A Comparison of Canadian and European Energy Standards for Household Appliances

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Executive Summary

This study explores the Canadian and European energy standards for household appliances that are modelled for Passive House compliance in PHPP for residential buildings. The household appliances included in this report are: dishwashers, clothes washers, clothes dryers, refrigerators, freezers, combination refrigerator-freezers, and cooktops.

The Canadian, European and, ENERGY STAR® standards for household appliances have different metrics depending on the type of appliance. To compare the Canadian, European, and ENERGY STAR standards, these metrics are converted and compared to the PHPP metrics for the individual appliances found in the electricity worksheet of PHPP.

This study also investigates the energy modelling and usage assumptions to understand how product efficiency and occupancy usage influence the annual energy demand of appliances.

Product efficiency requirements varying greatly across product categories, appliances types and product standards. The European requirements are generally more stringent than their Canadian counterparts, but this is not always the case. The Best in Class appliances available in the German market are generally more energy efficient then the top performing ENERGY STAR appliances, however there are some exceptions.

The assumed cycles per year for dishwashers, clothes washers and clothes dryers vary greatly over the various energy standards investigated in this study. Due to the lack of external data, it is difficult to say if the difference in cycles per year are based on cultural practices or just varying assumptions. The usage assumptions for PHPP are lower than HOT2000 especially for clothes washer. PHPP cycles per year are more aligned with those used by the European Energy Standard except for dishwashers which is drastically lower. This differences in usage assumptions between Canadian and European standards have a large impact on the calculated annual energy demand. This is most notable for clothes dryers, for which there is substantial variability in cycles per year assumed by the various energy standards. The annual energy demand of dishwashers and clothes washers on the other hand are less effected by the usage assumptions.

An excel tool **PHPP Appliance Input Calculator** has also been developed to help PHPP Users extract data from EnerGuide or ENERGY STAR appliance labels and calculate an input that can be used in the Electricity worksheet of PHPP. As general guidance, appliance energy use should be changed in residential buildings only if planning or concept for efficient use of electricity exists, otherwise standard values already entered in PHPP should be used. When the products only meet the Canadian minimum requirements, PHPP users could generate a variant including the actual normal demand of the products as a stress test to see the impact on summer internal heat gains (IHG) and PER/PE demand.

1. Introduction

This study explores the Canadian and European energy standards for household appliances that are modelled for Passive House compliance in PHPP for residential buildings. The household appliances included in this report are: dishwashers, clothes washers, clothes dryers, refrigerators, freezers, combination refrigerator-freezers, and cooktops. The energy regulations for these appliances can be found here:

Canada - http://www.nrcan.gc.ca/energy/regulations-codes-standards/6861

Europe - https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficient-products

ENERGY STAR requirements for household appliances are also reported to represent the best available appliances, in terms of energy performance, available on the North American market. The ENERGY STAR name and symbol are trademarks registered in Canada by the United States Environmental Protection Agency and are administered and promoted by Natural Resources Canada.

The Canadian, European and, ENERGY STAR standards for household appliances have different metrics depending on the type of appliance. To compare the Canadian, European, and ENERGY STAR standards, these metrics are converted and compared to the PHPP default inputs for the individual appliances found in the electricity worksheet of PHPP.

The default values in PHPP are based on surveys, reports or data of the VDEW, the HEA, ZVEI and Agb (Arbeitsgemeinschaft Energiebilanzen), as well as PHI's own studies and extrapolations of electricity consumption and comparison with actual data. This includes studies from 1985/86 (commissioned by the Land Government of Hesse), research for CEPHEUS (Cost Efficient Passive Houses as European Standards), as well as consultancy services carries out for the cities of Wiesbaden and Hannover.

German Best in class products are taken from spargeraerte.de and are provided for comparison. The authors have not completed an exhaustive search and make no claims that the products definitely represent the best available products on the German market.

HOT2000 default assumptions for appliance energy demand are also compared.

An excel tool **PHPP Appliance Input Calculator** has also been developed to help PHPP Users extract data from EnerGuide or EnergyStar appliance labels and calculate an input that can be used in the Electricity worksheet of PHPP.

2. Dishwasher

2.1. Definitions and Performance Requirements

2.1.1. Canadian Energy Standard

Test Standard: CAN/CSA-C373-14

Energy Efficiency Standard:

Energy performance standards are separated based on the size (standard vs. compact). The energy efficiency standard specifies a maximum total annual energy consumption of 307 kWh for standard dishwashers and 222 kWh for a compact dishwasher. The calculation is based on 215 cycles per year and eight (8) place settings plus six (6) serving pieces for standard dishwasher and four (4) place settings plus six (6) serving pieces for a compact dishwasher.

2.1.2. European Energy Standard

Ecodesign Requirements (Energy Related):

The ecodesign requirement, for dishwashers, is an energy efficiency index (EEI) of less than 63.

The EEI is calculated as follows:

$$EEI = \frac{AE_c}{SAE_C} \times 100$$

Where,

AE_C = weighted annual energy consumption of the household dishwasher

SAE_C = standard annual energy consumption of the household dishwasher

The standard annual energy consumption (SAEC) is calculated in kWh/year.

For household dishwashers with rated capacity ps ≥ 10 and width > 50 cm (standard):

$$SAE_C = 7.0 \times ps + 378$$

For household dishwashers with a rated capacity of ps ≤ 9 or ps > 9 and width ≤ 50cm (compact):

$$SAE_C = 25.2 \times ps + 126$$

Where,

ps = number of place setting

2.1.3. ENERGY STAR®

The efficiency requirement for ENERGY STAR dishwashers is a total annual energy of less than 270 kWh/year for standard dishwashers (capacity ≥ 8 place settings + 6 serving pieces) and less than 203 kWh/year for compact dishwasher (capacity < 8 place settings + 6 serving pieces). The testing conditions are 8 place settings plus 6 serving pieces for standard dishwashers and 4 place settings plus 6 serving pieces for compact dishwashers. The calculation for total annual energy is based on 215 cycles/year.

2.2. Comparison of Performance Requirements

2.2.1. PHPP

The default PHPP input for a dishwasher is 1.1 kWh/cycle[1], assuming 12 place settings[2].

2.2.2. Canadian Energy Standard

The Canadian energy efficiency standard for dishwashers can be translated into a kWh/cycle value by dividing the annual energy consumption by the total number of standard cleaning cycles per year. The Canadian test standard CAN/CSA-C373-14 assumes 215 cycles per year. In order to compare the Canadian energy efficiency standard for dishwashers with the default PHPP input the annual energy consumption should be scaled to 12 place settings, as assumed in PHPP. The Canadian test standard CAN/CSA-C373-14 specifies a test load size of 8 place settings for a standard dishwasher.

A linear relationship between the annual energy consumption and load size (place settings) is assumed in order to scale the maximum annual energy demand as defined in the Canadian Energy Standard to 12 place settings. It is noted that there was no information in the Canadian testing standard CAN/CSA-C373-14 that could be used to calculate how the energy use of a dishwasher would scale with the number of place settings.

Standard

$$Annual\ Energy\ Demand_{12\ ps} = 307kWh \times \frac{12\ pc}{8pc} = 460.50\ kWh$$

$$Norm\ Demand = \frac{460.50\ kWh/year}{215\ cycles/year} = 2.14\ kWh/cycle$$

A similar calculation is done for a compact dishwasher. Results are shown in Table 2.1 below.

2.2.3. European Energy Standard

The European ecodesign requirement for dishwashers can be translated into a PHPP Normal Demand value (kWh/cycle) by dividing the weighted annual energy consumption of a household dishwasher (AE_C) by the average number of cycles per year. The calculation assumes 12 place settings based on the assumption in PHPP. An average of 280 cycles per year is referenced in the ecodesign requirement and used in this calculation.

Standard

$$SAE_C = 7.0\ \times\ ps + 378 = 7.0\ \times\ 12 + 378 = 462.00\ kWh/year$$

$$AE_c = SAE_C \times \frac{EEI}{100} = \frac{462.00\ kWh}{year} \times \frac{63}{100} = 291.06\ kWh/year$$

[1] At present, documented sources for these data were not available. The default inputs in PHPP are plausible values from older versions of PHPP based on different sources and publications.

[2] PHPP uses the terminology measure cover which is equivalent to a place setting. PHPP uses the European standard EN50242 which also includes serving pieces, accessed December 17 2018: https://de.wikipedia.org/wiki/EN_50242,

$$Norm\ Demand = \frac{291.06\ kWh/year}{280\ cycles/year} = 1.04\ kWh/cycle$$

A similar calculation is done for a compact dishwasher, except the equation for the standard annual energy consumption (SAE_C) of a compact household dishwasher is used. Results are shown in Table 2.1.

2.2.4. ENERGY STAR®

The ENERGY STAR requirements for dishwashers can be translated into a kWh/cycle value by dividing the annual energy demand by the number of loads per year. ENERGY STAR assumes an annual usage of 215 loads per year[3]. It is noted that these figures are based on 8 place settings for a standard dishwasher.

Using the same methodology as outlined in the section 2.2.2, the total annual energy consumption is scaled to 12 place settings to compare with the PHPP default input.

Standard

$$Annual\ Energy\ Demand_{12\ pc} = 270kWh \times \frac{12\ pc}{8pc} = 405.00\ kWh$$

$$Norm\ Demand = \frac{405.00\ kWh/year}{215\ cycles/year} = 1.88\ kWh/cycle$$

A similar calculation is done for compact dishwasher. Results are shown in Table 2.1

The top performing ENERGY STAR standard and compact dishwashers were found to have an annual energy demand of 199 kWh[4] and 144kWh[5] respectively. A similar calculation is done to convert to a PHPP Normal Demand (kWh/cycle). The results are shown in Table 2.1.

2.2.5. Best in Class available in the German Market

Calculations of the PHPP Normal Demand (kWh/cycle) for the best in class standard dishwasher available in the German Market are calculated using the same methodology as in section 2.2.2. The most energy efficient standard dishwasher (ps ≥ 10) has an annual electricity consumption of 188kWh and a capacity of 10 place settings as found on spargeraete.de[6]. The calculation assumes 280 cycles per year as per the European Energy Standard.

$$Annual\ Energy\ Demand_{12\ pc} = 188kWh \times \frac{12\ pc}{10pc} = 225.60\ kWh$$

[3] U.S. Department of Energy test procedure, Code of Federal Regulation, Title 10, Section 430, Subpart B, Appendix C

[4] Miele - G 6935 SCi, accessed on: September 19, 2018, https://www.energystar.gov/productfinder/product/certified-residential-dishwashers/details/2279011

[5] Fisher and Paykel – DCS -71327, accessed on: December 27, 2018, https://www.energystar.gov/productfinder/product/certified-residential-dishwashers/details/2300702

[6] Bosch SPS66TW01E, accessed on: December 20, 2018 https://www.spargeraete.de/SearchResults/Details/SPUEL_BOSCH_SPS66TW01E

$$Norm\ Demand = \frac{225.60\ kWh/year}{280\ cycles/year} = 0.81\ kWh/cycle$$

A similar calculation is done for the most energy efficient compact dishwasher (ps ≤ 9) which has an annual electricity consumption 176kWh and a capacity of 9 place settings[7].

[7] Bosch SPS86M12DE, accessed on: December 18, 2018
https://www.spargeraete.de/SearchResults/Details/SPUEL_BOSCH_SPS86M12DE

2.2.6. Dishwasher Normal Demand Comparison

Table 2.1: Dishwasher PHPP Normal Demand

	PHPP Default	Canadian Energy Standards		European Energy Standards		ENERGY STAR				Best in Class German Market	
						Minimum Requirement		Top Performing			
		Standard	Compact	Standard	Compact	Standard	Compact	Standard	Compact	Standard	Compact
Normal Demand (kWh/cycle)	1.10	2.14	3.10	1.04	1.39	1.88	2.83	1.39	2.01	0.81	0.84
% relative to PHPP default		195%	282%	95%	126%	171%	258%	126%	183%	73%	76%
Total kWh per year	215	418	604	203	271	367	552	271	392	157	163

Table 2.1 summarizes the PHPP Normal Demand for the various scenarios calculated above, all normalized to 12 place settings, along with the % difference relative to the PHPP default. Also shown are the resultant kWh/year based on 195 cycles per year[8]. From the results it is clear that ENERGY STAR rated dishwashers are generally less energy efficient than the PHPP default. The Best in class dishwashers available in the German market have superior performance to the top performing ENERGY STAR dishwashers.

[8] Number of cycles per year is calculated as 65 cycles per person multiplied by 3 people

3. Clothes Washer

3.1. Definitions and Performance Requirements

3.1.1. Canadian Energy Standard

Test standard: CAN/CSA-C360-13

Energy Efficiency Standard:

Energy performance standards are separated based on the rotational axis (vertical or horizontal) and size (standard vs compact). For this study, the energy performance of a vertical-axis (top loading) compact[9] clothes washer, and horizontal-axis (front loading) standard[10] clothes washer are investigated, as these are the least and most stringent performance requirements, respectively. The energy efficiency standard specifies a minimum integrated modified energy factor of 32.56L/(kWh/cycle) for a vertical-axis (top loading) compact clothes washer and 52.10 for a horizontal-axis (front loading) standard clothes washer, respectively.

The Integrated Modified Energy Factor (IMEF) is defined as

$$IMEF = \frac{C}{E_{TE} + D_E + E_{TLP}}$$

Where,

C = the capacity of the clothes container (L)

E_{TE} = the total per-cycle energy consumption, assuming electrically heated water is being used (kWh/cycle)

D_E = the per-cycle energy required to remove moisture from the test load (kWh/cycle)

E_{TLP} = per cycle combined low-power mode energy consumption (kWh/cycle)

Testing for the machine's electrical energy, hot water energy consumption and energy required for the removal of the remaining moisture in the wash load is done at minimum, maximum and average load sizes which are determined by the capacity of the washer (refer to Table 3 in CAN/CSA-C360-13). Testing is also done at different wash temperatures depending on the number of selections available. This can include up to 7 different temperature settings: extra-hot wash, hot wash, warm wash, cold wash, warm wash and warm wash/warm rinse cycles. The test load should be spun dry until the Remaining Moisture Content (RMC) is between 54-61% of bone-dry test load. For reference, the default remaining moisture content in PHPP is 60%.

The remaining moisture content is calculated as follows

$$RMC = \frac{WC - WI}{WI}$$

[9] Compact clothes washers are defined as a clothes washer with a capacity of less than 45L

[10] Standard clothes washers are defined as a clothes washer with a capacity of 45L or greater

Where,

WC = the weight of the test load immediately after completion of the wash cycle (kg)

WI = the bone-dry weight of the test load (kg)

The EnerGuide label for clothes washers also includes an annual energy consumption (kWh/year), based on 295 cycles/year, which does not include the energy to remove the remaining moisture. However, there is no performance requirement for annual energy consumption in the Canadian Energy Standard. Therefore, the IMEF must be used to calculate the minimum performance requirement.

3.1.2. European Energy Standard

Ecodesign Requirements (Energy Related):

The ecodesign requirement, for all washing machines, is an energy efficiency index (EEI) of less than 68.

The EEI is calculated as follows:

$$EEI = \frac{AE_c}{SAE_C} \times 100$$

Where,

AE_C = weighted annual energy consumption of the household washing machine (kWh/year)

SAE_C = standard annual energy consumption of the household washing machine (kWh/year)

The **standard annual energy consumption (SAE_C)** is calculated in kWh/year as follows:

$$SAE_C = 47.0 \times c + 51.7$$

Where,

c = rated capacity of the household washing machine (kg)

The **weighted annual energy consumption (AE_C)** is calculated in kWh/year as follows:

$$AE_C = E_t \times 220 + \frac{\left[P_0 \times \frac{525600 - (T_t \times 220)}{2} + P_1 \times \frac{525600 - (T_t \times 220)}{2}\right]}{60 \times 1000}$$

Where,

E_t = weighted energy consumption

P_0= weighted power in “off mode”

P_1 = weighted power in “left-on mode”

T_t= programme time

220 = total number of standard washing cycles per year

E_t, P_0, P_1 and T_t are calculated based on testing done at full load and partial load and at 40°C and 60°C. Details on the testing and calculation can be found in Annex II of the EU ecodesign regulation for household washing machines.

The weighted AEc does not include the remaining moisture content and is therefore comparable to the AEc defined by the CAN/CSA-C360-13. The remaining moisture content is defined as the residual moisture contained in the load at the end of the spinning phase, expressed in a percentage of water content. The manufacturer is required to disclose information on the remaining moisture content contained in the load at the end of the spinning phase (for the main washing programmes at full or partial load) in the form of a booklet of information among other items to the consumer.

