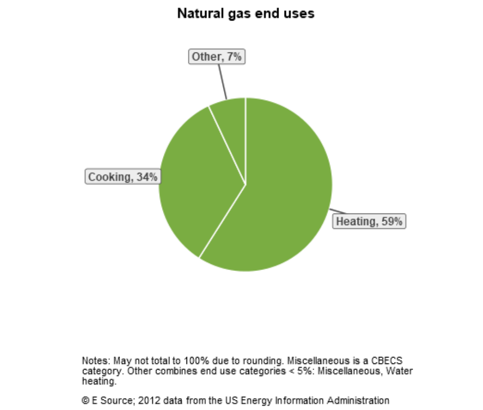
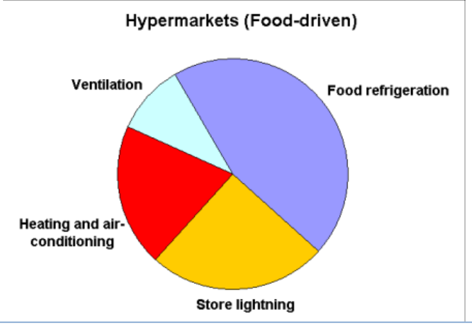
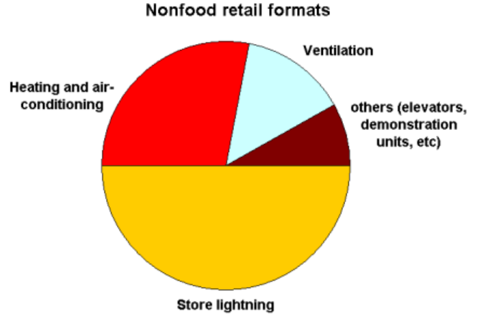
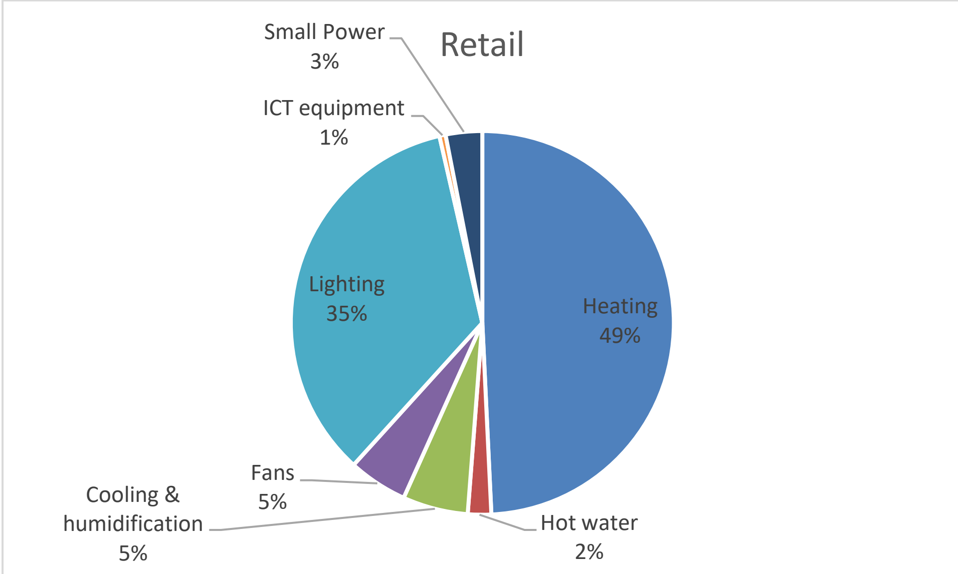
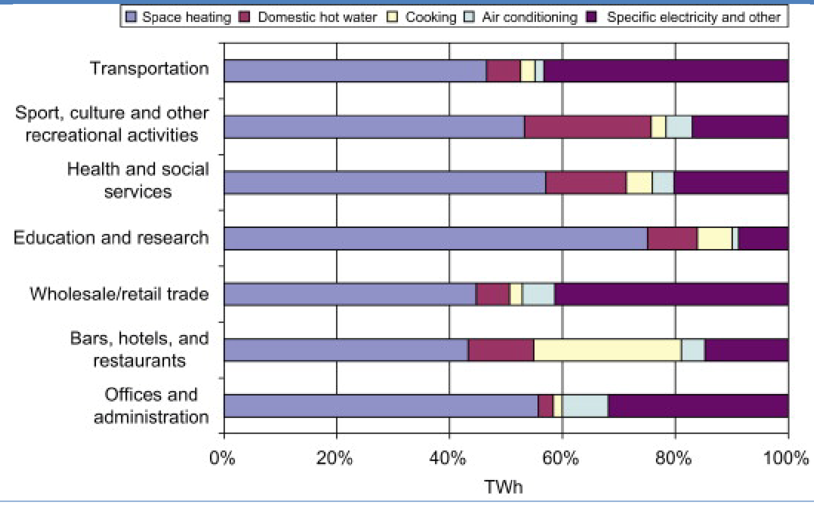
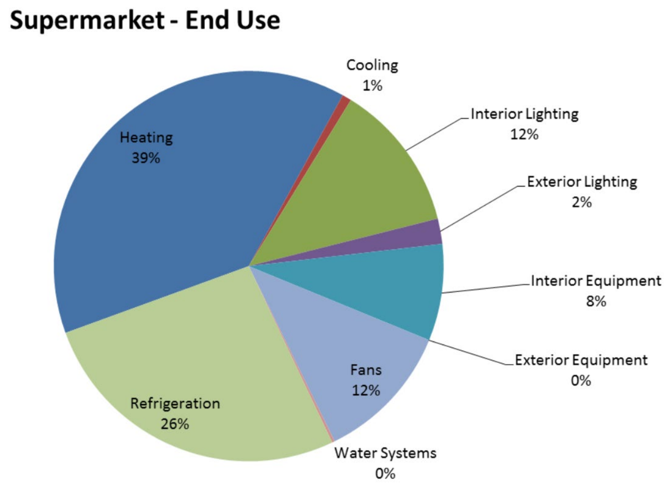
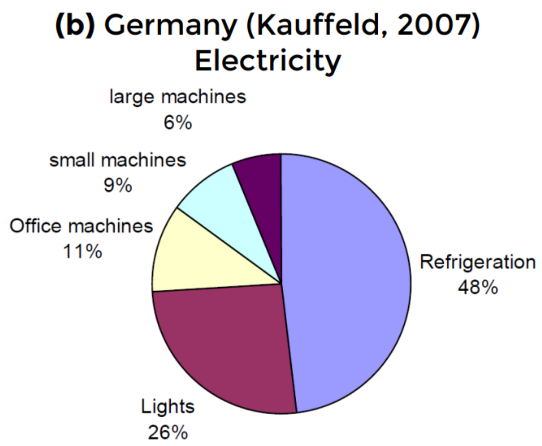
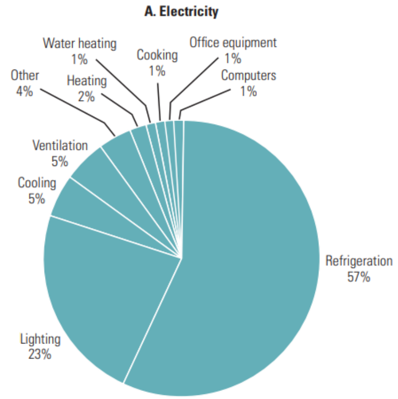
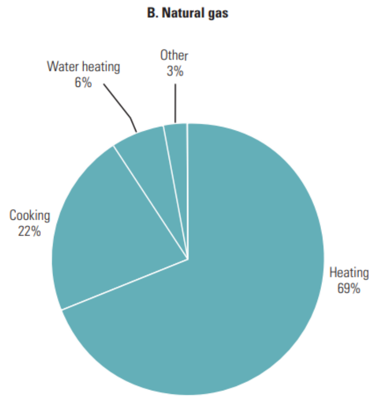
A Literature study of energy consumption for energy application

