

Optimizing heat pump control strategies under capacity-based and dynamic electricity tariffs

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Abstract

This research, conducted in collaboration with Intellisol NV, focuses on developing an automated Excel-based simulation tool to quantify the economic impact of residential heat pumps under dynamic electricity tariffs and the capacity tariff. The tool details energy consumption based on predefined parameters, accurately simulating both central heating and domestic hot water demand. Using this simulated consumption, the model subsequently calculates the exact energy costs for various control strategies under both fixed and dynamic tariffs over a multi-year period. Thanks to this instrument, Intellisol NV can map the interaction between heat pumps, solar panels, home batteries, and different control methods. This results in a clear and structured methodology to analyze which option is financially and energetically optimal for each specific user profile.

1 Introduction

The ongoing energy transition and the increasing volatility of electricity prices are forcing households to fundamentally rethink their consumption patterns. While fixed-rate energy contracts previously provided stability, the emergence of dynamic pricing models has introduced a new layer of complexity to the market [1]. In the Belgian context, this effect is intensified by the implementation of the capacity tariff, which shifts the focus of billing from pure volumetric consumption to the management of peak power demand [2].

This research is conducted in collaboration with Intellisol NV, a company specializing in sustainable energy technologies such as solar photovoltaic (PV) systems, home batteries, charging stations, and heat pumps. As an installer, Intellisol faces a growing demand from customers for clear advice on how these various technologies can optimally interact within the current variable and dynamic energy market.

Residential technologies offer essential opportunities to respond to price fluctuations and mitigate the financial impact of the capacity tariff [3]. However, the effectiveness of these investments depends heavily on the interaction between the hardware and the chosen electricity contract. For heat pumps specifically, there is significant uncertainty regarding whether active control strategies based on price signals are truly

cost-effective, given the complex balance between comfort and savings. Currently, there is a lack of accessible tools that make these potential savings transparent for the consumer.

The central question of this study is: *To what extent are the investment costs of a home battery or thermal buffer offset by the operational savings of a dynamic contract, and what is the added value of smart control strategies?* The goals of this research are as follows:

- The development of an automated calculation tool that quantifies the economic and energetic impact of various technological configurations.
- The provision of clear insight into potential savings for the end-user based on their specific setup.
- An evaluation of whether specific heat pump control strategies justify the investment compared to standard operational settings.

This research employs a quantitative analysis. Simulations based on historical price data and realistic consumption profiles test the performance of various combinations of contracts and storage systems. This data serves as the input for the developed tool, which compares different scenarios, including those with and without smart control strategies.

The hypothesis is that households utilizing a dynamic contract in combination with smart storage

technologies and automated heat pump control achieve a lower total cost of ownership, provided that the control strategy effectively manages peak demand without compromising comfort.

2 Method

The starting point of this research is the current uncertainty among Belgian households regarding the profitability of new energy technologies. While Intellisol NV provides the hardware such as heat pumps and batteries, customers often lack the analytical insight to choose the right energy contract or control strategy. The baseline for this study is a standard household with a fixed rate contract and no active storage management. The methodology aims to bridge the gap between technical installation and financial optimization, directly addressing the problem of unpredictable energy bills in a volatile market.

The foundation of this study lies in the systematic collection and preparation of high-resolution input data. Quarter hourly electricity prices for a dynamic contract are gathered to ensure the model reflects realistic market conditions over a full year. Furthermore, the parameters of the Belgian capacity tariff are incorporated, specifically the rules for determining monthly peak power and their translation into annual costs. To capture seasonal variations, representative household consumption profiles and solar photovoltaic production data are integrated into the dataset. Finally, technical and financial characteristics for home batteries and thermal storage such as capacity, efficiency and investment costs are compiled and validated.

The simulation of energy flows such as grid injection and battery charging cycles is performed using the specialized software PVSOL [4]. Within this program, the specific household consumption profile is uploaded, after which the technical configuration of the solar panels and the battery is integrated for an accurate yield calculation. This software based approach ensures that the interaction between generation and storage is based on realistic technical parameters and local solar irradiance data. This data then serves as the input for the subsequent financial analysis.

The developed Excel model serves as the central interface for the financial analysis and provides the computational backbone of the project. Designed for transparency and reproducibility, the model is structured into specific modules for contracts, capacity tariffs and energy flows. For households equipped with a smart meter, the model allows for the direct upload of detailed fifteen-minute interval

data to ensure highly precise calculations. If such data is unavailable, the model simulates annual consumption based on user defined parameters, ensuring the tool remains accessible for a diverse range of users.

A structured series of scenarios is developed to evaluate the impact of contract choice and technology adoption. The analysis begins with baseline scenarios comparing fixed and dynamic contracts without additional technologies. Subsequently, solar panels are introduced to assess how self-consumption and injection behaviour influence total costs. In the final phase, the potential added value of a home battery or thermal storage tank specifically focusing on heat pump control strategies is examined by simulating operation throughout the year. Each scenario uses identical consumption profiles, ensuring that differences in outcomes are attributed solely to the chosen technological configuration.