3.1.3. ENERGY STAR®

Efficiency requirements are based on product type. Different clothes washer types include: top vs front-loading, greater than 2.5ft^3 (standard) or equal to or less than 2.5 ft^3(compact). For this study, the energy performance of a compact front-loading (<2.5ft^3) and a standard front-loading (>2.5ft^3) clothes washer are used. Compact top-loading clothes washer were not investigated as no ENERGY STAR units could be found during the preparation of this report. The ENERGY STAR standard specifies a minimum Integrated Modified Energy Factor (IMEF) of 2.07 ft^3/kWh/cycle (58.62 L/(kWh/cycle and 2.76 ft^3/kWh/cycle (78.15 L/(kWh/cycle)) for the compact front-loading and standard front-loading clothes washers, respectively. The IMEF has the same definition as defined for the Canadian Energy Standard except the capacity is measured in ft^3.

3.2. Comparison of Performance Requirements

3.2.1. PHPP

The default PHPP input for a clothes washer is 1.1 kWh/cycle[11], assuming one cycle consists of a 5kg load at a residual dampness of 60%.

3.2.2. Canadian Energy Standard

For this analysis the smallest capacity top-loading compact, a standard front-loading clothes washer with a capacity that would equate to an average load size of 5kg (according to Table 3 in CAN/CSA-C360-13), and the largest capacity front-loading standard clothes washers available on the Canadian market are compared. The 5kg load is chosen to match the PHPP normalized load size. The clothes washers available in Canada are listed on the NRCan website. The smallest and largest units were also chosen according to the availability of similar sized clothes washers for ENERGY STAR and German Best in Class, in order to have the results be comparable (i.e. to mitigate the influence of washer capacity on the results). Since the smallest compact clothes washer in the German market was found to have a capacity of 3kg (see Section 3.2.5), the top-loading compact clothes washer chosen had a capacity of 43.89L which is equivalent to a maximum load of 2.9kg.

The calculation for the Canadian requirements for clothes washers in kWh/cycle are as follows

Vertical-axis (top loading) standard clothes washer - smallest unit

[11] At present, documented sources for these data were not available. The default inputs in PHPP are plausible values from older versions of PHPP based on different sources and publications.

The smallest compact top loading clothes washer unit is 43.89L, has an IMEF of 32.57L/(kWh/cycle) and an annual energy consumption of 100 kWh. The minimum total demand per cycle including machine energy, hot water energy and the energy to remove the remaining moisture is calculated as the capacity of the clothes washer divided by the IMEF (as defined in the Canadian standard) and multiplied by a scaling factor that adjusts the results to the PHPP default load of 5 kg. The scaling factor assumes a linear relationship between the load size and energy consumption. This is not strictly true, as there is energy that the machine would consume if it were run with no load. The European standard equation for SAEc hints at this by allocating a portion of the annual energy that independent of the capacity. The assumed linear relationship is deemed to be a reasonable assumption, however, as the equation suggests the majority of the energy demand is load-dependent (e.g. for a 5kg load, over 80% of the annual energy is dependant on capacity). Referring to Table 3 in *CAN/CSA-C360-13*, the capacity of the clothes washer (L) can be translated into an average load (kg). The average load for a 43.89 L capacity clothes washer is 2.9kg and so the scaling factor is 5kg divided by 2.9kg.

$$Total\ Demand\ per\ cyle = \frac{43.89\ L}{32.56\ \mathrm{L}/(\frac{\mathrm{kWh}}{\mathrm{cycle}})} \times \frac{5kg}{2.9kg} = 3.16\ kWh/cycle$$

In order to calculate the PHPP Normal Demand (kWh/cycle), the moisture removal energy must be calculated and subtracted from the above total demand per cycle. The moisture removal energy (D_E) is calculated by subtracting the demand per cycle (machine + hot water) from the total demand per cycle (machine + hot water + moisture). It is noted that is it not possible to calculate a Normal Demand without selecting a specific machine, because the Canadian Standard does not specify a maximum Annual Energy Demand. These values are thus derived from the EnerGuide label of the smallest standard front-loading clothes washer to provide a representative machine.

$$D_E = \frac{43.89\ L}{32.57\ \mathrm{L}/(\frac{\mathrm{kWh}}{\mathrm{cycle}})} - \frac{100\ kWh}{295\ \mathrm{cycles}} = 1.01\frac{kWh}{cycle}$$

This moisture removal energy is then scaled to a 5kg load.

$$D_E = 1.01 \times \frac{5kg}{2.9kg} = 2.37\ kWh/cycle$$

Subtracting the moisture removal energy from the total demand per cycle, a normal demand can be calculated.

$$Normal\ Demand = 3.16\frac{kWh}{cycle} - 2.37\frac{kWh}{cycle} = 0.80\ kWh/cycle$$

The EnerGuide performance measures for the smallest capacity top-loading compact, a standard front-loading clothes washer with a capacity that would equate to an average load size of 5kg (as according to Table 3 in CAN/CSA-C360-13), and the largest capacity front-loading standard clothes washers are summarized in Table 3.1. A similar calculation is done for these units to convert to a PHPP normal demand (kWh/cycle). The results are shown in Table 3.4.

Table 3.1 EnerGuide performance measures for largest and smallest top front-loading and top-loading clothes washers

	Top-loading (vertical axis) compact	Front-loading (horizontal axis) standard	
	smallest[12]	Avg load size 5kg[13]	largest[14]
Capacity (L)	43.89	127.99	163.30
Annual Energy Consumption (kWh)	100	128	120
IMEF (L/(kWh/cycle))	32.57	78.16	87.78

3.2.3. European Energy Standard

The European ecodesign requirement for clothes washer can be translated into a PHPP Normal Demand value (kWh/cycle) by dividing the weighted annual energy consumption of a household clothes washer (AE_C) by the average number of cycles per year. An average of 220 cycles per year is referenced in the ecodesign requirement and used in this calculation. The European testing standard tests at full load (max capacity) and partial load (half of full load) with a weighting of 3/7 for full load and 4/7 for partial loads. Therefore, for a 5kg average test load the dryer capacity would need to be 7kg

$$Average\ test\ load = \frac{(3 \times full\ load) + (4 \times partial\ load)}{7}$$

$$5kg = \frac{(3 \times full\ load) + (4 \times \frac{full\ load}{2})}{7} = \frac{5\ \times full\ load}{7}$$

$$full\ load = \frac{5kg\ \times 7}{5} = 7kg$$

$$capacity = full\ load = 7kg$$

All Clothes Washers

$$SAE_C = 47.0\ \times\ c + 51.7 = 47 \times 7kg + 51.7 = 380.70\ kWh/year$$

[12] Kenmore - 4443*81*, accessed: December 30, 2018, http://oee.nrcan.gc.ca/pml-lmp/index.cfm?action=app.formHandler&operation=details-details&ref=21721195&appliance=CLOTHESWASHERS&nr=1

[13] Maytag - MHW5630H**, accessed: December 30, 2018, http://oee.nrcan.gc.ca/pml-lmp/index.cfm?action=app.formHandler&operation=details-details&ref=24775104&appliance=CLOTHESWASHERS&nr=1

[14] LG - WM9500H*A, accessed: December 30, 2018, http://oee.nrcan.gc.ca/pml-lmp/index.cfm?action=app.formHandler&operation=details-details&ref=16681817&appliance=CLOTHESWASHERS&nr=1

$$AE_c = SAE_C \times \frac{EEI}{100} = \frac{380.70\ kWh}{year} \times \frac{68}{100} = 258.88\ kWh/year$$

$$Norm\ Demand = \frac{258.88\ kWh/year}{220\ cycles/year} = 1.18\ kWh/cycle$$

3.2.4. ENERGY STAR®

The ENERGY STAR requirements are calculated using the same methodology as used in section 3.2.2. For this analysis, the smallest capacity front-loading compact, a standard front-loading clothes washer with a capacity that would equate to an average load size of 5kg (as according to Table 3 in CAN/CSA-C360-13), and the largest capacity front-loading standard clothes washers are compared. It is noted that there were no top-loading compact clothes washers listed in the ENERGY STAR database at the time of access.

A summary table of the performance measures is shown in Table 3.2.

Table 3.2 EnergyStar performance measures for the smallest capacity front-loading compact, a standard front-loading clothes washer with a capacity that would equate to an average load size of 5kg, and the largest front-loading standard clothes washers.

	Front-loading (horizontal axis) compact	Front-loading (horizontal axis) standard	
	smallest[15]	Avg load size 5kg[16]	largest[17]
Capacity (L)	56.6	127.4	164.1 L
Annual Energy Consumption (kWh)	67	79	120
IMEF (L/(kWh/cycle))	99.05	90.56	87.73

The energy performance of the top performing ENERGY STAR clothes washers are shown Table 3.2. The Normal Demand is calculated by scaling the annual energy consumption to a 5kg load and dividing by 295 cycles per year.

Front-loading (horizontal axis) compact

$$Normal\ Demand = \frac{67kWh}{295\ cycles} \times \frac{5kg}{2.59kg} = 0.44kWh/cycle$$

[15] Beko - WTE 7604XLW0accessed: December 30, 2018, https://www.energystar.gov/productfinder/product/certified-clothes-washers/details/23181351

[16] Maytag - MHW8150E**, accessed: December 30, 2018, https://www.energystar.gov/productfinder/product/certified-clothes-washers/details/2310392

[17] LG - WM9500H*A, accessed: December 30, 2018, https://www.energystar.gov/productfinder/product/certified-clothes-washers/details/2310479

3.2.5. Best in Class available in the German Market

Calculations of the Normal Demand (kWh/cycle) for the best in class standard clothes washers available in the German Market are calculated by scaling the annual energy consumption to a capacity of 7kg (average test load size of 5kg) and dividing by 220 cycles per year[18].

A summary table of the performance measures of the best in class clothes washers as found on spargeraete.de is shown in Table 3.3.

Table 3.3 Spargeraete performance measures for the smallest capacity front-loading compact, a standard front-loading clothes washer with a capacity that would equate to an average load size of 5kg, and the largest front-loading standard clothes washers

	Front-loading (horizontal axis) compact	Front-loading (horizontal axis) standard	
	smallest[19]	Avg load size 5kg[20]	largest[21]
Capacity (kg)	3	8	11
Annual Energy Consumption (kWh)	112	58	130

Front loading (horizontal axis) smallest unit

A linear relationship between the annual energy consumption and the capacity of the clothes washer is assumed. The Normal Demand is then calculated by scaling the annual energy consumption linearly to a capacity of 7kg.

$$Norm\ Demand = \frac{112 \frac{kWh}{year} \times \frac{7kg}{3kg}}{220\ cycles/year} = 1.19\ kWh/cycle$$

The same calculation is repeated for the other best in class clothes washers.

[18] The annual electricity consumption is calculated on the basis of 220 washer per year

[19] Eumenia Euronova 1012, accessed: February 25, 2019 https://www.spargeraete.de/SearchResults/Details/WA_EUMENIA_EURONOVA1012

[20] Telefunken, accessed: February 25, 2019 https://www.spargeraete.de/SearchResults/Details/WA_TELEFUNKEN_TFW0641FE55

[21] Hoover DWFLS G411AH, accessed: February 25, 2019 https://www.spargeraete.de/SearchResults/Details/WA_HOOVER_DWFLSG411AH184

3.2.6. Clothes Washer Normal Demand Comparison

Table 3.4 Clothes Washer PHPP Normal Demand

	PHPP Default	Canadian Energy Standards			European Energy Standards	ENERGY STAR						Best in Class German Market		
						Minimum Requirement			Top Performing					
		Top-loading compact	Front-loading standard			Front-loading compact	Front-loading standard		Front-loading compact	Front-loading standard		Front-loading compact	Front-loading standard	
		smallest	5kg avg load	Largest	5kg avg load	smallest	5kg avg load	Largest	smallest	5kg avg load	Largest	smallest	5kg avg load	Largest
Capacity (kg)		2.9	8.46	10.69	7	3.82	8.46	10.88	3.82	8.46	10.88	3	8	11
Specific Demand (kWh/cycle)[22]		0.34	1.25	1.68		0.62	0.49	0.64	0.23	0.27	0.41	0.51	0.26	0.59
Normal Demand (kWh/cycle)	1.10	0.80	1.28	1.39	1.73	1.20	0.50	0.52	0.44	0.27	0.33	1.19	0.23	0.38
% difference relative to PHPP default		72%	116%	127%	157%	109%	46%	47%	40%	25%	30%	108%	21%	34%
Total kWh per year	188	136	218	218	296	205	86	89	75	47	57	203	39	64

Table 3.4 summarizes the PHPP Normal Demand for the various scenarios calculated above, all normalized to a 5 kg load, along with the % difference relative to the PHPP default and the resultant kWh/year based on 171 cycles per year[23]. The capacity of the clothes washer used in the calculation along with the Specific Demand (not normalized to a 5kg load) is also shown. From the results it is clear that all ENERGY STAR rated clothes washers, except the front-loading compact, will definitely be more energy efficient than the PHPP default. Note that no adjustments have been made to account for potential differences in the test temperatures between test standards, due to a) the complexity of the test procedures and b) the large variation in temperature settings across products. It is therefore assumed that a typical load is run at the same temperature, whether in North America or Europe.

[22] Not scaled to 5kg but based on the actual capacity

[23] Number of cycles per year is calculated as 57 cycles per person multiplied by 3 people

4. Clothes Dryers

4.1. Definitions and Performance Requirements

4.1.1. Canadian Energy Standard

Test Standard: CAN/CSA-C361-12 or 10 C.F.R Appendix D2

Energy Efficiency Standard:

The requirement for clothes dryers in Canada are based on the product type. Different dryer types include: conventional vs ventless, standard vs compact, 120V vs 240V and combination washer-dryer. For this study, the energy performance of a ventless compact electric (240V) dryer is compared to that of a conventional (vented) standard electric dryer[24]. The energy efficiency standard specifies a minimum combined energy factor of 1.16 kg/kWh and 1.69 kg/kWh for a ventless compact electric dryer and conventional standard electric dryer respectively.

The Combined Energy Factor is defined as[25]:

$$CEF = \frac{C(kg)}{E_{on} + E_{standby}}$$

Where,

C = load size (kg)

E_{on} = Machine Electric Energy Use During Operation Cycle

$E_{standby}$ = Machine Electric Energy Use During Standby

Testing is done using a test load size of 3.83kg (8.46lbs) for standard size dryers and 1.36kg (3lbs) for compact size dryers.

4.1.2. European Energy Standard

Ecodesign Requirements (Energy Related):

As of November 1 2015, the ecodesign requirement for a condenser household tumble dryer is an energy efficiency index (EEI) of less than 76.

The EEI is calculated as follows:

$$EEI = \frac{AE_c}{SAE_C} \times 100$$

Where,

AE_C = weighted annual energy consumption of the household tumble dryer

[24] There is no energy efficiency standard for ventless standard dryers

[25] https://www.energystar.gov/products/appliances/clothes_dryers/key_product_criteria

SAE_C = standard annual energy consumption of the household tumble dryer

For household tumble dryers that are not air-vented, the **standard annual energy consumption (SAE_C)** is calculated in kWh/year as follows:

$$SAE_C = 140 \times c^{0.8}$$

For household tumble dryers that are air-vented, the **standard annual energy consumption (SAE_C)** is calculated in kWh/year as follows:

$$SAE_C = 140 \times c^{0.8} - \left(30 \times \frac{T_t}{60}\right)$$

Where,

c = the rated capacity of the household tumble drier for the standard cotton programme (kg)

T_t = the weighted programme time for the standard cotton programme (min)

The **weighted annual energy consumption (AE_C)** is calculated in kWh/year as follows:

$$AE_C = E_t \times 160 + \frac{\left[P_0 \times \frac{525600 - (T_t \times 160)}{2} + P_1 \times \frac{525600 - (T_t \times 160)}{2}\right]}{60 \times 1000}$$

Where,

E_t = weighted energy consumption (kWh)

P_0= power in "off mode" for the standard cotton programme at full load (W)

P_1 = weighted power in "left-on mode" for the standard cotton programme at full load (W)

T_t= weighted programme time (min)

160 = total number of drying cycles per year

E_t and T_t are calculated based on testing done at full load (max capacity) and partial load. Details on the testing and calculation can be found in Annex II of the EU ecodesign regulation for household washing machines.