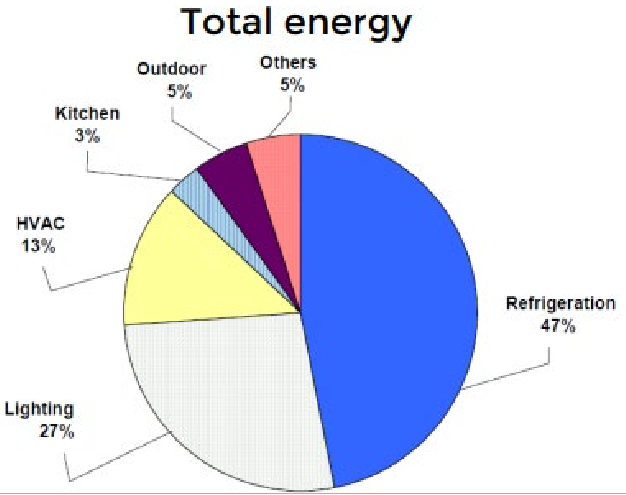
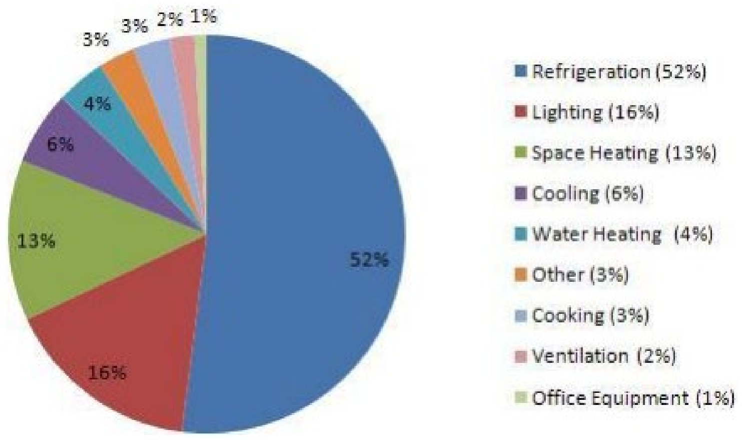
Sector	Intensity	Building related %	Source and data availability	Breakdown electricity (or total energy)	Break down natural gas
US retail	197 kWh/ m^2 and 389.529 MJ/m^2	Electricity, 57%	[Business Energy Advisor | Retail Buildings (bizenergyadvisor.com)] data from US Energy Information Administration, 2012		
US grocery store	565 kWh/m^2 and 431.52 MJ/m2	Electricity, 13%	[Business Energy Advisor | Retail Buildings (bizenergyadvisor.com)] data from US Energy Information Administration, 2012 also data for sector dry cleaners and hotels/motels.		