This methodology is explicitly linked to SDG 7.3, which targets a global doubling of the rate of improvement in energy efficiency by 2030 [5]. The research contributes to this goal by developing a tool that optimizes the efficiency of existing residential systems. By implementing smart control strategies for heat pumps and storage units, the study identifies ways to reduce energy waste and lower the total energy demand from the grid. This approach ensures that energy is consumed more intelligently, making the transition to sustainable systems financially viable while maximizing the efficiency of every kilowatt hour produced.

The results of each scenario are evaluated using a combination of financial and energetic performance indicators. Beyond calculating the total annual electricity cost, the model quantifies self-consumption rates and peak power reduction. To ensure robustness, the model undergoes internal validation to verify formula consistency. Furthermore, a sensitivity analysis examines how variations in electricity prices or battery size affect the results, with outputs compared against external benchmarks for realism.

3 Results

3.1 Modelling Scenarios: Simulation versus Empirical Data

The effectiveness of the analytical model depends on the quality and type of input data used for the calculations. The model distinguishes between two primary data sources: simulated consumption profiles and historical data from smart meters.

Each source serves a specific purpose in the decision-making process, allowing the tool to be used both for prospective planning and for the retrospective optimisation of existing energy systems.

The simulation function is particularly valuable for users in the pre-construction or renovation phase of a residential project. When actual consumption data is not yet available, the model generates an indication of expected electricity demand based on household parameters. This allows prospective homeowners to assess the potential savings of technologies such as photovoltaic systems, home batteries, or thermal buffers before making significant capital investments.

For households already equipped with a smart meter, the model offers the ability to import actual annual data at fifteen-minute intervals. This empirical approach provides a highly accurate reflection of the current energy behaviour and costs. By using this historical data, the model can precisely calculate the financial impact of integrating new technologies, showing exactly how the investment would alter the household's existing electricity bill and peak power usage.

The use of high-resolution data ensures that the interaction between volatile energy prices and the Belgian capacity tariff is accurately captured. Whether using simulated or imported data, the results highlight how shifting consumption patterns or adding storage can lower the total cost of ownership. This dual approach ensures that the findings are robust and applicable to a wide variety of residential energy situations.

In this research, a specific building is chosen as the primary case study. Table 1 outlines the different rooms, their respective levels, their surface areas in m², and the design temperatures that are used to calculate the heat loss.

Table 1: Room dimensions and temperatures

Room	Level	Area (m ²)	Design Temp (°C)
Basement	-1	95.72	4
Living room 1	0	22.04	21
Kitchen	0	22.96	21
Storage	0	13.87	18
Toilet	0	1.54	18
Living room 2	0	16.45	21

Entrance	0	9.04	18
Bathroom	1	15.36	24
Bedroom 1	1	20.20	21
Bedroom 2	1	21.51	21
Bedroom 3	1	16.45	21
Toilet	1	1.54	18
Night hall	1	10.19	18
Office	2	7.27	21
Bedroom 4	2	6.81	21
Total heated area		280.95	

3.2 Methodology for Data Input and Simulation Sequence

The reliability of the results is guaranteed through a structured step-by-step plan for data input, adapted to the information available to the user. For households already equipped with a smart meter, this serves as the most direct data source; annual consumption data can be exported from the grid operator's portal and uploaded directly into the Excel model. This method provides a highly precise reflection of actual energy behaviour and the associated costs.

For properties without smart meter data, such as new-build projects, the process begins with a thorough technical analysis of the building envelope. To accurately simulate the consumption of the central heating system, it is necessary to first determine the transmission heat loss of the dwelling. This calculation is based on specific building characteristics, focusing on the physical properties of walls, floors, roofs, and glazing. It is important to note that the residence is currently equipped with a conventional gas-fired boiler connected to an underfloor heating system.

The specialised software Heatbox is utilised to determine these specific heat loss values. Figure 1 displays a representative result from such a calculation, where the total transmission loss serves as the foundation for further consumption simulations within the Excel model. A key feature of this model is its dynamic nature; the data imported from Heatbox can be adjusted at any time, allowing the user to evaluate the immediate impact of different insulation levels on the final energy costs.

In addition to the structural specifications, Heatbox allows for the precise adjustment of the desired

indoor temperature for each individual room. Table 1 provides an overview of the various rooms along with their respective temperature settings. Since heat demand is directly dependent on the temperature differential between the interior and exterior, any modification within a specific space result in an immediate update of the total calculations. For the representative dwelling in this study, a total transmission heat loss of 7.13 kW was calculated based on the structural data and room-specific temperatures. This result of the heat loss calculation is illustrated in Figure 1 and serves as the energetic baseline for the subsequent simulation of the central heating consumption within the Excel model.