4.1.3. ENERGY STAR®

Efficiency requirements are based on product type. Different dryer types include: vented vs ventless, gas vs electric, standard vs compact, 120V vs. 240V. For this study, the energy performance of a ventless or vented electric, standard (4.4 cu-ft or greater capacity) and a ventless electric compact (240V) are compared. The energy efficiency standard specifies a minimum combined energy factor (CEF) of 3.93 lbs/kWh (1.79 kg/kWh) and a test load size of 8.45lbs (3.83kg) for ventless or vented electric standard dryers and a minimum combined energy factor (CEF) of 2.68 lbs/kWh (1.22 kg/kWh) and a test load size of 3lbs (1.36kg) for a ventless electric compact dryer. It is noted that for compact dryers the minimum combined energy factor (CEF) is lower for 240V as compared to 120V, meaning the 240V compact dryer is permitted to use more energy than the 120V with the same load size. The CEF has the same definition as defined for the Canadian Energy Standard except the load size is measured in lbs.

4.2. Comparison of Performance Requirements

4.2.1. PHPP

The default PHPP input for a dryer is 3.5kWh/cycle[26] [27], assuming one cycle consists of a 5kg load.

4.2.2. Canadian Energy Standard

The Canadian energy efficiency standard for dryers can be translated into a kWh/cycle value by dividing the PHPP normalized load size of 5kg by the combined energy factor (CEF):

Ventless compact electric dryer:

$$Norm\ Demand = \frac{5kg/cycle}{1.16\ \mathrm{kg/kWh}} = 4.31\ kWh/cycle$$

A similar calculation is done for conventional (vented) standard electric dryers to convert to a normal demand (kWh/cycle). Results are shown in Table 4.2.

4.2.3. European Energy Standard

The European ecodesign requirement for dryers can be translated into a kWh/cycle value by dividing the weighted annual energy consumption of a household tumble dryer (AE_C) by the average number of cycles per year. An average of 160 cycles per year is referenced in the ecodesign requirement and used in this calculation. The European testing standard tests at full load (max capacity) and partial load (half of full load) with a weighting of 3/7 for full load and 4/7 for partial loads. Therefore, for a 5kg average test load the capacity of the dryer would need to be 7kg

$$Average\ test\ load = \frac{(3 \times full\ load) + (4 \times partial\ load)}{7}$$

$$5kg = \frac{(3 \times full\ load) + (4 \times \frac{full\ load}{2})}{7} = \frac{5\ \times full\ load}{7}$$

$$full\ load = \frac{5kg\ \times 7}{5} = 7kg$$

$$capacity = full\ load = 7kg$$

Ventless electric dryer:

$$SAE_C = 140\ \times\ c^{0.8} = 140\ \times\ (7kg)^{0.8} = 664.06\ kWh/year$$

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[26] PHPP uses the word "use" to represent cycle

[27] At present, documented sources for these data were not available. The default inputs in PHPP are plausible values from older versions of PHPP based on different sources and publications.

$$AE_c = SAE_C \times \frac{EEI}{100} = \frac{664.06\ kWh}{year} \times \frac{76}{100} = 504.68\ kWh/year$$

$$Norm\ Demand = \frac{504.68\ kWh/year}{160\ cycles/year} = 3.15\ kWh/cycle$$

Vented electric dryer:

The weighted programme time is assumed to be 80 minutes[28]

$$SAE_C = 140\ \times\ c^{0.8} - \left(30 \times \frac{T_t}{60}\right) =\ 140\ \times\ (7kg)^{0.8} - \left(30 \times \frac{80}{60}\right) =\ 624.06\ kWh/year$$

$$AE_c = SAE_C\ \times \frac{EEI}{100} = \frac{624.06\ \ kWh}{year} \times \frac{76}{100} = 474.28\ kWh/year$$

$$Norm\ Demand = \frac{474.28\ kWh/year}{160\ cycles/year} = 2.96\ kWh/cycle$$

4.2.4. ENERGY STAR®

The ENERGY STAR requirements for clothes dryers can be translated into a PHPP Normal Demand value (kWh/cycle) by dividing the assumed load size of 11lbs (5kg) by the combined energy factor (CEF).

Ventless Electric Compact

$$Norm\ Demand = \frac{11\ lbs/cycle}{2.68\ \mathrm{lbs/kWh}} = 4.10\ kWh/cycle$$

A similar calculation is done for ventless and vented electric standard dryers to convert to a PHPP Normal Demand (kWh/cycle). Results are shown in Table 4.2.

A similar calculation is done for the top performing ventless compact[29], standard vented[30] and standard ventless dryers[31]. Results are shown in Table 4.2.

4.2.5. Best in Class available in the German Market

Calculations of the PHPP Normal Demand (kWh/cycle) for the best in class standard clothes dryers available in the German Market are calculated by scaling the annual energy consumption to a capacity of 7kg (average test load size of 5kg) and dividing by 160 cycles per year[32].

[28] https://uploads.engieinsight.com/2016/04/27220752/clothes_dryers_web.pdf
[29] Miele - Miele : TWI180 WP, accessed: September 24, 2018
https://www.energystar.gov/productfinder/product/certified-clothes-dryers/details/2308247
[30] LG – DLHX4372*, accessed: September 18 2018,
https://www.energystar.gov/productfinder/product/certified-clothes-dryers/details/2289158
[31] Whirlpool - WED99HED*+, accessed: September 18 2018,
https://www.energystar.gov/productfinder/product/certified-clothes-dryers/details/2266022
[32] The annual electricity consumption is calculated on the basis of 160 washer per year

A summary of the performance measures for the best in class clothes dryers as found on spargeraete.de is shown in the Table 4.1.

Table 4.1 Spargeraete performance measures of best in class clothes dryers

	Standard Ventless Dryer	Standard Vented Dryer
Capacity (kg)	5	4
Annual Energy Consumption (kWh)	158	296

Ventless[33]

A linear relationship between the annual energy consumption and capacity of the clothes dryers is assumed.

$$Norm\ Demand = \frac{158\frac{kWh}{year} \times \frac{7kg}{5kg}}{160\ cycles/year} = 1.38\ kWh/cycle$$

A similar calculation is repeated for the best in class standard vented dryer[34]. Results are shown in Table 4.2.

[33] Beko DPU 7306 XE, Accessed on: December 20, 2018 https://www.spargeraete.de/SearchResults/Details/TRO_BEKO_DPU7306XE

[34] Amica WTA 14303 W, Accessed on: December 27, 2018 https://www.spargeraete.de/SearchResults/Details/TRO_AMICA_WTA14303W

4.2.6. Clothes Dryer Normal Demand Comparison

Table 4.2 Clothes Dryer PHPP Normal Demand

	PHPP Default	Canadian Energy Standards		European Energy Standards		ENERGY STAR					Best in Class German Market	
						Minimum Requirement		Top Performing				
		Ventless compact	Vented standard	Ventless	Vented	Ventless Compact	Ventless and Vented Standard [35]	Ventless Compact	Vented Standard	Ventless Standard	Ventless	Vented
Capacity (ft^3)		< 4.4	> 4.4	9.6[36]	9.6[36]	< 4.4	> 4.4	4.1	7.3	7.4	6.9[36]	5.5[36]
Norm Demand (kWh/cycle)	3.50	4.31	2.96	3.15	2.96	4.10	2.80	1.73	2.56	2.44	1.38	3.24
% relative to PHPP default		123%	85%	90%	85%	117%	80%	49%	73%	70%	40%	93%
Total kWh per year	599	737	506	539	507	702	479	295	437	418	236	554

Table 4.2 summarizes the PHPP Normal Demand calculated for the various scenarios described above, all normalized to a 5kg load, along with the % difference relative to the PHPP default. Also shown are the resultant kWh/year based on 171 cycles per year[37]. From the results it is clear that, apart from the ventless compact, an ENERGY STAR rated clothes dryer will definitely be more energy efficient than the PHPP default. The top performing ENERGY STAR and Best in Class German ventless products all use heat pump technology.

[35] Minimum requirement for vented and ventless is the same. There is no specific requirement for heat pump dryers

[36] Capacity in kg is converted to ft^3 by using a factor of 1.37ft^3/kg. This factor is derived using the calculated average ratio between the washing machine capacity and the maximum load size of 0.55ft^3/kg from data in Table 3 in CAN/CSA-C360-13. It is then assumed that there is a ratio of 2.5 between the load capacity in kg of clothes washer and a clothes dryer with the same volumetric capacity. This equates to a load capacity of 0.55x2.5=1.37 ft3/kg for clothes dryers.

[37] Number of cycles per year is calculated as 57 cycles per person multiplied by 3 people

5. Refrigerator

5.1. Definitions and Performance Requirements

5.1.1. Canadian Energy Standard

http://www.nrcan.gc.ca/energy/regulations-codes-standards/products/6877

Test Standard: CAN/CSA-C300-15

Energy Efficiency Standard:

Energy performance standards are separated based on the product type (semi-automatic defrost, automatic defrost, manual defrost, and built-in[38] with automatic defrost). For this study, the energy performance of the refrigerator type with the highest energy demand (built-in with automatic defrost), a type with medium demand (automatic defrost), and the type with the lowest demand (manual defrost) are compared.

For a built-in with automatic defrost refrigerator, the energy efficiency standard specifies a maximum total annual energy consumption of:

$$Maximum\ Energy\ Consumption = 0.283\ AV + 228.5$$

For an automatic defrost refrigerator, the energy efficiency standard specifies a maximum total annual energy consumption of:

$$Maximum\ Energy\ Consumption = 0.250\ AV + 201.6$$

For a manual defrost refrigerator, the energy efficiency standard specifies a maximum total annual energy consumption of:

$$Maximum\ Energy\ Consumption = 0.240\ AV + 193.6$$

Where,

AV = the adjusted volume in litres = refrigerator volume + 1.76 x the freezer volume

Refrigerators are tested at an ambient temperature of 32°C (without door openings) to simulate typical room conditions of an ambient temperature of 21°C with door openings and compartment temperature of 3.9°C. For manual, semi-automatic, and partial automatic defrost refrigerators, the refrigerators are tested after steady-state conditions have been achieved and for at least 2 or more cycles (a compressor cycle consists of a complete ON and OFF period of the motor) or 3 hours if no OFF period occurs. For automatic defrost refrigerators, the test period begins after stead-state conditions have been achieved and shall run from one point during a defrost period to the same point during the next defrost period. The measured energy consumption during this test period is then extrapolated to an annual consumption.

5.1.2. European Energy Standard

https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32009R0643&from=EN

[38] Built-in refrigerators are designed to be installed totally encased by kitchen cabinets

Ecodesign Requirements (Energy Related):

The ecodesign requirement, for compression-type refrigerating appliances, is an energy efficiency index (EEI) of less than 42. Types of refrigerator appliances include: compression-type or absorption-type and other type. Compression-type is the most common and therefore used in this report.

The EEI is calculated as follows:

$$EEI = \frac{AE_c}{SAE_C} \times 100$$

Where,

AE_C = weighted annual energy consumption of the household refrigerating appliance

SAE_C = standard annual energy consumption of the household refrigerating appliance

The standard annual energy consumption (SAE_C) is calculated in kWh/year and rounded to two decimal places, as:

$$SAE_c = V_{eq} \times M + N + CH$$

Where,

CH = 50 kWh/year for household refrigerating appliances with a chill compartment with a storage volume of at least 15 litres[39]

The M and N values depend on the refrigerating appliance category. In this case there is only one category that applies to refrigerators with no freezer compartments (refrigerators with freezer compartments will be covered in section 6. Combination - Refrigerator/Freezer).

For a refrigerator with one or more fresh-food storage compartments[40],

M = 0.233

N = 245

Veq = the equivalent volume of the household refrigerating appliance = sum of the equivalent volumes of all compartments

$$V_{eq} = \left[\sum_{c=1}^{c=n} V_c \times \frac{25 - T_c}{20} \times FF_c\right] \times CC \times BI$$

Where,

V_C = the storage volume of the compartment

T_C = nominal temperature of the compartment

[39] There is only one option for the value of CH

[40] There are 9 other options for these parameters, but they do not apply to refrigerators with no freezer compartments

FF, CC and BI are correction factors defined in Table 5.1

Table 5.1 Correction Factors

Correction Factor	Value	Condition
FF (frost-free)	1.2	For frost-free frozen-food storage compartments
	1	Otherwise
CC (climate-class)	1.2	For T class (tropical) appliances
	1.1	For ST class (subtropical) appliances
	1	Otherwise
BI (built-in)	1.2	For built-in appliances under 58cm in width
	1	Otherwise

Refrigerators are tested at an ambient temperature of 25°C and a compartment temperature of 5°C.

5.1.3. ENERGY STAR®

https://www.energystar.gov/products/appliances/refrigerators/key_product_criteria

ENERGY STAR efficiency requirements for refrigerators and freezers is 10% less measured energy use than the minimum federal efficiency standards. Under the National Appliance Energy Conservation Act, the U.S. Department of Energy (DOE) establishes maximum energy consumption standards for refrigerators and freezers. These maximum energy consumptions standards in the US are the same as those outlined above for Canada for all product types.

5.2. Comparison of Performance Requirements

5.2.1. PHPP

The default PHPP input for refrigerator is 0.78 kWh/day[41].

5.2.2. Canadian Energy Standard

The Canadian energy efficiency standard for refrigerators can be translated into a kWh/day value by dividing the maximum total annual energy consumption by 365 days. To calculate the maximum energy consumption a capacity of 102.00 L and 971.20 L is used, which is equivalent to the adjusted volume. These values represent the minimum and maximum refrigerator volumes of all models, in all the product types, available in Canada listed on the NRCan website[42]. The Canadian testing standards use a temperature difference of 32°C - 3.9°C = 28.1°C whereas the European testing standard uses a temperature difference of 25°C - 5°C = 20°C. It is assumed that the default PHPP normal demand would follow the European Energy Standards and so the Canadian Energy Standard values are scaled to the same temperature difference as the European Energy Standard using Carnot's theorem. A previous investigation by one of the authors determined that the heat loss consequence of opening an overheard door in a heated repair shop in a cold climate briefly for a couple dozen times per day leads to negligible heat loss. In contrast, using a higher ambient temperature difference will substantially increase the

[41] At present, documented sources for these data were not available. The default inputs in PHPP are plausible values from older versions of PHPP based on different sources and publications.

[42] National Resource Canada, Accessed: July 16, 2018
http://oee.nrcan.gc.ca/pml-lmp/index.cfm?action=app.welcome-bienvenue

refrigerator heat loss. It is therefore unclear why the CAN/CSA-C300-15 specifies a higher ambient temperature.

Carnot's Theorem

If the useful cooling demand for a fridge using the temperatures T_{room} and T_{fridge} according to the European testing standards is Q and similarly in the Canadian testing standards the useful demand is Q_0 using the temperatures $T_{room,0}$ and $T_{fridge,0}$,

Then $Q/Q_0 = (T_{room}-T_{fridge})/(T_{room,0}-T_{fridge,0})$.

In addition, the compressor efficiency is dependent on the temperature of the hot and cold reservoir T_h and T_c. From the Carnot theorem, we can assume that, with a more or less constant, but yet unknown factor f, the electricity demand for the fridge under Canadian test conditions is

$$P_0 = f\,\frac{T_{h,0} - T_{c,0}}{T_{c,0}}\,Q_0$$

and correspondingly for Europe

$$P = f\,\frac{T_h - T_c}{T_c}\,Q$$

where, approximately, $T_h = T_{room} + 10$ K, $T_c = T_{fridge} - 10$ K

Combining all the above equations,

$$\frac{P}{P_0} = \frac{T_{c,0}}{T_{h,0} - T_{c,0}} \times \frac{T_h - T_c}{T_c} \times \frac{T_{room} - T_{fridge}}{T_{room,0} - T_{fridge,0}}$$
$$= \frac{267.05K}{315.15K - 267.05K} \times \frac{308.15K - 268.15K}{268.15K} \times \frac{298.15K - 278.15K}{305.15K - 277.05K} = 0.59$$

Built-in Refrigerators with Automatic Defrost (minimum capacity):

$$Maximum\ Energy\ Consumption = 0.283\ AV + 228.5 = 0.283\ \times 102.00 + 228.5 = 257.37\ kWh$$

$$Scaled\ Annual\ Energy\ Consumption = 257.37\ kWh \times 0.59^{43} = 151.71\ kWh$$

$$Norm\ Demand = \frac{151.71\ kWh}{365\ \text{days}} = 0.42\ kWh/day$$

A similar calculation is done for a maximum adjusted volume (AV) of 971.20 L, results are show in Table 5.3.