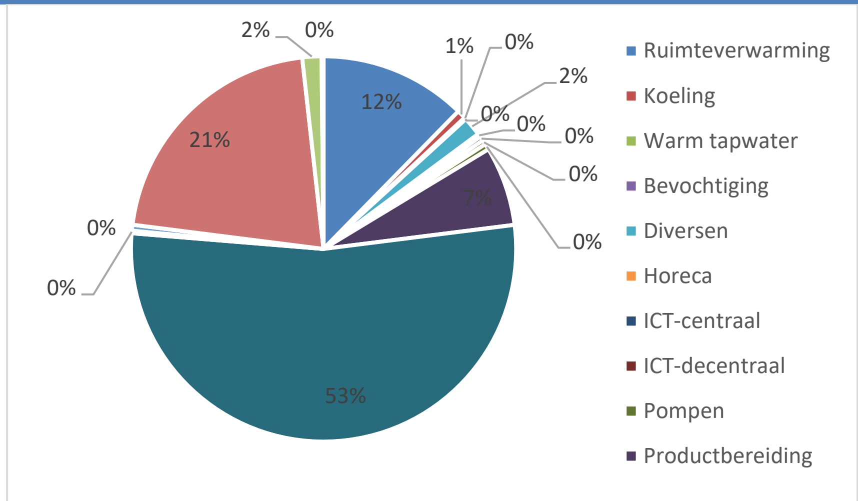
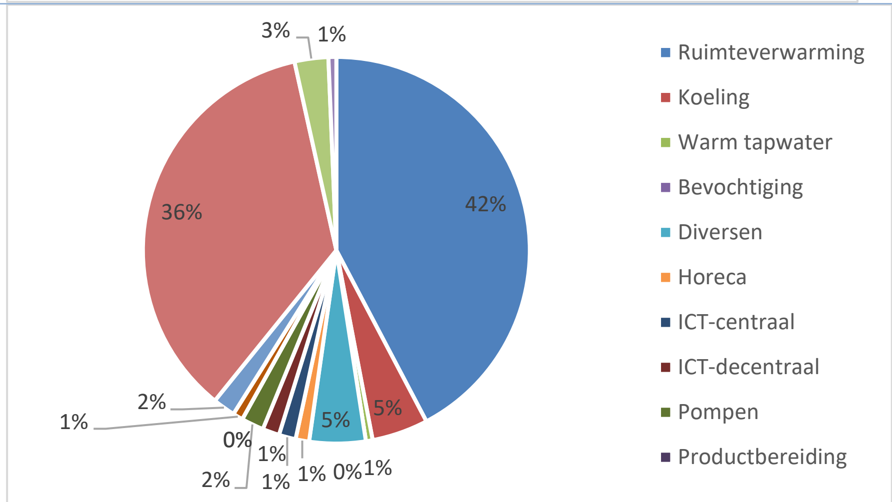
Sector	Intensity	Building related %	Source and data availability	Breakdown electricity (or total energy)	Break down natural gas
European Food driven retail	75% electricity	55% (visual estimation)	[untitled (europa.eu)] Issue paper on the energy efficiency of stores 2009 pie data from Eurocommerce, but numerical data not found..	(Total energy)  	
European Non- food retail	“”	92% (visual estimation)	[untitled (europa.eu)] Issue paper on the energy efficiency of stores 2009	(Total energy)  	