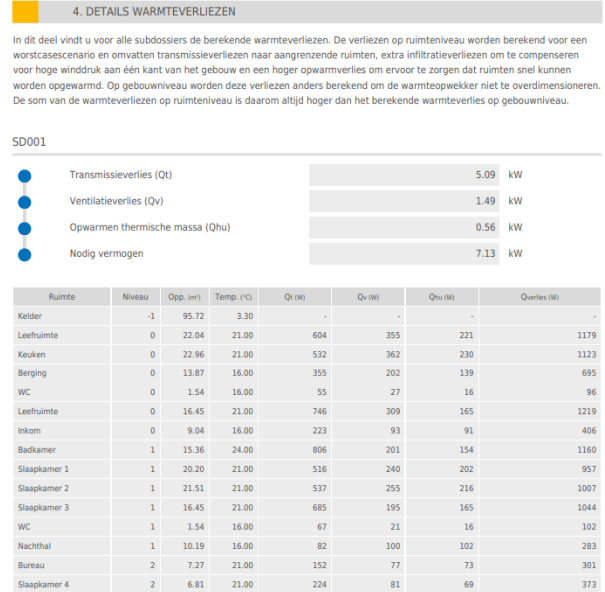
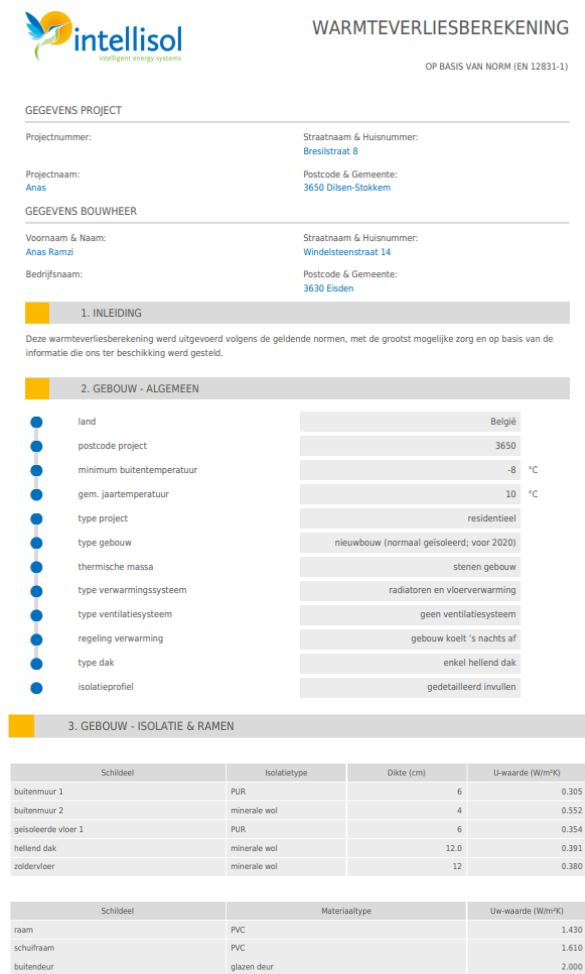


Figure 1: Heat Loss calculation

3.3 Central Heating Consumption Simulation

To establish an accurate annual consumption profile, the model incorporates a wide range of input parameters. In addition to the design temperature derived from Heatbox, specific user settings are applied, such as the desired indoor temperature, holiday settings, and night-time reduction parameters (including start time and duration). These data points are combined with fifteen-minute interval ambient temperature data for a full year from the Maastricht region [6]. By linking these temperatures to the specific Coefficient of Performance (COP) characteristics of the heat pump, the model generates a realistic electricity demand on a quarterly basis.

The model offers the flexibility to select from four distinct control strategies, each with a unique impact on the simulated consumption. The first option is the constant temperature control, where the system maintains a fixed indoor temperature (e.g. 20°C) throughout the year. The second method is based on degree days, where heating is deactivated when the outdoor temperature exceeds a set threshold (such as 16°C); while widely used, this method is less precise for short-term fluctuations [7]. A third option considers the average daily temperature, recording zero consumption if the average remains above the threshold. The final method is the heating season control, which allows the user to define specific dates during which the heating system is entirely deactivated.

The model can further account for variations in user behaviour through a dedicated holiday function. Users can input specific start and end dates during which the property enters an energy-saving mode, such as maintaining a constant temperature of 15°C during their absence. This feature leads to a significant reduction in simulated consumption during those periods, thereby enhancing the reliability of the total annual cost calculation.