All Refrigerators with Automatic Defrost (minimum capacity):

$$Maximum\ Energy\ Consumption = 0.250\ AV + 201.6 = 0.250\ \times 102.00 + 201.6 = 227.10\ kWh$$

[43] This is the conversion factor is used to scale the electricity demand for a refrigerator under Canadian testing standards to the European testing standards using Carnot's theorem.

$$Scaled\ Annual\ Energy\ Consumption = 227.10\ kWh \times 0.59 = 133.87\ kWh$$

$$Norm\ Demand = \frac{133.87\ kWh}{365\text{ days}} = 0.37\ kWh/day$$

A similar calculation is done for a maximum adjusted volume (AV) of 971.20 L, results are show in Table 5.3.

All Refrigerators with Manual Defrost (minimum capacity):

$$Maximum\ Energy\ Consumption = 0.240\ AV + 193.6 = 0.240\ \times 102.00 + 193.6 = 218.08\ kWh$$

$$Scaled\ Annual\ Energy\ Consumption = 218.08\ kWh \times 0.59 = 128.55\ kWh$$

$$Norm\ Demand = \frac{128.55\ kWh}{365\text{ days}} = 0.35\ kWh/day$$

A similar calculation is done for a maximum adjusted volume (AV) of 971.20 L, results are show in Table 5.3.

5.2.3. European Energy Standard

The European ecodesign requirement for refrigerators can be translated into a kWh/day value by dividing the weighted annual energy consumption of a household refrigerator (AE_C) by 365 days. The same minimum and maximum refrigerator volumes from the analysis for the Canadian Energy Standard is used to calculate the equivalent volume.

Minimum Capacity

$$V_{eq} = \left[V_c \times \frac{25 - T_c}{20} \times FF_c\right] \times CC \times BI = 102.00\ L \times \frac{25-5}{20} \times 1 \times 1 \times 1 = 102.00\ L$$

$$SAE_c = V_{eq} \times M + N + CH = 102.00 \times 0.233 + 245 + 50 = 318.77\ kWh/year$$

$$AE_c = SAE_C \times \frac{EEI}{100} = \frac{318.77\ kWh}{year} \times \frac{42}{100} = 133.88\ kWh/year$$

$$Norm\ Demand = \frac{133.88\ kWh/year}{365\text{ days}} = 0.37\ kWh/day$$

A similar calculation is done for a maximum adjusted volume (AV) of 971.20 L, results are show in Table 5.3.

5.2.4. ENERGY STAR®

The ENERGY STAR requirement for refrigerators can be calculated as 10% less than the Canadian normal demand

Minimum Performance- Built-in Refrigerators with Automatic Defrost (minimum capacity):

$$Norm\ Demand = 0.42\frac{kWh}{day} \times 0.9 = 0.37\ kWh/day$$

A similar calculation is done for the maximum adjusted volume (AV) of 971.20 L as well as Automatic Defrost Refrigerators and Manual Defrost Refrigerators, results are shown in Table 5.3.

The performance parameters of the top performing ENERGY STAR refrigerators (with no freezer) are summarized in Table 5.2.

Table 5.2 EnergyStar performance measures for the smallest and largest automatic defrost, manual defrost and built-in automatic defrost refrigerators

	Automatic Defrost		Manual Defrost		BI + Automatic Defrost	
	min[44]	max[45]	min[46]	max[47]	min[48]	max[49]
Capacity (ft^3)	5.5	20.5	7.8	13.0	10.9	23.5
Capacity (L)	155.74	580.74	220.87	368.12	308.65	665.45
Annual Energy Demand (kWh/year)	240	310	160	254	283	375

To calculate a PHPP Normal Demand, the Annual Energy Demand is scaled by the temperature difference used in the European Energy Standard (as done in section 5.2.2) and divided by 365 days.

Top Performing – Automatic Defrost (minimum capacity):

$$Scaled\ Annual\ Energy\ Consumption = 240\ kWh \times 0.59^{50} = 141.47\ kWh$$

$$Norm\ Demand = \frac{141.47\ kWh}{365\ \text{days}} = 0.39\ kWh/day$$

A similar calculation is done for the other ENERGY STAR refrigerators, results are shown in Table 5.3.

[44] Silhouette Professional - DAR055D1BSSPR, Accessed: December 30, 2018 https://www.energystar.gov/productfinder/product/certified-residential-refrigerators/details-plus/2303205
[45] Gallery - FGVU21F8QT*, Accessed: December 30, 2018 https://www.energystar.gov/productfinder/product/certified-residential-refrigerators/details-plus/2220998
[46] Samsung - RP22M3105**, Accessed: December 30, 2018 https://www.energystar.gov/productfinder/product/certified-residential-refrigerators/details-plus/2302490
[47] Gorenje - HS3862EF, Accessed: December 30, 2018 https://www.energystar.gov/productfinder/product/certified-residential-refrigerators/details-plus/2257404
[48] Liebherr - HRB 1120, Accessed: December 30, 2018 https://www.energystar.gov/productfinder/product/certified-residential-refrigerators/details-plus/2207542
[49] Sub-Zero - BI-36R/*/**, Accessed: December 30, 2018 https://www.energystar.gov/productfinder/product/certified-residential-refrigerators/details-plus/2230805
[50] This is the conversion factor is used to scale the electricity demand for a refrigerator under Canadian testing standards to the European testing standards using Carnot's theorem.

5.2.5. Best in Class available in the German Market

The smallest refrigerator available in the German market (with an energy efficiency class of at least A++) has a capacity of 106L and an Annual Energy Demand of 60kWh[51]. The PHPP Normal Demand is calculated as the Annual Energy Demand divided by 365 days.

$$Norm\ Demand = \frac{60\ kWh}{365\ \text{days}} = 0.16\ kWh/day$$

A similar calculation is done for the largest refrigerator available in the German market (with an energy efficiency class of at least A++), which has a capacity of 395L and an annual energy demand of 117kWh[52], the results are shown in Table 5.3.

[51] Techwood - KS 1501, Accessed: December 30, 2018
https://www.spargeraete.de/SearchResults/Details/KUEHL_TECHWOOD_KS1501
[52] AEG - S74010KDXF, Accessed: December 30, 2018
https://www.spargeraete.de/SearchResults/Details/KUEHL_AEG_S74010KDXF

5.2.6. Refrigerator Normal Demand Comparison

Table 5.3 Refrigerator PHPP Normal Demand

	PHPP Default	Canadian Energy Standards			European Energy Standards [53]	ENERGY STAR						Best in Class German Market
		Built-in automatic defrost	Automatic defrost	Manual Defrost		Minimum Requirement			Top Performing			
						Built-in automatic defrost	Automatic Defrost	Manual Defrost	Built-in automatic defrost	Automatic Defrost	Manual Defrost	Automatic Defrost
Norm Demand (kWh/day)	0.78	0.42/ 0.81	0.37/ 0.72	0.35/ 0.69	0.37/ 0.60	0.37/ 0.73	0.33/ 0.65	0.32/ 0.62	0.46/ 0.61	0.39/ 0.50	0.26/ 0.41	0.16/ 0.32
% difference relative to PHPP default		53%/ 104%	47%/92%	45%/ 88%	47%/ 77%	48%/ 94%	42%/ 83%	41%/ 80%	59%/ 78%	50%/ 64%	33%/ 53%	21%/ 41%
Capacity (L)		102 / 971			102 / 971	102 / 971			308 / 665	115 / 580	220 / 368	106 / 395
Total kWh per year	285	152/ 297	134/ 262	129/ 252	134/ 219	137/ 267	120/ 236	116/ 226	167/ 221	141/ 183	94/ 150	60/ 117
Total kWh/L/yr		1.49/ 0.31	1.31/ 0.27	1.26/ 0.26	1.31/ 0.23	1.34/ 0.27	1.13/ 0.23	1.18/ 0.24	0.54/ 0.33	0.91/ 0.31	0.43/ 0.41	0.57/ 0.30

Table 5.3 summarizes the PHPP Normal Demand calculated in the scenarios above, along with the % difference relative to the PHPP default and the resultant kWh/year. The minimum requirement for certain fridge types for the Canadian Energy Standard and ENERGY STAR are lower than the PHPP default. Two of the smallest Top Performing ENERGY STAR appliances appear to perform worse than the ENERGY STAR minimum. This is because these two smallest top performing ENERGY STAR are larger than the smallest available in the Canadian market. The Best in Class German refrigerators outperform the top performing ENERGY STAR products when comparing refrigerators of similar capacity.

[53] Compression-type refrigerating appliances

6. Freezer

6.1. Definitions and Performance Requirements

6.1.1. Canadian Energy Standard

http://www.nrcan.gc.ca/energy/regulations-codes-standards/products/6941

Test Standard: CAN/CSA-C300-15

Energy Efficiency Standard:

Energy performance standards are separated based on the product type (upright vs chest, automatic vs manual defrost, built-in, with and without icemaker, and compact vs standard). For this study, the energy performance of the freezer type with the highest demand (a built-in upright freezer with automatic defrost with an automatic icemaker), the type with the lowest demand (a chest freezer), and the type with medium demand (upright freezer with automatic defrost) are compared.

For a built-in upright freezer with automatic defrost with an automatic icemaker, the energy efficiency standard specifies a maximum total annual energy consumption of:

$$Maximum\ Energy\ Consumption = 0.348\ AV + 344.9$$

For a chest freezer[54], the energy efficiency standard specifies a maximum total annual energy consumption of:

$$Maximum\ Energy\ Consumption = 0.257\ AV + 107.8$$

For an upright freezer with automatic defrost, the energy efficiency standard specifies a maximum total annual energy consumption of:

$$Maximum\ Energy\ Consumption = 0.305\ AV + 228.3$$

Where,

AV = the adjusted volume in litres = refrigerator volume + 1.76 x the freezer volume

Freezers are tested at an ambient temperature of 32°C (without door openings) to simulate typical room conditions of an ambient temperature of 21°C with door openings. Freezers are tested at a temperature of -17.8°C.

6.1.2. European Energy Standard

https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32009R0643&from=EN

Ecodesign Requirements (Energy Related):

The ecodesign requirement, for compression-type refrigerating appliances, is an energy efficiency index (EEI) of less than 42. Types of refrigerator appliances include: compression-type or absorption-type and other type. Compression-type is the most common and therefore used in this report.

The EEI is calculated as follows:

[54] This includes all chest freezers

$$EEI = \frac{AE_c}{SAE_C} \times 100$$

Where,

AE_C = weighted annual energy consumption of the household washing machine

SAE_C = standard annual energy consumption of the household washing machine

The standard annual energy consumption (SAE_C) is calculated in kWh/year and rounded to two decimal places, as:

SAEc = Veq × M + N + CH

Where,

CH = 50 kWh/year for household refrigerating appliances with a chill compartment with a storage volume of at least 15 litres[55]

The M and N values depends on the refrigerating appliance category. In this case there are two categories that apply to freezers,

For an upright freezer,

M = 0.593

N = 315

And for a chest freezer

M = 0.472

N = 286

Veq = the equivalent volume of the household refrigerating appliance = sum of the equivalent volumes of all compartments

$$V_{eq} = \left[\sum_{c=1}^{c=n} V_c \times \frac{25 - T_c}{20} \times FF_c\right] \times CC \times BI$$

Where,

V_C = the storage volume of the compartment

T_C = nominal temperature of the compartment

FF, CC and BI are correction factors defined in Table 6.1

Table 6.1 Correction Factors

Correction Factor	Value	Condition
FF (frost-free)	1.2	For frost-free frozen-food storage compartments

[55] There is only one option for the value of CH

PEEL PASSIVE HOUSE

	1	Otherwise
CC (climate-class)	1.2	For T class (tropical) appliances
	1.1	For ST class (subtropical) appliances
	1	Otherwise
BI (built-in)	1.2	For built-in appliances under 58cm in width
	1	Otherwise

Freezers are tested at an ambient temperature of 25°C and a compartment temperature of -18°C.

6.1.3. ENERGY STAR®

ENERGY STAR efficiency requirements for refrigerators and freezers is 10% less measured energy use than the minimum federal efficiency standards. Under the National Appliance Energy Conservation Act, the U.S. Department of Energy (DOE) establishes maximum energy consumption standards for refrigerators and freezers. These maximum energy consumptions standards in the US are the same as those outlined above for Canada.

6.2. Comparison of Performance Requirements

6.2.1. PHPP

The default PHPP input for a freezer is 0.88 kWh/day[56].

6.2.2. Canadian Energy Standard

The Canadian energy efficiency standard for freezers can be translated into a kWh/day value by dividing the maximum total Annual Energy Demand by 365 days. To calculate the maximum energy consumption a capacity of 30.00 L and 704.00 L is used, which equates to an adjusted volume of 52.80 and 1239.04L. These values represent the minimum and maximum refrigerator volumes of all models, in all the product types, available in Canada listed on the NRCan website [57]. The Canadian testing standards use a temperature difference of 32°C – (-17.8°C) = 49.8°C whereas the European testing standard uses a stemperature difference of 25°C – (-18°C) = 43°C. It is assumed that the default PHPP Normal Demand would follow the European Energy Standards and so the Canadian Energy Standard values are scaled to the same temperature difference as the European Energy Standard.

Built-in upright freezer with automatic defrost with an automatic icemaker (minimum capacity):

$$Maximum\ Energy\ Consumption = 0.348\ AV + 344.9 = 0.348\ \times 52.80 + 344.9 = 363.27\ kWh$$

$$Scaled\ Annual\ Energy\ Consumption = 363.27\ kWh \times 0.78^{58} = 283.34\ kWh$$

$$Norm\ Demand = \frac{283.34\ kWh}{365\ \text{days}} = 0.78\ kWh/day$$

[56] At present, documented sources for these data were not available. The default inputs in PHPP are plausible values from older versions of PHPP based on different sources and publications.
[57] http://oee.nrcan.gc.ca/pml-lmp/index.cfm?action=app.welcome-bienvenue
[58] This is the conversion factor is used to scale the electricity demand for a freezer under Canadian testing standards to the European testing standards using Carnot's theorem.

A similar calculation is done for a maximum adjusted volume (AV) of 704.00 L, the results are show in Table 6.4.

Chest freezer (minimum capacity):

$$Maximum\ Energy\ Consumption = 0.257\ AV + 107.8 = 0.257\ \times 52.80 + 107.8 = 121.37\ kWh$$

$$Scaled\ Annual\ Energy\ Consumption = 121.37\ kWh \times 0.78 = 94.66\ kWh$$

$$Norm\ Demand = \frac{94.66\ kWh}{365\ \text{days}} = 0.26\ kWh/day$$

A similar calculation is done for a maximum adjusted volume (AV) of 704.00 L, the results are show in Table 6.4.

Upright freezer with automatic defrost (minimum capacity):

$$Maximum\ Energy\ Consumption = 0.305\ AV + 228.3 = 0.305\ \times 52.80 + 228.3 = 244.40\ kWh$$

$$Scaled\ Annual\ Energy\ Consumption = 244.40\ kWh \times 0.78 = 190.63\ kWh$$

$$Norm\ Demand = \frac{190.63\ kWh}{365\ \text{days}} = 0.52\ kWh/day$$

A similar calculation is done for a maximum capacity of 704.00 L (AV of 1239.04L), the results are show in Table 6.4.

6.2.3. European Energy Standard

The European ecodesign requirement for freezers can be translated into a kWh/day value by dividing the weighted annual energy consumption of a household freezer (AE_C) by 365 days. The same minimum and maximum freezer volumes from the analysis for the Canadian Energy Standard is used to calculate the equivalent volume.

Upright freezer (minimum capacity),

$$V_{eq} = \left[V_c \times \frac{25 - T_c}{20} \times FF_c\right] \times CC \times BI = 30.00L \times \frac{25 - (-18)}{20} \times 1.2 \times 1 \times 1 = 77.40L$$

$$SAE_c = V_{eq} \times M + N + CH = 77.40 \times 0.539 + 315 + 50 = 406.72\ kWh/year$$

$$AE_c = SAE_C \times \frac{EEI}{100} = \frac{406.72\ kWh}{year} \times \frac{42}{100} = 170.82\ kWh/year$$

$$Norm\ Demand = \frac{170.82\ kWh/year}{365\ \text{days}} = 0.47\ kWh/day$$

A similar calculation is done for a maximum capacity of 704.00L and Chest Freezers, results are shown in Table 6.4.