Sector	Intensity	Building related %	Source and data availability	Breakdown electricity (or total energy)	Break down natural gas
Retail UK	192 kWh/m^2 electricity And 50 kWh/m^2 non electricity	96%	BEES_overarching_report_FINAL.pdf (publishing.service.gov.uk) 2014-2015 Method: survey	(total energy) 	

Sector	Intensity	Building related %	Source and data availability	Breakdown electricity (or total energy)	Break down natural gas
French wholesale/retail trade sector		55% (visual estimation)	Determinants of energy demand in the French service sector: A decomposition analysis - ScienceDirect 2009 Method: survey Figure gives data from 2001		
Canadian food and beverage stores	2.8 GJ/m^2	63%	Heads Up: Building Energy Efficiency – Volume 2, Issue 3 (March) (nrcan.gc.ca) 2009 Method: survey Data from chart: 2009 Survey of Commercial and Institutional Energy Use - Buildings 2009 (nrcan.gc.ca) Update Survey of Commercial and Institutional Energy Use (SCIEU) - Buildings 2014 – Data Tables | Natural Resources Canada (nrcan.gc.ca)		

Sector	Intensity	Building related %	Source and data availability	Breakdown electricity (or total energy)	Break down natural gas
German supermarkets		26%	Supermarket Refrigeration Systems in Germany - · PDF fileenergy related global warming contribution varies from 50 % for a R404A multiplex system with 300 kg refrigerant charge, 10 - [PDF Document] (documents.pub) No data souce		
Grocery store in the US		Electricity: 36%	Managing Energy Costs in Grocery Stores (dsoelectric.com) 2010 Data from the U.S. Energy Information Administration		

Sector	Intensity	Building related %	Source and data availability	Breakdown electricity (or total energy)	Break down natural gas
Supermarket Sweden		40%	Documents download module (europa.eu) Eco-friendly Supermarkets - an Overview 2000		
Australia grocery and food		41%	85180.pdf (qut.edu.au) Data from 2003 2 Australia Food and Grocery Council (2003) Environment Report. 2003, Produced by the Australian Food and Grocery Council as part of its Eco-Efficiency Agreement with Environment Australia (now the Department of Environment and Water).		

Sector	Intensity	Building related %	Source and data availability	Breakdown electricity (or total energy)	Break down natural gas
Supermarket		35%	Meijer 2009		
Shop non-food		68%	Meijer 2009		

Sector	Intensity	Building related %	Source and data availability	Breakdown electricity (or total energy)	Break down natural gas
Theoretical building related shop in NL	Only building related		Neprom, 2014