The final output of these calculations is presented in a comprehensive matrix that maps the consumption for every fifteen-minute interval of the year. This matrix is structured with the daily quarter-hour intervals on the horizontal axis and the calendar dates on the vertical axis. To make the vast amount of data interpretable, conditional formatting using a three-colour scale has been applied: green represents zero or minimal consumption, yellow/orange indicates moderate demand, and red signifies high consumption. This visual approach, as illustrated in Figure 2, clearly demonstrates the seasonal dynamics, with high consumption visible in winter (red zones) and minimal activity during the summer (green zones).

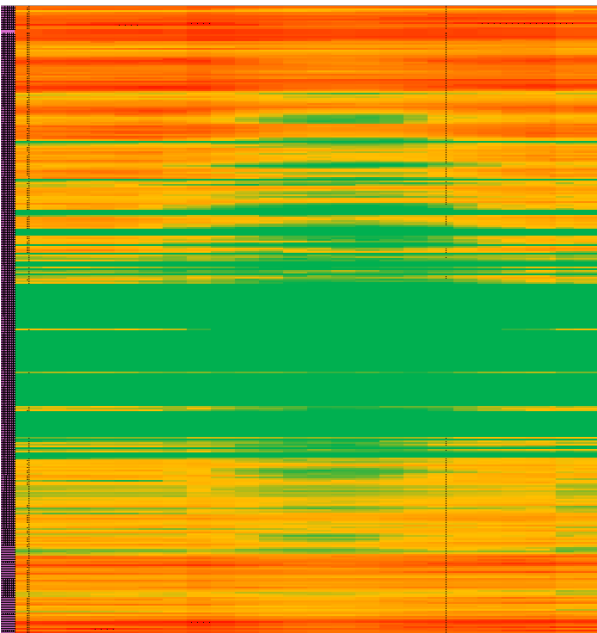


Figure 2: Heat loss matrix (Horizontal axis: Time of day (15-min intervals); Vertical axis: Calendar dates)

3.3.1 Weather-compensated control

To accurately simulate central heating consumption, the flow temperature of the water is essential. For this purpose, a manufacturer's characteristic curve was recreated in Excel shown in the next figure. Using this weather-compensated control, the model looks at the outdoor temperature

to determine the required water temperature for the heating system.

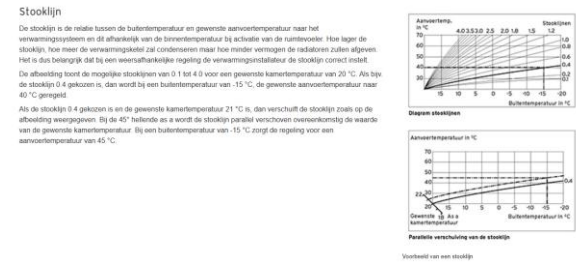


Figure 3: Heating curves

In the model, you can select different heating curves. In practice, you start with the lowest curve: this results in the lowest energy consumption but likely provides insufficient comfort. By gradually increasing the heating curve until the house is comfortably warm, you find the optimal point. This is the setting that achieves the lowest possible energy usage while still maintaining a comfortable home.