6.2.4. ENERGY STAR

The ENERGY STAR requirement for freezers can be calculated as 10% less than the Canadian normal demand.

Built-in upright freezer with automatic defrost and icemaker (minimum capacity):

$$Norm\ Demand = 0.78 \frac{kWh}{day} \times 0.9 = 0.70\ kWh/day$$

A similar calculation is done for a maximum capacity of 704.00 L and Chest Freezers, results are shown in Table 6.4.

The performance measures of the top performing ENERGY STAR freezers are summarized in Table 6.2

Table 6.2 EnergyStar performance measures for the smallest and largest built-in upright freezers with automatic defrost and icemaker, chest freezer, and upright freezer with automatic defrost

	Upright - high[59]		Chest Freezer[60]		Upright -med[61]	
	min[62]	max[63]	min[64]	max[65]	min[66]	max[67]
Capacity (ft^3)	7.8	21.4	2.5	21.7	1.1	21.3
Capacity (L)	220.87	605.98	70.79	614.48	31.15	603.15
Annual Energy Demand (kWh/year)	412	580	137	346	215	495

To calculate a PHPP Normal Demand, the Annual Energy Demand is scaled to the temperature difference used in the European Energy Standard (as done in section 6.2.2) and divided by 365 days.

Built-in upright freezer with automatic defrost and icemaker (minimum capacity):

$$Scaled\ Annual\ Energy\ Consumption = 412\ kWh \times 0.78^{68} = 321.35\ kWh$$

$$Norm\ Demand = \frac{321.35\ kWh}{365\ \text{days}} = 0.88\ kWh/day$$

[59] Built-in upright freezer with automatic defrost with an automatic icemaker
[60] All chest freezers
[61] Automatic defrost
[62] Liebherr - MF1851, Accessed: December 30, 2018
https://www.energystar.gov/productfinder/product/certified-residential-freezers/details/2330834
[63] Dacor - DRZ36980***, Accessed: December 30, 2018
https://www.energystar.gov/productfinder/product/certified-residential-freezers/details/2293045
[64] Avanti - CF24Q0W, Accessed: December 30, 2018
https://www.energystar.gov/productfinder/product/certified-residential-freezers/details/2255167
[65] Crosley- XCM22DM****, Accessed: December 30, 2018
https://www.energystar.gov/productfinder/product/certified-residential-freezers/details/2326487
[66] Midea - WHS-52FB1, Accessed: December 30, 2018
https://www.energystar.gov/productfinder/product/certified-residential-freezers/details/2210213
[67] Crosley - XUF21DM****, Accessed: December 30, 2018
https://www.energystar.gov/productfinder/product/certified-residential-freezers/details/2324327
[68] This is the conversion factor is used to scale the electricity demand for a freezer under Canadian testing standards to the European testing standards using Carnot's theorem.

A similar calculation is done for the other ENERGY STAR freezers, results are shown in Table 6.4.

6.2.5. Best in Class available in the German Market

The performance measures for the smallest and largest upright and chest freezers available in the German market (with an energy efficiency class of at least A++) are shown Table 6.3.

Table 6.3 Performance measure for the smallest and largest upright and chest freezers available in the German market

	Upright		Chest	
	min[69]	max[70]	min[71]	max[72]
Capacity (L)	30	399	98	451
Annual Energy Demand (kWh/year)	117	191	113	275

The PHPP Normal Demand is calculated as the annual energy demand divided by 365 days.

$$Norm\ Demand = \frac{117\ kWh}{365\ \text{days}} = 0.32\ kWh/day$$

A similar calculation is done the other freezers available in the German market, the results are shown in Table 6.4.

[69] Zanussi - ZFX 31401 WA, Accessed: December 30, 2018
https://www.spargeraete.de/SearchResults/Details/KUEHL_ZANUSSI_ZFX31401WA
[70] Liebherr – GP 4013, Accessed: December 30, 2018
https://www.spargeraete.de/SearchResults/Details/KUEHL_LIEBHERR_GP4013
[71] Amica - GT 15789 W, Accessed: December 30, 2018
https://www.spargeraete.de/SearchResults/Details/KUEHL_AMICA_GT15789W
[72] Beko - HSA 47530, Accessed: December 30, 2018
https://www.spargeraete.de/SearchResults/Details/KUEHL_BEKO_HSA47530

6.2.6. Freezer Normal Demand Comparison

Table 6.4 Freezer PHPP Normal Demand

	PHPP Default	Canadian Energy Standards			European Energy Standards		ENERGY STAR						Best in Class German Market	
							Minimum Requirement			Top Performing				
		Upright-high[73]	Chest[74]	Upright-med[75]	Upright	Chest	Upright-high[73]	Chest[74]	Upright-med[75]	Upright-high[73]	Chest[74]	Upright-med[75]	Upright	Chest
Norm Demand (kWh/ day)	0.88	0.78/ 1.66	0.26/ 0.91	0.52/ 1.30	0.47/ 1.55	0.43/ 1.37	0.70/ 1.49	0.23/ 0.82	0.47/ 1.17	0.88/ 1.24	0.29/ 0.74	0.46/ 1.06	0.32/ 0.52	0.31/ 0.75
% difference to PHPP default		88% / 188%	29% / 104%	59% / 147%	53% / 176%	49% / 156%	79% / 170%	27% / 93%	53% / 132%	100% / 141%	33% / 84%	52% / 120%	36% / 59%	35% / 86%
Capacity (L)		30 / 704			30 / 704		30 / 704			220 / 605	70/ 614	31 / 603	30 / 399	98 / 451
Total kWh per year	321	283 / 605	95 / 332	191 / 473	171/564	156 / 501	255 / 545	85 / 299	172 / 426	321 / 452	107 / 270	168 / 386	117 / 191	113 / 275
Total kWh/L/yr		9.44/ 0.86	3.16/ 0.47	6.35/ 0.67	2.21/ 0.31	2.02/ 0.28	8.50/ 0.77	2.84/ 0.43	5.72/ 0.60	1.45/ 0.75	1.51/ 0.44	5.38/ 0.64	3.90/ 0.48	1.15/ 0.61

Table 6.4 summarizes the PHPP Normal Demand calculated in the scenarios above, along with the % difference relative to the PHPP default and the resultant kWh/year. The choice of freezer type heavily influences whether the PHPP default value is exceeded, even when an ENERGY STAR rated appliance is chosen. The top performing ENERGY STAR freezers appear to have a higher Normal Demand then the minimum requirement, however, this is due to the restricted volumes available. When comparing the kWh/L/yr it is clear that the top performing ENERGY STAR freezers

[73] Built-in upright freezer with automatic defrost with an automatic icemaker (device type with highest energy consumption)
[74] All chest freezers
[75] Automatic defrost

fall within the range of ENERGY STAR minimum requirement and are at the lower end of the range. The Best in Class German products outperform the top performing ENERGY STAR products when comparing similar capacity freezers, except for chest freezers.

7. Refrigerator/Freezer

7.1. Definitions and Performance Requirements

7.1.1. Canadian Energy Standard

http://www.nrcan.gc.ca/energy/regulations/codes/standards/products/6877

Test Standard: CAN/CSA/C300/15

Energy Efficiency Standard:

Energy performance standards for refrigerator/freezers are separated based on the product type (automatic vs semi/automatic vs manual defrost, ice service, top/mounted vs side/mounted vs bottom mounted freezer, and compact vs standard). For this study, the energy performance of the type with the highest demand (a built/in refrigerator/freezer with automatic defrost, side/mounted freezer and through/the/door ice service), the type with the lowest demand (a refrigerator/freezer with semi/automatic or manual defrost), and the type with medium demand (automatic defrost and side/mounted freezer) are compared.

For a refrigerator/freezer with semi/automatic or manual defrost, the energy efficiency standard specifies a maximum total annual energy consumption of:

$$Maximum\ Energy\ Consumption = 0.282\ AV + 225.0$$

For a refrigerator/freezer with automatic defrost and side mounted freezer, the energy efficiency standard specifies a maximum total annual energy consumption of:

$$Maximum\ Energy\ Consumption = 0.301\ AV + 297.8$$

For a built/in refrigerator/freezers with automatic defrost and side/mounted freezer with through/the/door ice service, the energy efficiency standard specifies a maximum total annual energy consumption of:

$$Maximum\ Energy\ Consumption = 0.362\ AV + 502.6$$

Where,

AV = the adjusted volume in litres = refrigerator volume + 1.76 x the freezer volume

Refrigerator/Freezers are tested at an ambient temperature of 32°C (without door openings) to simulate typical room conditions of an ambient temperature of 21°C with door openings. Freezers compartments are tested at a temperature of /17.8°C and fresh food compartments at a temperature of 3.9°C.

7.1.2. European Energy Standard

https://eur/lex.europa.eu/legal/content/EN/TXT/HTML/?uri=CELEX:32009R0643&from=EN

Ecodesign Requirements (Energy Related):

The ecodesign requirement, for compression/type refrigerating appliances, is an energy efficiency index (EEI) of less than 42. Types of refrigerator appliances include: compression/type or absorption/type and other type. Compression/type is the most common and therefore used in this report.

The EEI is calculated as follows:

$$EEI = \frac{AE_c}{SAE_C} \times 100$$

Where,

AE_C = weighted annual energy consumption of the household washing machine

SAE_C = standard annual energy consumption of the household washing machine

The standard annual energy consumption (SAE_C) is calculated in kWh/year and rounded to two decimal places, as:

SAEc = Veq × M + N + CH

Where,

CH = 50 kWh/year for household refrigerating appliances with a chill compartment with a storage volume of at least 15 litres[76]

The M and N values depend on the refrigerating appliance category. In this case there is only one category that applies to refrigerator/freezers,

M = 0.777

N = 303

Veq = the equivalent volume of the household refrigerating appliance = sum of the equivalent volumes of all compartments

$$V_{eq} = \left[\sum_{c=1}^{c=n} V_c \times \frac{25 - T_c}{20} \times FF_c\right] \times CC \times BI$$

Where,

V_C = the storage volume of the compartment

T_C = nominal temperature of the compartment

FF, CC and BI are correction factors defined in Table 7.1

Table 7.1 Correction Factors

Correction Factor	Value	Condition
FF (frost/free)	1.2	For frost/free frozen/food storage compartments
	1	Otherwise
CC (climate/class)	1.2	For T class (tropical) appliances
	1.1	For ST class (subtropical) appliances
	1	Otherwise
BI (built/in)	1.2	For built/in appliances under 58cm in width

[76] There is only one option for the value of CH

Refrigerator/Freezers are tested at an ambient temperature of 25°C. Freezers compartments are tested at a temperature of /18°C and fresh food compartments at a temperature of 5°C.

7.1.3. ENERGY STAR®

ENERGY STAR efficiency requirements for refrigerators and freezers is 10% less measured energy use than the minimum federal efficiency standards. Under the National Appliance Energy Conservation Act, the U.S. Department of Energy (DOE) establishes maximum energy consumption standards for refrigerators and freezers. These maximum energy consumptions standards in the US are the same as those outlined above for Canada.

7.2. Comparison of Performance Requirements

7.2.1. PHPP

The default PHPP input for combination refrigerator/freezer is 1.00 kWh/day[77].

7.2.2. Canadian Energy Standard

The Canadian energy efficiency standard for combination refrigerator/freezers can be translated into a kWh/day value by dividing the maximum total annual energy consumption by 365 days. To calculate the maximum permitted energy demand, a minimum adjusted volume (AV) of 150.97 and a maximum AV of 1300.11 L are used. These values were calculated as the minimum and maximum AVs based on the refrigerator and freezer volumes of models available in Canada, as listed on the NRCan website[78]. The adjusted volume is calculated as the refrigerator volume + 1.76 x the freezer volume. The model with the minimum AV of 150.97 L has a refrigerator capacity of 21.89L and a freezer capacity of 73.34L. The model with the maximum AV of 1300.11 L has a refrigerator capacity of 538.59 L and a freezer capacity of 432.68 L. The same conversion factors to scale the temperature difference as described in section 5.2.2 and 6.2.2 are used in the calculation below. Since there are two conversion factors, one for the refrigerator components and one for the freezer components, the corresponding volume fraction of these components are applied to the conversion factors.

Refrigerator/freezers with semi/automatic or manual defrost (minimum capacity),

$$Maximum\ Energy\ Consumption = 0.282\ AV + 225.0 = 0.282\ \times 150.97 + 225.0 = 267.57\ kWh$$

$$\begin{aligned} &Scaled\ Annual\ Energy\ Consumption \\ &= 267.57\ \ kWh \times \left(\frac{21.89L}{21.89 + 73.34L} \times 0.59^{79} + \frac{73.34L}{21.89L + 73.34L} \times 0.78^{80}\right) \\ &= 267.57\ \ kWh \times 0.74^{81} = 196.98kWh \end{aligned}$$

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[77] At present, documented sources for these data were not available. The default inputs in PHPP are plausible values from older versions of PHPP based on different sources and publications.
[78] http://oee.nrcan.gc.ca/pml-lmp/index.cfm?action=app.welcome-bienvenue
[79] This is the conversion factor is used to scale the electricity demand for a refrigerator under Canadian testing standards to the European testing standards using Carnot's theorem.
[80] This is the conversion factor is used to scale the electricity demand for a freezer under Canadian testing standards to the European testing standards using Carnot's theorem.
[81] This is the conversion factor is used to scale the electricity demand for a refrigerator-freezer under Canadian testing standards to the European testing standards using Carnot's theorem.

$$Norm\ Demand = \frac{196.98\ kWh}{365\ \text{days}} = 0.54\ kWh/day$$

A similar calculation is done for a maximum adjusted volume (AV) of 1300.11 L, the results are show in Table 7.3.

Refrigerator/freezers with automatic defrost and side/mounted freezer (minimum capacity),

$$Maximum\ Energy\ Consumption = 0.301\ AV + 297.8 = 0.301\ \times 150.97 + 297.8 = 343.24\ kWh$$

$$Scaled\ Annual\ Energy\ Consupmtion = 343.24\ kWh \times 0.74 = 252.69\ kWh$$

$$Norm\ Demand = \frac{252.69\ kWh}{365\ \text{days}} = 0.69\ kWh/day$$

A similar calculation is done for a maximum adjusted volume (AV) of 1300.11 L, the results are show in Table 7.3.

Built/in refrigerator/freezers with automatic defrost and side/mounted freezer with through/the/door ice service (minimum capacity),

$$Maximum\ Energy\ Consumption = 0.362\ AV + 502.6 = 0.362\ \times 150.97 + 502.6 = 557.25\ kWh$$

$$Scaled\ Annual\ Energy\ Consupmtion = 557.25\ kWh \times 0.74 = 410.24\ kWh$$

$$Norm\ Demand = \frac{410.24\ kWh}{365\ \text{days}} = 1.12\ kWh/day$$

A similar calculation is done for a maximum adjusted volume (AV) of 1300.11 L, the results are show in Table 7.3.

7.2.3. European Energy Standard

The European ecodesign requirement for combination refrigerator/freezers can be translated into a kWh/day value by dividing the weighted annual energy consumption of a household refrigerator/freezer (AE_C) by 365 days.

Minimum Capacity

$$V_{eq} = \left[\sum_{c=1}^{c=n} V_c \times \frac{25 - T_c}{20} \times FF_c\right] \times CC \times BI$$

$$= \left[32.89L \times \frac{25-5}{20} + 73.34L \times \frac{25-(-18)}{20} \times 1.2\right] \times 1 \times 1$$

$$= 211.11L$$

$$SAE_c = V_{eq} \times M + N + CH = 211.11 \times 0.77 + 303 + 50 = 517.03\ kWh/year$$

$$AE_c = SAE_C \times \frac{EEI}{100} = \frac{517.03\ kWh}{year} \times \frac{42}{100} = 217.15\ kWh/year$$

$$Norm\ Demand = \frac{217.15\ kWh/year}{365\ \text{days}} = 0.59\ kWh/day$$

A similar calculation is done for a maximum equivalent volume (V_{eq}) of 1654.91 L, the results are show in Table 7.3.

7.2.4. ENERGY STAR®

The ENERGY STAR requirement for refrigerator/freezers can be calculated as 10% less than the Canadian normal demand

Semi/automatic or manual defrost (minimum capacity),

$$Norm\ Demand = 0.54\frac{kWh}{day} \times 0.9 = 0.49\ kWh/day$$

A similar calculation is done for a maximum adjusted volume (AV) of 1300.11 L, refrigerator/freezers with automatic defrost and side/mounted freezer, and built/in refrigerator/freezers with automatic defrost and side/mounted freezer with through/the/door ice service, results are shown in Table 7.3.