Binnentemp	20	Warmtevraag van de woning															
Stooklijn	0.4	Elektrisch Verbruik = Basis COP × Correctiefactor Watertemperatuur															
Buitemtemp		0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	4					
20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
19	20.286	20.572	20.858	21.144	21.43	21.716	22.002	22.288	22.574	22.86	25.72	20.286	20.572	20.858	21.144	21.43	21.716
18	20.572	21.144	21.716	22.288	22.86	23.432	24.004	24.576	25.148	25.72	31.44	20.572	21.144	21.716	22.288	22.86	23.432
17	20.858	21.716	22.574	23.432	24.29	25.148	26.006	26.864	27.722	28.58	37.16	20.858	21.716	22.574	23.432	24.29	25.148
16	21.144	22.288	23.432	24.576	25.72	26.864	28.008	29.152	30.296	31.44	42.88	21.144	22.288	23.432	24.576	25.72	26.864
15	21.43	22.86	24.29	25.72	27.15	28.58	30.01	31.44	32.87	34.3	48.6	21.43	22.86	24.29	25.72	27.15	28.58
14	21.716	23.432	25.148	26.864	28.58	30.296	32.012	33.728	35.444	37.16	54.32	21.716	23.432	25.148	26.864	28.58	30.296
13	22.002	24.004	26.006	28.008	30.01	32.012	34.014	36.016	38.018	40.02	60.04	22.002	24.004	26.006	28.008	30.01	32.012
12	22.288	24.576	26.864	29.152	31.44	33.728	36.016	38.304	40.592	42.88	65.76	22.288	24.576	26.864	29.152	31.44	33.728
11	22.574	25.148	27.722	30.296	32.87	35.444	38.018	40.592	43.166	45.74	71.48	22.574	25.148	27.722	30.296	32.87	35.444
10	22.86	25.72	28.58	31.44	34.3	37.16	40.02	42.88	45.74	48.6	77.2	22.86	25.72	28.58	31.44	34.3	37.16
9	23.146	26.292	29.438	32.584	35.73	38.876	42.022	45.168	48.314	51.46	82.32	23.146	26.292	29.438	32.584	35.73	38.876
8	23.432	26.864	30.296	33.728	37.16	40.592	44.024	47.456	50.888	54.32	88.64	23.432	26.864	30.296	33.728	37.16	40.592
7	23.718	27.436	31.154	34.872	38.59	42.308	46.026	49.744	53.462	57.18	94.36	23.718	27.436	31.154	34.872	38.59	42.308
6	24.004	28.008	32.012	36.016	40.02	44.024	48.028	52.032	56.036	60.04	100.08	24.004	28.008	32.012	36.016	40.02	44.024
5	24.29	28.58	32.87	37.16	41.45	45.74	50.03	54.32	58.61	62.9	105.8	24.29	28.58	32.87	37.16	41.45	45.74
4	24.576	29.152	33.728	38.304	42.88	47.456	52.032	56.608	61.184	65.76	111.52	24.576	29.152	33.728	38.304	42.88	47.456
3	24.862	29.724	34.586	39.448	44.31	49.172	54.034	58.896	63.758	68.62	117.24	24.862	29.724	34.586	39.448	44.31	49.172
2	25.148	30.296	35.444	40.592	45.74	50.888	56.036	61.184	66.332	71.48	122.96	25.148	30.296	35.444	40.592	45.74	50.888
1	25.434	30.888	36.302	41.736	47.17	52.604	58.036	63.472	68.904	74.34	128.68	25.434	30.888	36.302	41.736	47.17	52.604
0	25.72	31.44	37.16	42.88	48.6	54.32	60.04	65.76	71.48	77.2	134.4	25.72	31.44	37.16	42.88	48.6	54.32
-1	26.006	32.012	38.018	44.024	50.03	56.036	62.042	68.048	74.054	80.06	140.12	26.006	32.012	38.018	44.024	50.03	56.036
-2	26.292	32.584	38.876	45.168	51.46	57.752	64.044	70.336	76.628	82.92	145.84	26.292	32.584	38.876	45.168	51.46	57.752
-3	26.578	33.156	39.734	46.312	52.89	59.468	66.046	72.624	79.202	85.78	151.56	26.578	33.156	39.734	46.312	52.89	59.468
-4	26.864	33.728	40.592	47.456	54.32	61.184	68.048	74.912	81.776	88.64	157.28	26.864	33.728	40.592	47.456	54.32	61.184
-5	27.15	34.3	41.45	48.6	55.75	62.9	70.05	77.2	84.35	91.5	163	27.15	34.3	41.45	48.6	55.75	62.9
-6	27.436	34.872	42.308	49.744	57.18	64.616	72.052	79.488	86.924	94.36	168.72	27.436	34.872	42.308	49.744	57.18	64.616
-7	27.722	35.444	43.166	50.888	58.61	66.332	74.054	81.776	89.498	97.22	174.44	27.722	35.444	43.166	50.888	58.61	66.332
-8	28.008	36.016	44.024	52.032	60.04	68.048	76.056	84.064	92.072	100.08	180.16	28.008	36.016	44.024	52.032	60.04	68.048
-9	28.294	36.588	44.882	53.176	61.47	69.764	78.058	86.352	94.646	102.94	185.88	28.294	36.588	44.882	53.176	61.47	69.764
-10	28.58	37.16	45.74	54.32	62.9	71.48	80.06	88.64	97.22	105.8	191.6	28.58	37.16	45.74	54.32	62.9	71.48
-11	28.866	37.732	46.596	55.464	64.33	73.36	82.062	90.928	99.794	108.66	197.32	28.866	37.732	46.596	55.464	64.33	73.36
-12	29.152	38.304	47.456	56.608	65.76	74.912	84.064	93.216	102.37	111.52	203.04	29.152	38.304	47.456	56.608	65.76	74.912
-13	29.438	38.876	48.314	57.752	67.19	76.628	86.068	95.504	104.94	114.38	208.76	29.438	38.876	48.314	57.752	67.19	76.628
-14	29.724	39.448	49.172	58.896	68.62	78.344	88.068	97.792	107.52	117.24	214.48	29.724	39.448	49.172	58.896	68.62	78.344
-15	30.01	40.02	50.03	60.04	70.05	80.06	90.07	100.08	110.09	120.1	220.2	30.01	40.02	50.03	60.04	70.05	80.06
-16	30.296	40.592	50.888	61.184	71.48	81.776	92.072	102.37	112.66	122.96	225.92	30.296	40.592	50.888	61.184	71.48	81.776
-17	30.582	41.164	51.746	62.328	72.91	83.492	94.074	104.65	115.24	125.82	231.64	30.582	41.164	51.746	62.328	72.91	83.492
-18	30.868	41.736	52.604	63.472	74.34	85.208	96.076	106.94	117.81	128.68	237.36	30.868	41.736	52.604	63.472	74.34	85.208
-19	31.154	42.308	53.462	64.616	75.77	86.924	98.078	109.23	120.39	131.54	243.08	31.154	42.308	53.462	64.616	75.77	86.924
-20	31.44	42.88	54.32	65.76	77.2	88.64	100.08	111.52	122.96	134.4	248.8	31.44	42.88	54.32	65.76	77.2	88.64

Figure 4: Flow temperatures

3.4 Domestic Hot Water (DHW) Simulation

In addition to space heating, Domestic Hot Water (DHW) consumption accounts for a significant portion of the total energy demand. To simulate this consumption accurately, the model employs a detailed set of parameters for each household member. Key variables include the number of

An interactive weekly schedule has been developed to simulate daily usage patterns, allowing users to define showering habits for each individual. Figure 5 illustrates the structure of this schedule: for every day of the week, it can be specified whether a person showers in the morning, around noon, or in the afternoon, linked to specific time slots. This granular input ensures that peaks in hot water demand are correctly distributed throughout the day, which is vital for calculating heat pump efficiency and the potential role of thermal storage or battery systems.

[illegible]

Once these individual parameters and time slots are entered, the model automatically generates a consistent weekly consumption profile. This weekly schedule is then extrapolated into a full annual schedule at fifteen-minute intervals, as shown in the next figure, accounting for the specific days throughout the year. This automated translation from personal habits into an annual matrix allows the model to accurately evaluate the cumulative impact of hot water demand on the total energy bill and the overall efficiency of the storage system.

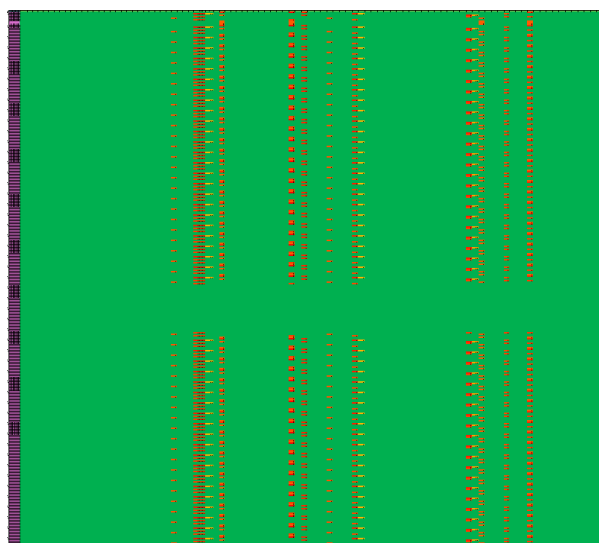


Figure 6: Domestic Hot matrix (Horizontal axis: Time of day (15-min intervals); Vertical axis: Calendar dates)

To complete the simulation of hot water usage, an electric boiler is added to the model. This is done by filling in two simple details: the size of the boiler (the capacity) and how fast it can heat up (the charging power in kWh per quarter-hour). By combining this data with the showering habits mentioned in the previous step, the model calculates exactly how much energy is needed to bring the boiler back up to temperature.

The model also allows you to choose exactly when the boiler should heat up. By default, the boiler is set to charge between 0:00 and 6:00, 9:00 and 11:00, and 15:00 and 18:00. These times can be easily adjusted within the formula. This allows you to test, for example, whether it is cheaper to charge the boiler during the day using your own solar energy or at night.

Additionally, you can read the 'SOC matrix' of the boiler in the next figure. SOC stands for State of Charge, which simply shows how "full" the boiler is at any moment of the day. This allows you to see at a glance if there is enough hot water left after a shower or if the boiler is nearly empty and needs to start recharging.



Figure 7: SOC of boiler (Horizontal axis: Time of day (15-min intervals); Vertical axis: Calendar dates)

The boiler results are displayed in a coloured matrix, similar to the heating consumption. In this view, red represents a full boiler that has reached the set temperature (e.g. 60 degrees). The greener the colour becomes, the emptier the boiler is or the lower the water temperature has dropped. This

makes it very easy to see when the boiler is being drained by a shower and how quickly it turns 'red' (full) again during the scheduled charging times.

Once all individual components — general usage, heating, and the boiler — have been calculated separately, these different matrices are automatically added together based on the chosen parameters. This total consumption is then converted from a matrix view into a simple list format. The main advantage of this is that the data can be exported immediately. This list can then be imported into the PV*SOL software, where we add solar panels, batteries, and other technologies to further simulate the complete energy system.