The performance measures of the top performing ENERGY STAR refrigerator/freezers are summarized in Table 7.2.

Table 7.2 Energ yStar performance measures for the smallest and largest refrigerator/freezers with automatic defrost, and built/in refrigerator/freezers with automatic defrost and icemaker.

	Automatic defrost with icemaker [82]		Automatic defrost[83]	
	min[84]	max[85]	min[86]	max[87]
Capacity (ft^3)	8	24.2	8.8	24.8
Capacity (L)	226.53	685.27	249.19	702.26
AV (L)	366.18	824.02	305.82	855.17
Annual energy demand (kWh/year)	465	633	370	525

To calculate a normal demand, the annual energy demand is scaled to the temperature difference used in the European Energy Standard (as done in section 7.2.2) and divided by 365 days. It is noted that there were no ENERGY STAR rated refrigerator/freezers listed with manual defrost.

[82] Built-in refrigerator-freezers with automatic defrost, bottom mounted freezer and icemaker
[83] Refrigerator-freezers with automatic defrost and bottom mounted freezer
[84] Liebherr - MF1851, Accessed: December 30, 2018
https://www.energystar.gov/productfinder/product/certified-residential-freezers/details/2330834
[85] Dacor - DRZ36980***, Accessed: December 30, 2018
https://www.energystar.gov/productfinder/product/certified-residential-freezers/details/2293045
[86] Avanti - CF24Q0W, Accessed: December 30, 2018
https://www.energystar.gov/productfinder/product/certified-residential-freezers/details/2255167
[87] Crosley- XCM22DM****, Accessed: December 30, 2018
https://www.energystar.gov/productfinder/product/certified-residential-freezers/details/2326487

Built/in refrigerator/freezers with automatic defrost, bottom/mounted freezer and icemaker (minimum capacity),

$$Scaled\ Annual\ Energy\ Consumption = 465\ kWh \times 0.74 = 342.32kWh$$

$$Norm\ Demand = \frac{342.32\ kWh}{365\ \text{days}} = 0.94\ kWh/day$$

A similar calculation is done for the other ENERGY STAR refrigerator/freezers, results are shown in Table 7.3.

7.2.5. Best in Class available in the German Market

The smallest refrigerator/freezer available in the German market (with an energy efficiency class of at least A++) has a refrigerator capacity of 96 L, freezer capacity of 45 L and an annual energy demand of 103 kWh/year[88]. The normal demand is calculated as the annual energy demand divided by 365 days.

$$Norm\ Demand = \frac{103kWh}{365\ \text{days}} = 0.28\ kWh/day$$

The largest refrigerator/freezer[89] available in the German market (with an energy efficiency class of at least A++) has a refrigerator capacity of 394 L, a freezer capacity of 211 L, and an Annual Energy Demand of 370 kWh. A similar calculation is done for this refrigerator/freezer, results are shown in Table 7.3.

[88] PKM - KG 208.4, Accessed: December 31, 2018
https://www.spargeraete.de/SearchResults/Details/KUEHL_PKM_KG2084
[89] Sharp - SJ-EX820FSL, Accessed: December 31, 2018
https://www.spargeraete.de/SearchResults/Details/KUEHL_SHARP_SJEX820FSL

7.2.6. Refrigerator/Freezer Normal Demand Comparison

Table 7.3 Refrigerator/Freezer PHPP Normal Demand

	PHPP Default	Canadian Energy Standards			European Energy Standards[90]	ENERGY STAR					Best in Class German Market
		Manual defrost[91]	Automatic Defrost[92]	Automatic Defrost with ice service[93]		Minimum Requirement			Top Performing		
						Manual Defrost[91]	Automatic Defrost [92]	Automatic Defrost with ice service [93]	Automatic Defrost[94]	Automatic Defrost with icemaker[95]	
Norm Demand (kWh/day)	1.00	0.54/ 1.09	0.69/ 1.27	1.12/ 1.80	0.59/ 1.89	0.49/ 0.98	0.62/ 1.15	1.01/ 1.62	0.75/ 0.97	0.94/ 1.17	0.28/ 1.01
% difference relative to PHPP default		54% / 109%	69% / 127%	112% / 180%	59% / 189%	49% / 98%	62% / 115%	101% / 162%	75% / 97%	94% / 117%	28% / 101%
Total Capacity (L)		95 / 971			95 / 971	95 / 971			226 / 685	249 / 702	141 / 605
Total kWh per year	365	197 / 399	253 / 465	410 / 656	217 / 688	177 – 359	227 / 418	369 / 591	272/ 354	342 / 427	103 / 370
Total kWh/L/yr		2.07/ 0.41	2.65/ 0.48	4.31/ 0.68	2.28/ 0.71	1.86/ 0.37	2.39/ 0.43	3.88/ 0.61	1.20/ 0.52	1.37/ 0.61	0.73/ 0.61

Table 7.3 summarizes the PHPP Normal Demand calculated in the scenarios above, along with the % difference relative to the PHPP default and the resultant kWh/year. The choice of refrigerator/freezer type and size heavily influences whether the PHPP default value is exceeded, even

[90] Compression-Type
[91] Refrigerator-freezers with semi-automatic or manual defrost
[92] Refrigerator-freezers with automatic defrost and side-mounted freezer
[93] Built-in refrigerator-freezers with automatic defrost and side-mounted freezer with through-the-door ice service
[94] Refrigerator-freezers with automatic defrost and bottom mounted freezer
[95] Built-in refrigerator-freezers with automatic defrost, bottom mounted freezer and icemaker

when an ENERGY STAR rated appliance is chosen.   No conclusive comparison can be made between the best in class German and top performing ENERGY STAR refrigerator/freezers.

8. Cooking

8.1. Definitions and Performance Requirements

8.1.1. Canadian Energy Standard

http://www.nrcan.gc.ca/energy/regulations/codes/standards/products/6937

The energy efficiency standard specifies a maximum total annual energy consumption of 258 kWh/year for electric cooktops. The only energy efficiency standard for gas ranges is that it must not have a continuous burning pilot light.

The total annual energy for an electric cooktop is based on the measurement of the cooktop efficiency and the annual useful cooking energy output. The annual useful cooking energy was determined by field survey data obtained by NIST. In the survey, appliances were monitored during actual home use to determine the total energy consumed. The annual useful energy for a cooktop was calculated by multiplying the annual cooking energy consumption of the appliance by the efficiency of the appliance.

8.1.2. European Energy Standard

https://eur/lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2014:029:0033:0047:EN:PDF

Ecodesign Requirements (Energy Related):

The ecodesign requirement for a domestic electric hob is a maximum energy consumption (EC) of 195 Wh/kg. The energy consumption of a domestic electric hob (EC) is measured in Wh per kg of water heated in a normalised measurement (Wh/kg) considering all cookware pieces under standardised test conditions and rounded to the first decimal place. For gas/fired hobs, the ecodesign requirement is a minimum energy efficiency (EE) of 55%.

The EE is calculated as follows,

$$EE_{gas\ burner} = \frac{E_{theoretic}}{E_{gas\ burner}} \times 100$$

Where,

$E_{gas\ burner}$= energy content of the consumed gas for the prescribed heating in MJ and rounded to the first decimal place

$E_{theoretic}$= theoretic minimum required energy for the corresponding prescribed heating in MJ and rounded to the first decimal place

8.1.3. ENERGY STAR®

There is no ENERGY STAR label for residential cooktops, ovens, ranges, or microwave ovens currently**.**

8.2. Comparison of Performance Requirements

8.2.1. PHPP

The default PHPP input for cooking depends on the type of cooktop[96] [97]:

a. Gas = 0.25 kWh/Use
b. Quartz Halogen Ceramic = 0.22 kWh/Use
c. Induction Ceramic = 0.2 kWh/Use

The average of these three options is 0.22 kWh/Use. The PHPP manual (section 32.3.6) states that the kWh/use is the energy needed for boiling 1.5L of water.

8.2.2. Canadian Energy Standard

To calculate a kWh/Use value, the maximum total annual energy consumption would need to be divided by the number of uses per year. Due to the lack of data available on the number of uses per year it is not possible to calculate an accurate kWh/Use value.

8.2.3. European Energy Standard

The European ecodesign requirement for combination refrigerator/freezers can be translated into a kWh/Use value by multiplying the energy consumption (measured in Wh per kg of water heated) by 1.5kg (1.5L of water) assumed in PHPP.

$$Norm\ Demand = 195Wh/kg \ \times 1.5kg/Use = 0.29\ kWh/Use$$

8.2.4. Cooking Normal Demand Comparison

Given the lack of concrete information, no direct conclusions can be drawn about the relative efficiency of Canadian cooking appliances to the PHPP default values or the European Energy Standard.

[96] PHPP does not include an option for electric coil as it is not common in Germany
[97] At present, documented sources for these data were not available. The default inputs in PHPP are plausible values from older versions of PHPP based on different sources and publications.

9. Comparison of PHPP and HOT2000

HOT2000 is an energy simulation tool for low/rise residential buildings developed by Natural Resources Canada (NRCan). The program has default assumptions for the annual energy demand of a dishwasher, clothes washer, clothes dryer, refrigerator, and stove based on the modelled occupancy.

The purpose of this analysis is not to provide recommendations for the cycles per year to use for modeling in PHPP but to assess the impact of assumed cycles per year and appliance efficiency on the appliance energy demand for a typical household.

Table 9.1 compares the assumptions for cycles/year for dishwashers, clothes washers and clothes dryers, between HOT2000v11.4b5, PHPPv9.5, the Canadian Energy Standard/ ENERGY STAR, and the European Energy Standard/Spargeraete.de. For PHPP and HOT2000, a household occupancy of 3 people is assumed, as this provides a reasonable match to the figures in Canadian and European Standards. For reference, the average occupancy in Canada is 2.4 occupants/household[98], while in Germany it is 2 occupants/household[99]. The usage assumptions for PHPP are lower than HOT2000 especially for clothes washer, while the assumptions for HOT2000 and the Canadian Energy Standard/ ENERGY STAR are aligned except for clothes dryers. This difference is due to the assumed utilization factor for clothes dryers. A utilization factor is used in both HOT2000 and PHPP for clothes dryers. HOT2000 allows for a % use of dryer to be inputted with a default assumption that 71.4% washer loads are dried in the clothes dryers. PHPP calculates a utilization factor based on the residual dampness entry. The default assumption is a residual dampness of 0.60 which leads to a utilization factor of 88%. The utilization factor for clothes dryers from the Canadian Standard and from the European Energy Standard can be calculated by dividing the assumed cycles per year for clothes dryers by the cycles per year for clothes washers. The Canadian Energy Standard therefore assumes a utilization factor of 96% (283/295) whereas the European Energy Standard assumes a utilization factor of 73% (160/220). PHPP cycles per year are more aligned with those used by the European Energy Standard/Spargerate.de except for dishwashers which is substantially lower. It is noted that the cycles per year used by spargerate.de are the same as those in European Energy Standard.

Table 9.1 Cycles per year comparison

	HOT2000	PHPP	Canadian Energy Standard/ ENERGY STAR	European Energy Standard/ Spargeraete.de
Dishwasher (cycles/year)	214	195	215	280
Clothes Washer (cycles/year)	296[100]	171[101]	295	220

[98] 2016 Census Profile for Canada, Accessed May 6 2019: https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/details/page.cfm?Lang=E&Geo1=PR&Code1=01&Geo2=&Code2=&Data=Count&SearchText=Canada&SearchType=Begins&SearchPR=01&B1=All&TABID=1

[99] Eurostat, Accessed May 6 2019: https://ec.europa.eu/eurostat/statistics-explained/index.php/Household_composition_statistics#Household_size

[100] Based on default assumption that 71.4% of washer loads are dried in the machine

[101] Based on an assumption of 57 cycles/occupant/year

Clothes Dryer (cycles/year)	212[102]	150[103]	283	160

Table 9.2 compares the units (# of place settings for dishwashers or kg of clothes for clothes washers and dryers) per year referenced in HOT2000, PHPP, the Canadian Energy Standard/ ENERGY STAR and the European Energy Standard/Spargeraete.de. The units per cycle are based on the test load size defined in the testing standards of the corresponding energy standard. For HOT2000 it is assumed the # place settings and kg per cycle is equal to the Canadian Energy Standard and ENERGY STAR test load sizes. Since the test load sizes for dishwashers, clothes washers and clothes dryers are not fixed for the European Energy Standard and instead depend on the capacity of the unit, the smallest and largest capacity available on Spargeraete.de were used to calculate the range of units required for testing.

For dishwashers, the # place settings per year modelled in PHPP is above the range for HOT2000, the Canadian Energy Standard and ENERGY STAR and below the range for the European Energy Standard/Spargeraete.de. For clothes washers, the kg of clothes per year modelled in PHPP is within the range of, and closer to the minimum for, HOT2000, the Canadian Energy Standard, ENERGY STAR, the European Energy Standard/Spargeraete.de. For clothes dryers, the kg of clothes per year modelled in PHPP is within the range but closer to the maximum of HOT2000, in mid/range of the the Canadian Energy Standard/ENERGY STAR and within the range but closer to the minimum of the European Energy Standard/Spargeraete.de. It is clear from the above observations that there is no consistent pattern in the PHPP usage assumptions relative to HOT2000 or any of the energy standards.

Meals per year for cooktops are not included here due to lack of data from HOT2000, the Canadian Energy Standard for cooktops, and the European Energy Standard for cooktops.

Table 9.2 Units (# place settings or kg of clothes) per year comparison

	HOT2000		PHPP	Canadian Energy Standard/ ENERGY STAR		European Energy Standard/ Spargeraete.de	
	min	max		min	max	min	max
Dishwasher (place settings/ year)	855	1,710	2,340	860	1,720	2,520	4,480
Clothes Washer (kg/year)	631	1,787	855	628	1,779	660	2,640
Clothes Dryer (kg/year)	288	811	715	385	1,085	640	960

In Figure 9.1, HOT2000 default annual energy demand[104] for dishwashers, clothes washers, clothes dryers, refrigerator/freezers, and cooking is compared to PHPP defaults, the Canadian Energy Standard, the European Energy Standard, ENERGY STAR top performing appliances, and best in class appliances available in the German market. The same HOT2000 default occupancy of 3 people is used for all calculations. For this comparison the maximum and minimum annual energy demand across all product

[102] Based on an assumption of 1.9 cycle/occupant/week
[103] Based on an assumption of 57 cycles/occupant/year and a utilization factor of 0.88
[104] The annual energy demand is based on the rated performance, not energy modelling results

types are shown. Annual energy demand is calculated as the normal demand (kWh/cycle or kWh/day) multiplied by the cycles per year, as shown in Table 9.1, or by 365 days.

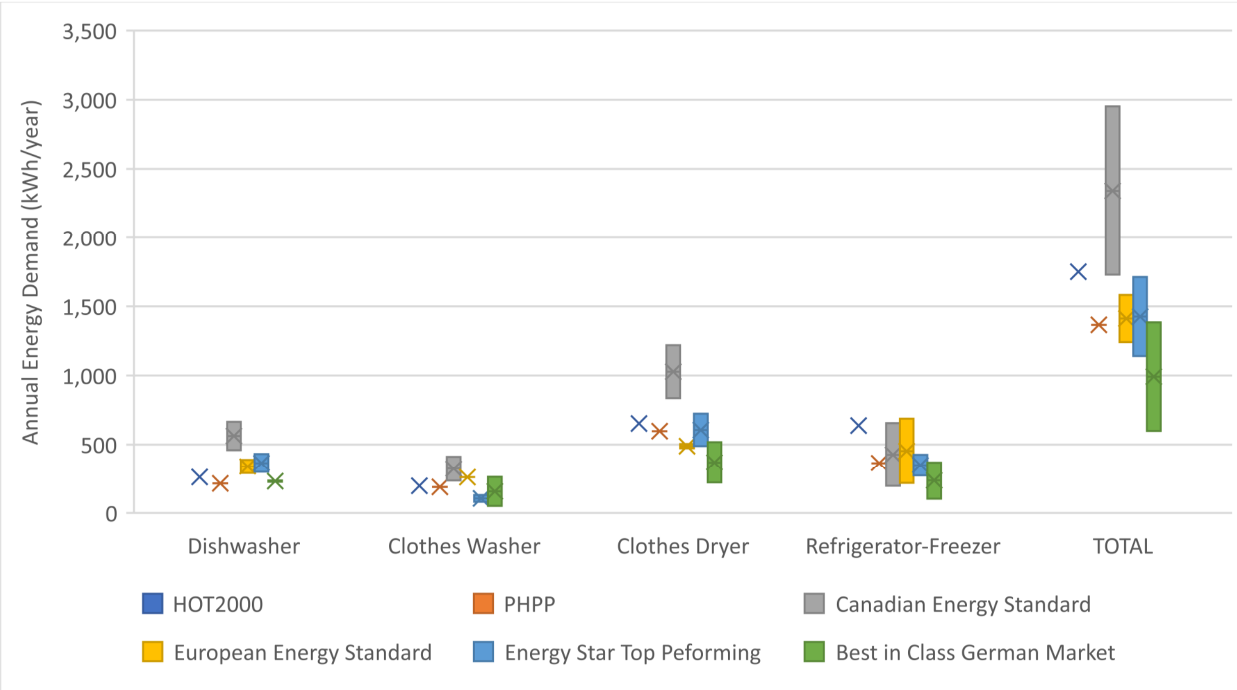

Figure 9.1 Comparison of default annual energy Demand from HOT2000 and PHPP with the Canadian Energy Standards, European Energy Standards, ENERGY STAR top performing and Best in Class in the German Market for household appliances, based on usage figures from Table 9.3 and assumed occupancy of 3 occupants/household.