3.5 PV-Sol

Following the consumption calculations in Excel, the PV*SOL software is used for the technical installation. The dwelling is designed in 3D with the correct orientation. By selecting the city (Maastricht), the software automatically determines the annual solar radiation for that location. The number of solar panels is then added to the roof, a suitable inverter is chosen, and an appropriate battery system is selected.

In the next step, the consumption list from Excel (containing the 15-minute interval data) is uploaded into the software. This provides PV*SOL with precise information on when electricity is required for heating, the boiler, and other appliances. The software then performs the calculations to determine how effectively the solar panels and the battery can meet this demand.

Once the simulation is complete, the results (the 15-minute interval data generated by PV*SOL) are extracted and fed back into the Excel model. This allows for a highly accurate calculation of the final energy costs, as the model now shows exactly how much power is self-generated, how much is drawn from the battery, and what portion must still be purchased from the grid.

3.6 Cost Calculation and Tariffs

Once the data from PV*SOL has been imported into the Excel model, the energy costs are calculated. A comparison is made between two different types of contracts. Firstly, the cost is determined for a fixed contract, using a rate of €0.35 per kWh [8]. Secondly, the costs are calculated based on a dynamic contract. For this simulation, the EPEX market prices from 2024 are used, allowing costs to fluctuate in line with the energy market.

In addition to the energy cost itself, the model accounts for other cost components. The capacity tariff is calculated based on official figures from Fluvius, using a rate of €53.39 per kW [9]. The revenue from electricity that is not consumed immediately or stored in the battery is also included. This injection compensation (feed-in tariff) is determined by the price of the energy component as established by the VREG [8]. By combining all these factors, a precise overview of the total annual energy bill is created.

3.7 Cost Calculation and Tariffs

Once the PV*SOL simulations are completed, the data is exported to a specific Excel file. The data is uploaded into the designated areas within the 'Injection and Consumption' tab. The model is programmed to automatically perform all calculations, requiring no further manual input.

A clear overview of the various cost components is generated in the results tab. This allows for a direct comparison between the costs of the dynamic tariff, the fixed contract, the capacity tariff, and the injection compensation. This provides a straightforward result indicating which option is financially the most beneficial for the chosen scenario.

As shown in figure 8, the user can select the specific installation to be simulated, such as a configuration featuring a heat pump (HP), solar panels (PV), and a battery. Once this selection is made, the results are displayed in the top-left corner of the screen. The costs for the different energy bills are calculated and shown immediately. Furthermore, the consumption peaks are clearly displayed in the table, which is essential for calculating the capacity tariff shown in figure 9.

Factuur	
Vast + Cap - Injectie	869,0532032
Dynamisch + Cap - Injectie	586,2539103
id maar 1 selecteren anders 0	
Verbruik WP na PV (zonder boiler)	☐
Verbruik WP na PV (met boiler)	☐
totaal verbruik (WP zonder boiler) na PV	☐
totaal verbruik (WP met boiler) na PV	☐
Verbruik WP na PV+Batterij (zonder boiler)	☐
Verbruik WP na PV+Batterij (met boiler)	☐
totaal verbruik (WP zonder boiler) na PV+Batte	☐
totaal verbruik (WP met boiler) na PV+Batterij	☒

Figure 7: Invoice calculation

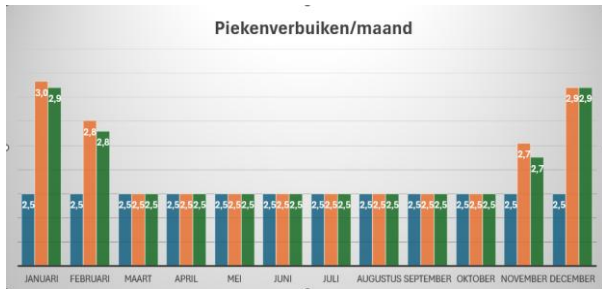


Figure 9: Monthly peaks in kW

3.8 Building Automation and Smart Control Systems

In addition to the simulations performed in Excel and PV*SOL, the actual control strategy for the technical installation within the building is examined. The installation is connected to a geothermal bore field and two pumps, which serve three distinct circuits: the air handling units, the apartments, and two 30 kW heat pumps. Since these heat pumps are non-modulating, they cannot operate at partial capacity and must function on an on/off basis. This complete installation is illustrated in Figure 10.