The results show that the default figures in HOT2000 have a higher energy demand assumed for household appliances, in particular for refrigerators, as compared to PHPP (28% for three occupants). For refrigerating appliances, the energy demand varies greatly depending on the type and size of the appliance: HOT2000 default figures align more with the higher end of the Canadian or European Energy Standard whereas PHPP defaults align more with ENERGY STAR or the lower end of the Canadian or European Energy Standard and top end of German Best in Class. Figure 9.1 also reveals that purchasing a small ENERGY STAR rated refrigerator without a built/in ice maker will have one of the biggest impacts on total annual energy demand.

Because of the differing usage patterns, it is difficult to directly compare HOT2000 and PHPP modelling for dishwashers, clothes washers, and clothes dryers from the data in Figure 9.1. To gain better insight, calculations were undertaken with fixed patterns and separately for fixed energy performance levels.

Figure *9.2* and Figure 9.3 show results using the minimum and maximum Normal Demands for dishwashers, clothes washers, and clothes dryers for each standard multiplied by a fixed usage (cycles per year) from PHPP and HOT2000, respectively. The total annual energy demand (which includes the refrigerator/freezer annual energy from Figure 9.1) is also shown.

The figures show the impact of the energy performance level on both the individual appliance and total annual energy demand. For dishwashers and clothes dryers, the absolute annual energy demand varies considerably for both Canadian Standard and ENERGY STAR rated appliances. ENERGY STAR rated clothes washers vary little. The HOT2000 default usage leads to a higher annual energy demand for clothes washers and clothes dryers (Figure 9.3) compared to the PHPP default cycles per year (

Figure *9.2*), whereas the dishwasher annual energy demand is fairly similar. Overall, HOT2000 default Normal Demand figures result in a 7% higher total annual energy demand compared to PHPP default figures, regardless of cycles per year assumptions.

For dishwashers, the energy performance levels for the best in class dishwashers available in the German market are generally more energy efficient than the top performing ENERGY STAR dishwashers. For clothes washers and clothes dryers, the performance is variable depending on the product type so no general conclusion can be made. The PHPP default figures are optimistic for Canadian Standard dishwashers, so product/specific data should be used in PHPP. For Canadian Standard clothes washers and clothes dryers, the PHPP default Normal Demand figures are reasonable. If ENERGY STAR versions are specified, using product/specific data in PHPP is preferred. Overall, if all appliances are specified as ENERGY STAR, using PHPP default Normal Demand figures will provide somewhat conservative results. Where none of the appliances are ENERGY STAR, results will be optimistic. Additionally, specifying an ENERGY STAR dishwasher or clothes dryer has a bigger impact than a clothes washer.

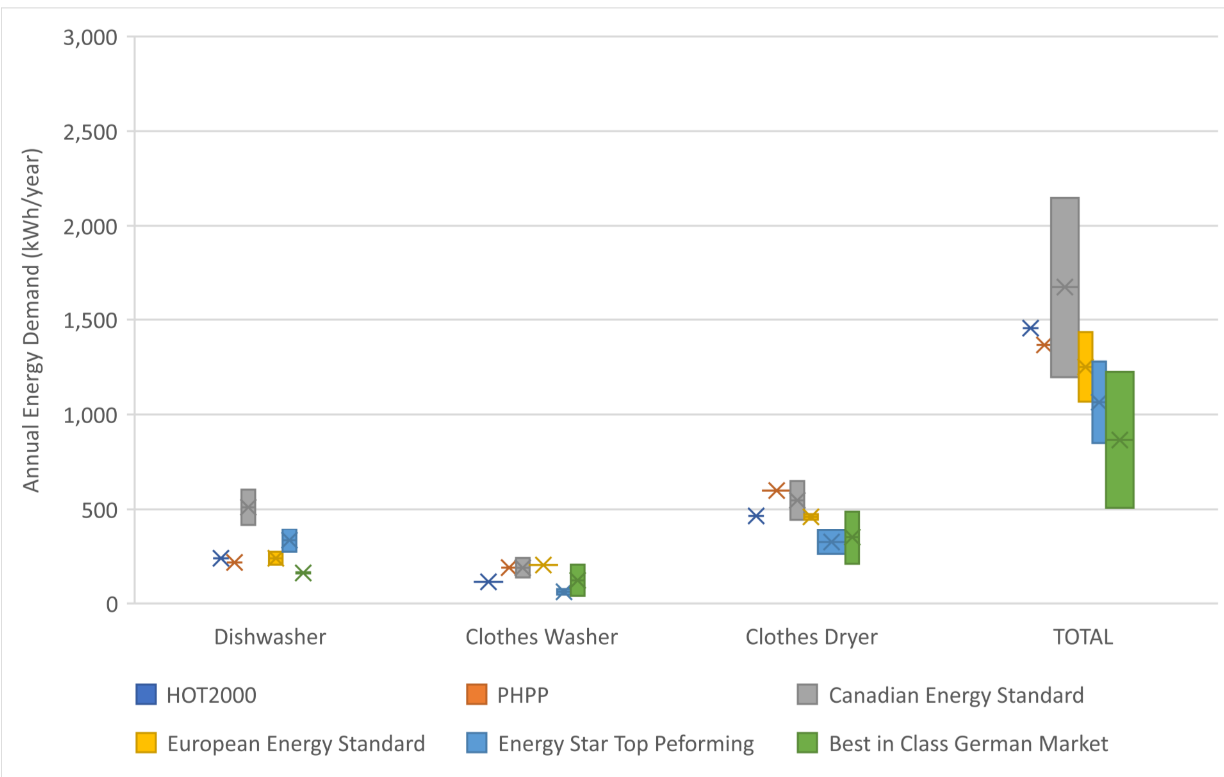

Figure 9.2 Comparison of annual energy demand for the various standards, using a fixed usage (cycles per year) from PHPP and normalized to 5kg or 12 place settings. The totals include refrigerator energy demand figures from Figure 9.1.

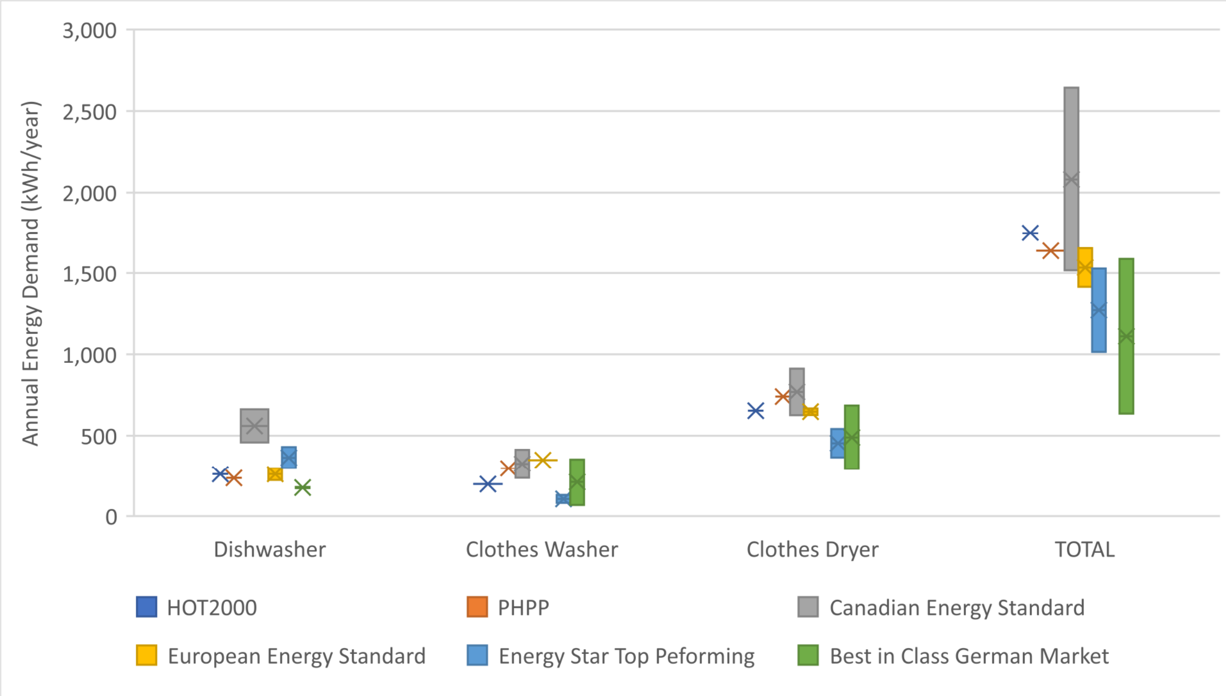

Figure 9.3 Comparison of annual energy demand for the various standards, using a fixed usage (cycles per year) from HOT2000 and normalized to 5kg or 12 place settings. *The totals include refrigerator energy demand figures from Figure 9.1.*

Figure 9.4, Figure 9.5, and Figure 9.6 show results calculated using fixed minimum and maximum energy performance levels (Normal Demand) for dishwashers, clothes washers, and clothes dryers, from HOT2000, top performing ENERGY STAR, and Best in Class appliances in the German Market, multiplied by the usage (cycles/year) specified in the corresponding energy standard.

For example, in Figure 9.5, top performing ENERGY STAR dishwashers have a minimum normal demand of 1.29kWh/cycle for a standard dishwasher and a maximum value of 2.01kWh/cycle for a compact dishwasher (see Table 2.1). These maximum and minimum normal demands are multiplied by the cycles per year assumed in HOT2000, PHPP, the Canadian Energy Standard and European Energy Standard (Table 9.4). The same methodology is also applied to ENERGY STAR top performing clothes washers and clothes dryers.

These results give insight into the impact of usage pattern assumptions. Most notable is that the higher cycles per year figure for HOT2000 and the Canadian Energy Standard has a large impact on the annual energy demand for clothes dryers, even when energy efficient products (ENERGY STAR or Best in Class in the German Market) are chosen. The annual energy demand of dishwashers and clothes washers on the other hand are less effected by usage pattern assumptions in absolute terms.

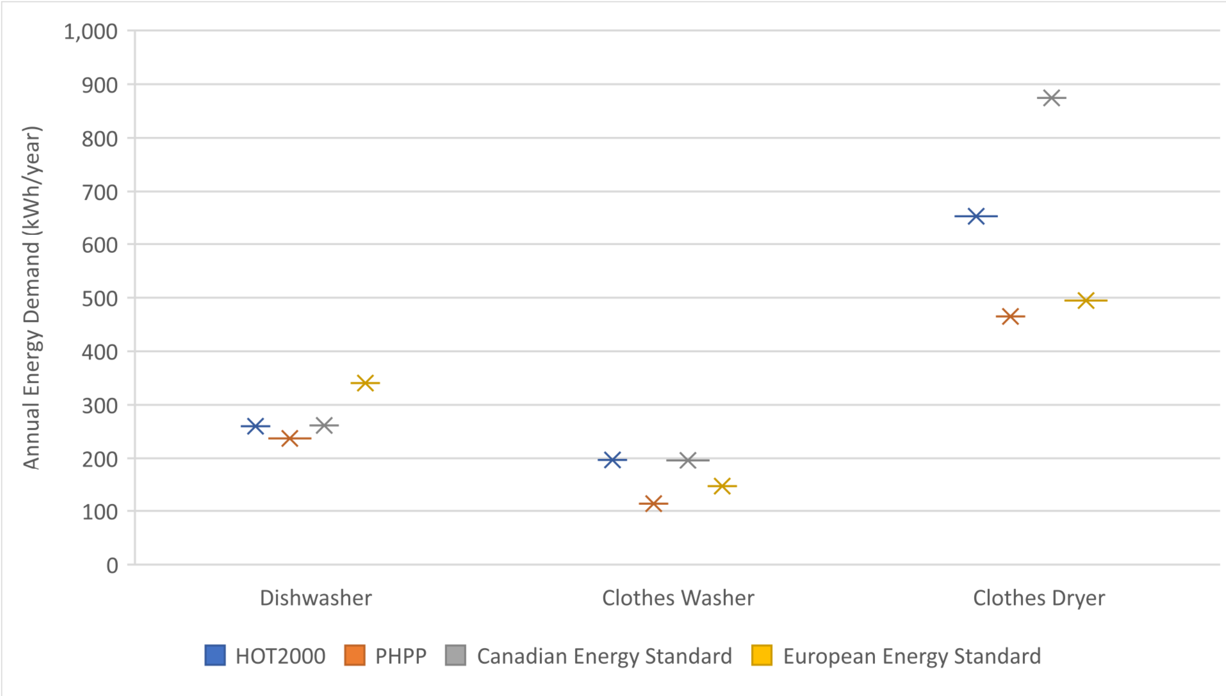

Figure 9.4 Comparison of annual energy demand based on the usage assumptions for the various standard , using a fixed energy performance (Normal Demand) from HOT2000.

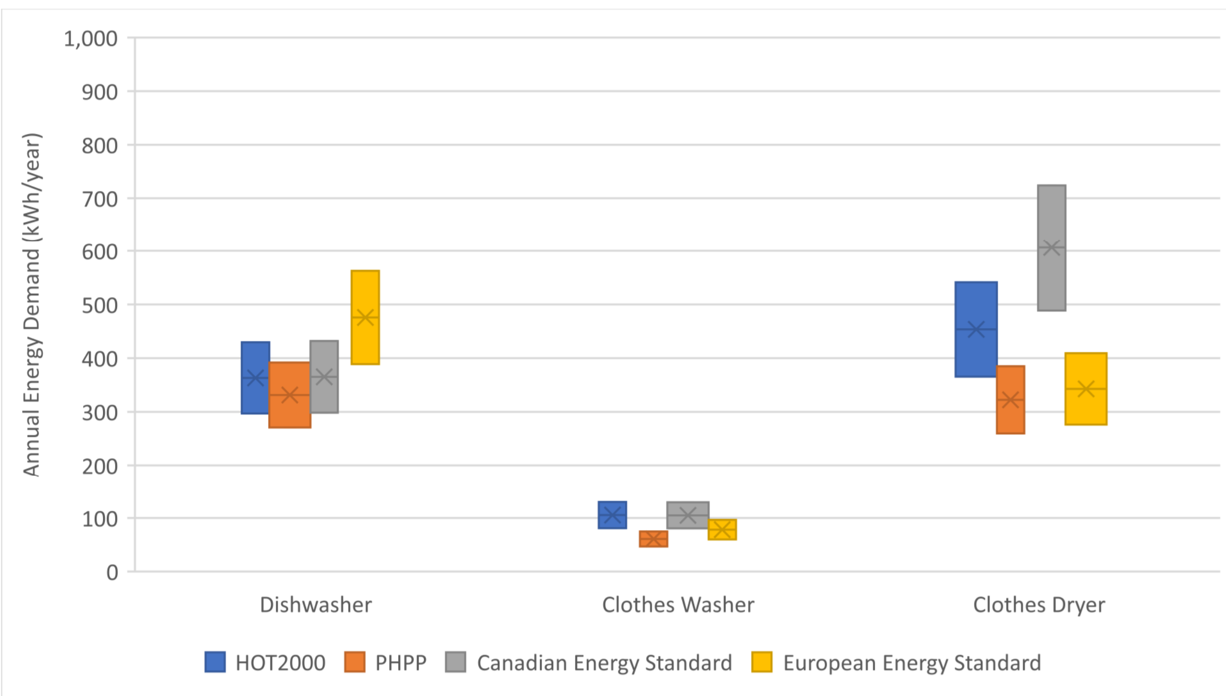

Figure 9.5 Comparison of annual energy demand based on the usage assumptions for the various standard, using the minimum and maximum energy performance (normal demand) from top performing ENERGY STAR appliances.

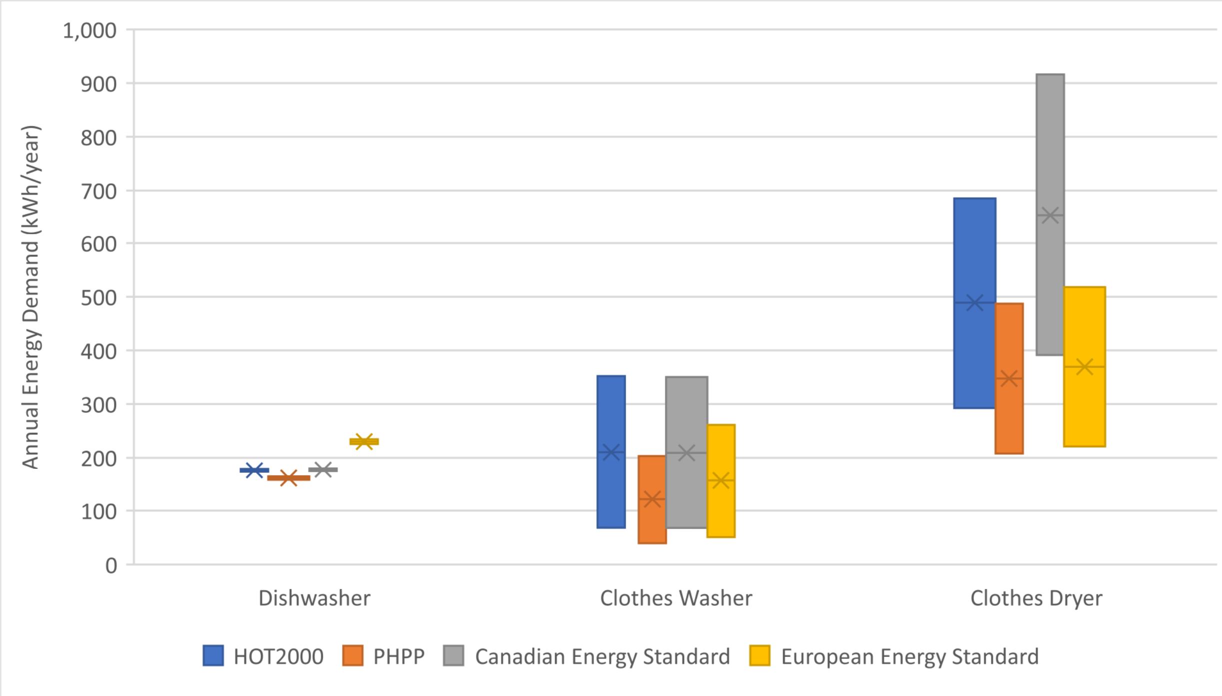

Figure 9.6 Comparison of annual energy demand based on the usage assumptions for the various standard, using the minimum and maximum energy performance (Normal Demand) from the Best in Class appliances in the German Market.

Figure 9.7 illustrates the total annual energy demand of all appliances (dishwashers, clothes washers, clothes dryers and refrigerator/freezers) from Figure 9.4 (HOT2000 normal demand), Figure 9.5 (Top performing ENERGY STAR normal demand), and Figure 9.6 (Best in Class German market normal demand). The total annual energy includes refrigerator/freezer annual energy consumption from Figure 9.1.

The results show that overall, the higher cycles per year for the Canadian Energy Standard results in the highest total annual energy consumption (on average), for all appliances (dishwashers, clothes washers and refrigerator/freezers) irrespective of the appliance energy performance standard. Similarly, the PHPP figures are consistently much lower than the HOT2000 figures, regardless of the performance standard. This indicates a consistent discrepancy in the assumed usage patterns between the two energy modelling tools. PHPP is also consistently below or at the bottom range of the European Standard, whereas HOT2000 is in the middle or above European range, although the same assumed occupancy of 3 people/household is used. One could conclude from this that PHPP's usage assumptions are low. However, the authors have not found external data to corroborate this statement. Further work is clearly required to establish accurate usage patterns to improve modelling accuracy for typical households.

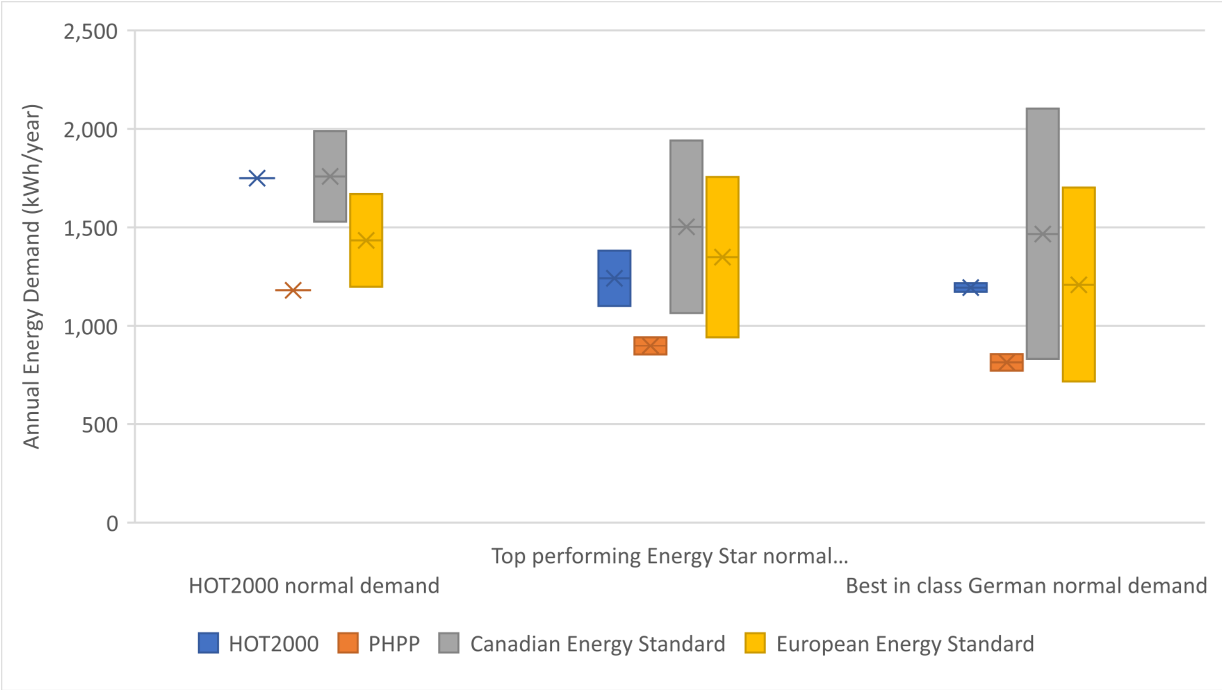

Figure 9.7 Comparison of the total annual energy demand for the various standards, using the minimum and maximum energy performance (Normal Demand) from HOT2000, the top performing ENERGY STAR and the Best in Class appliances in the German Market. The total annual energy includes refrigerator/freezer energy demand figures from Figure 9.1.

10. Summary

This study investigated the differences between in Normal Demand between PHPP defaults, Canadian, European and ENERGY STAR product standards, ENERGY STAR Top and German Best in Class. It also investigated the energy modelling and usage assumptions to understand how product efficiency and usage patterns influence the annual energy demand of appliances.

Table 10.1 summarizes the Normal Demand by appliance type and product standard. Product efficiency requirements vary greatly across product categories, appliances types and product standards. The European requirements are generally more stringent, but this is not always the case. The Best in Class appliances available in the German market are generally more energy efficient then the top performing ENERGY STAR appliances, however there are some exceptions (clothes washers and vented standard clothes dryers).

Figure 10.1 summarizes the total appliance annual energy demand (dishwasher, clothes washer, clothes dryer, and refrigerator/freezer) by Product performance and Usage pattern. The results show that HOT2000 usage patterns (cycles/year) result in higher annual energy demand compared to the PHPP default usage patterns. Additionally, the total annual appliance energy demand is much lower for E ENERGY STAR top performing appliances or Best in Class appliances in the German market compared to the HOT2000 or PHPP defaults, while for the Canadian Standard the opposite is true. These observations confirm that product efficiency has a significant impact on the calculated total annual energy demand.

As general guidance, appliance energy use should be changed in residential buildings only if planning or concept for efficient use of electricity exists, otherwise standard values already entered in PHPP should be used. When the products only meet the Canadian minimum requirements, PHPP users could generate a variant including the actual normal demand of the products as a stress test to see the impact on summer internal heat gains (IHG) and PER/PE demand.

Table 10.1 Summary of PHPP Normal Demand by Appliance Type and Product Standard

Dishwasher	PHPP Default	Canadian Energy Standards		European Energy Standards		ENERGY STAR				Best in Class German Market	
						Minimum Requirement		Top Performing			
		Standard	Compact	Standard	Compact	Standard	Compact	Standard	Compact	Standard	Compact
Normal Demand (kWh/cycle)	1.10	2.14	3.10	1.04	01.39	1.88	2.83	1.39	2.01	0.81	0.84

Clothes Washer	PHPP Default	Canadian Energy Standards			European Energy Standards largest	ENERGY STAR						Best in Class German Market		
						Minimum Requirement			Top Performing					
		Top/loading compact	Front/loading standard			Front/loading compact	Front/loading standard		Front/loading compact	Front/loading standard		Front/loading compact	Front/loading standard	
		smallest	5kg avg load	Largest		smallest	5kg avg load	Largest	smallest	5kg avg load	Largest	smallest	5kg avg load	Largest
Capacity (kg)		2.9	8.46	10.69	7	3.82	8.46	10.88	3.82	8.46	10.88	3	8	11
Normal Demand (kWh/cycle)	1.10	0.80	1.28	1.39	1.73	1.20	0.50	0.52	0.44	0.27	0.33	1.01	0.23	0.40

Clothes Dryer	PHPP Default	Canadian Energy Standards		European Energy Standards		ENERGY STAR					Best in Class German Market	
						Minimum Requirement		Top Performing				
		Ventless compact	Vented standard	Ventless standard	Vented standard	Ventless Compact	Ventless and Vented Standard	Ventless Compact	Vented Standard	Ventless Standard	Ventless standard	Vented standard
Capacity (ft^3)		< 4.4	> 4.4	9.6[105]	9.6	< 4.4	> 4.4	4.1	7.3	7.4	6.9	5.5
Norm Demand (kWh/cycle)	3.50	4.31	2.96	3.15	2.96	4.10	2.80	1.73	2.56	2.44	1.38	3.24

Refrigerator	PHPP Default	Canadian Energy Standards			European Energy Standards	ENERGY STAR						Best in Class German Market
						Minimum Requirement			Top Performing			
		Built/in automatic defrost	Automatic defrost	Manual Defrost		Built/in automatic defrost	Automatic Defrost	Manual Defrost	Built/in automatic defrost	Automatic Defrost	Manual Defrost	Automatic Defrost
Capacity (L)		102 – 971			208 – 665	115 – 580	220 – 368	106 – 395	102 – 971			208 – 665
Norm Demand (kWh/day)	0.78	0.42 – 0.81	0.37 – 0.72	0.35 – 0.69	0.37 – 0.60	0.37 – 0.73	0.33 – 0.65	0.32 – 0.62	0.46 – 0.61	0.39 – 0.50	0.26 – 0.41	0.16 – 0.32

Freezers	PHPP Default	Canadian Energy Standards			European Energy Standards		ENERGY STAR						Best in Cla German Market	
		Upright/high	Chest	Upright/med	Upright	Chest	Minimum Requirement			Top Performing			Upright	C
							Upright/high	Chest	Upright/med	Upright/high	Chest	Upright/med		
Capacity (L)		30 – 704			220 – 605	70 – 614	31 – 603	30 – 399	98 / 451	30 – 704			220 – 605	7 6
Norm Demand (kWh/ day)	0.88	0.78 – 1.66	0.26 – 0.91	0.52 – 1.30	0.47 – 1.55	0.43 – 1.37	0.70 – 1.49	0.23 – 0.82	0.47 – 1.17	0.88 – 1.24	0.29 – 0.74	0.46 – 1.06	0.32 – 0.52	0 – 0

Refrigerator/Freezer	PHPP Default	Canadian Energy Standards			European Energy Standards	ENERGY STAR					Best in Class German Market
		Manual defrost	Automatic Defrost	Automatic Defrost with ice service		Minimum Requirement			Top Performing		
						Manual Defrost	Automatic Defrost	Automatic Defrost with ice service	Automatic Defrost	Automatic Defrost with icemaker	
Capacity (L)		95 – 971			226 – 685	249 – 702	141 – 605	95 – 971			226 – 685
Norm Demand (kWh/day)	1.00	0.54 – 1.09	0.69 – 1.27	1.12 – 1.80	0.59 – 1.89	0.49 – 0.98	0.62 – 1.15	1.01 – 1.62	0.75 – 0.97	0.94 – 1.17	0.28 – 1.01

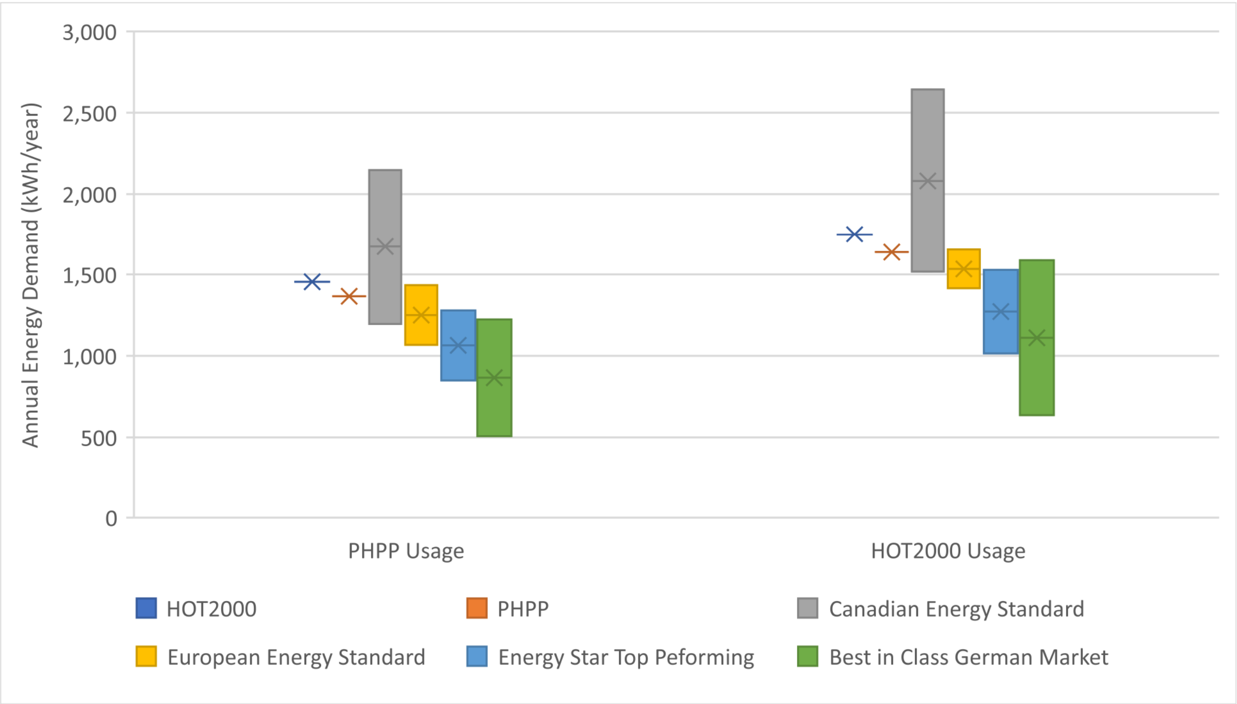

Figure 10.1 Summary of Total Annual Appliance Energy Demand by Product Performance Level and Usage Pattern

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