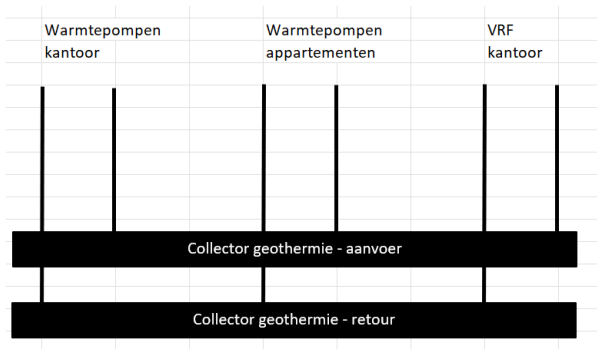


Figure 10: Complete installation

Smart Control Based on Solar Injection To maximise the self-consumption of solar energy, a Smappee energy monitor communicates with a central control system (PLC TwinCAT). When 5 kW of solar energy is being injected back into the grid, the first compressor of the heat pump is started. If the injection reaches 10 kW, the second heat pump is also activated. If the heat pumps are already running and there is still a surplus of at least 5 kW, the buffer tank temperature is further increased by 4 to 6 °C.

Control Based on Electricity Prices The system uses an API to retrieve current 'day-ahead' market electricity prices from ENTSO-E. The heating system (heating curve) automatically adjusts based on these prices:

- **Low Prices (< €80/MWh):** The heating curve is incrementally increased from 25 °C to 27 °C, 29 °C, or 31 °C to store cheap energy within the building.
- **Negative Prices:** A relay is triggered to increase the buffer tank temperature by an additional 5 °C.
- **High Prices (80 – 150 €/MWh):** The heating curve is lowered to 23 °C to reduce consumption.
- **Extremely High Prices (> €150/MWh):** A relay is activated to shut down the heat pumps entirely to avoid high costs.

The heat pumps utilise 'Smart Grid' contacts. When both contacts are closed (status 1-1), the 5 °C temperature increase is implemented. To maintain comfort, the target room temperature is lowered during weekends but never fully switched off. Additionally, four indoor sensors are placed on the east and west sides of the building. For heating purposes, the system prioritises the sensors on the cold side of the building to ensure a comfortable indoor climate throughout.

The central heating installation consists of the two heat pumps connected to a 1,500-litre buffer tank. From this buffer tank, the water is directed to a three-way valve. This valve mixes the warm water from the buffer with the return water from the system to regulate the flow temperature.

From the central collector, the water is distributed across seven building wings (Wings A to F). Each wing is equipped with its own active mixing circuit and individual pump, allowing the temperature of each zone to be controlled independently. To protect the installation, a safety limit ensures the manifold temperature never drops below 15 °C to prevent condensation issues. This complete installation is illustrated in Figure 11.

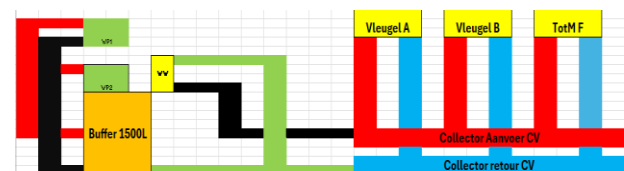


Figure 11: Installation of the building

4 Conclusions

This study investigated the financial and energetic impact of transitioning from fixed to dynamic energy tariffs within the Belgian market context. The primary objective was to determine the extent to which smart technologies and control strategies

could offset investment costs and reduce the total cost of ownership for a residential building. By developing an automated calculation tool, the interaction between dynamic pricing, capacity tariffs, and storage systems was quantified.

The empirical analysis demonstrated that transitioning to a dynamic energy tariff represented the most effective method for immediate cost reduction, even without significant capital investment. However, the data showed that active management of the consumption profile was essential to fully exploit this potential. Without proactive control, monthly peaks remained unchanged, which negatively impacted the capacity tariff. By scheduling high-consumption appliances during midday hours, energy demand was met by the local PV system, effectively limiting grid withdrawal.

Regarding the technological configuration, the research found that a well-dimensioned PV and battery system typically reached a payback period of 8 to 10 years. Systems equipped with a battery often reached profitability within a similar timeframe, provided that over-dimensioning was avoided. The simulations, based on 2024 EPEX prices, confirmed that weather-compensated control with the lowest possible heating curve was essential for optimal efficiency.

Specific attention was paid to heat pump control strategies. The results indicated that night-time temperature setbacks were only cost-effective if maintained for a sufficient duration. For instance, a setback of only four or five hours was not financially beneficial, whereas accepting a lower morning temperature (e.g., 18 °C) and restoring comfort only upon returning home provided a clear financial advantage. These findings highlighted that smart steering is a critical component in maximizing the value of a dynamic contract.

In conclusion, the study proved that households utilizing a dynamic contract in combination with smart storage and automated heat pump control achieved a significantly lower total cost of ownership. It should be noted that the calculations represented a "worst-case" scenario, as internal and external heat gains were not included. In practice, heat emitted by occupants and solar radiation would likely result in an even lower energy bill than the figures presented in this study.

Future research could further refine these findings by integrating real-time internal heat gain data and occupancy sensors to automate the heating

setback more precisely. Additionally, exploring the impact of vehicle-to-grid (V2G) technologies as an extension of the current battery models could provide further insights into long-term grid stability and cost optimization for companies like Intellisol NV.

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