Energy Transition in The Dutch Dwelling Stock
Exploring the Extent of Inertia Against Change

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Abstract

The residential sector accounts for 30% of the total energy consumed by all sectors on average worldwide. This significant share makes an energy transition in the residential sector one of the most important frontiers of sustainability transitions. Netherlands aims to achieve a remarkable reduction in the energy consumption in residential buildings with policies mainly aiming at new constructions, and little attention is being paid to the existing dwelling stock. However, the existing dwelling stock creates an inertia against a transition. Although this is a widely accepted issue, the extent of such an inertia has not been analyzed explicitly. In that respect, we aim to conduct a preliminary study in order to demonstrate the importance of the existing dwelling stock, and the inertia it can cause during an energy transition process. Besides, we also aim to explore effectives of certain policy options that can alleviate this inertia. For that purpose, a simulation model is developed and initialized based on the Dutch housing system. The set of experiments discussed in the paper provides a better understanding about this inertia, as well as what needs to be done for achieving significant progress in a residential energy transition.

1. Introduction

One of the most important developments during the last couple of decades is the increasing global energy awareness. The issues that drive the development of such an awareness are various, including global climate change, security of fossil fuel supply[1], and potential risk of future fossil fuel scarcity. This awareness manifests itself in national, as well as international policy circles in the form of discussions and policies aiming for transitions to energy sustainability. Such a transition is a challenge with multiple frontiers, and built-environment constitute one of the most important frontiers.

According to the figures presented by Swan and Ugursal, the residential sector accounts for 30% of the total energy consumed by all sectors on average worldwide (Swan and Ugursal 2009). The situation for the northern part of the European Union, which includes the Netherlands, is very similar to the reported world averages, since 41% of the total final energy consumption comes from buildings, with 30% being used in residential buildings (Santin,

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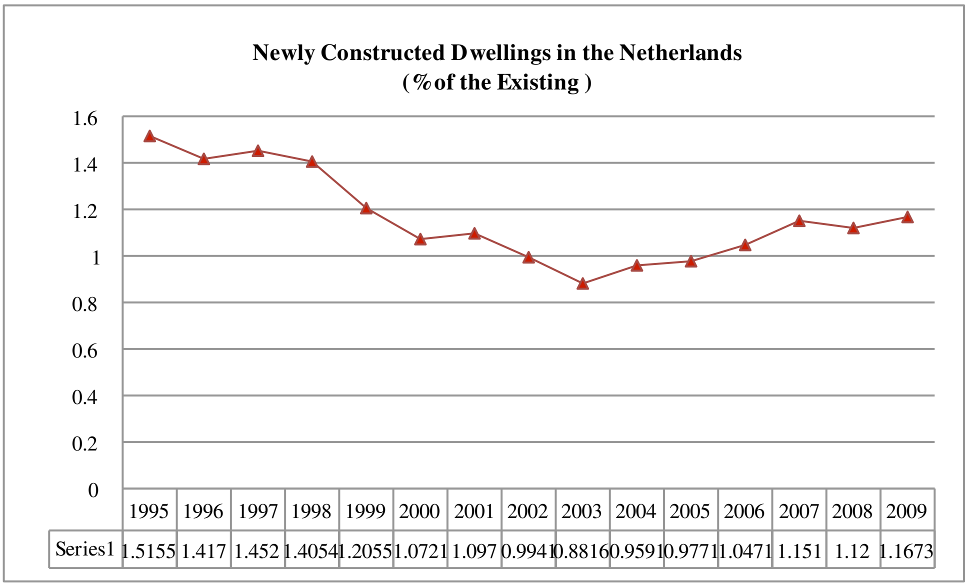
[1] In the light of the events in the North Africa taking place during the first half of 2011, and their potential impact on the Arabic countries, the security of supply issue became an even more important concern.

Itard et al. 2009). This significant share makes an energy transition in the residential sector one of the most important frontiers of sustainability transitions.

European Union has already recognized the importance of residential sector with respect to energy sustainability, and has been aiming to trigger a transition through various initiatives. The Energy Performance of Buildings Directive (EPBD), which is accepted in 2003, is one of such initiatives that aim at decreasing energy consumption in buildings in relation to heating, cooling, ventilation, domestic hot water, and lighting (Sunikka 2005). Being a member state, the Netherlands has been using a set of national policies in order to comply with the EPBD directive, and to achieve a remarkable reduction in the energy consumption in residential buildings. However, almost all of these policies are focusing on new constructions (Sunikka and Boon 2002; Sunikka 2006; Itard and Meijer 2008), and little attention is being paid to the existing dwelling stock. For example, there are Dutch regulations (inline with EPBD) about the minimum level of energy efficiency of the buildings (i.e. Energy Performance Coefficient (EPC)), and these energy efficiency standards are only obligatory for newly constructed buildings (Beerepoot 2007). However, new constructions constitute a very limited addition to the dwelling stock. As can be seen in Figure 1, the scale of new construction ranges between 0.9 to 1.5% of the existing dwelling stock. As a result, the aggregate change in the residential sector that can be achieved through policies that focus mainly on these new dwellings is limited. In other words, the pace of change in the energy consumption is slow, and the existing dwelling stock creates an inertia against a transition under the current policy regime. This issue has already been raised by some scholars who urge for policies that focus more on improvement of the existing dwellings (Priemus 2005).



	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Series1	1.5155	1.417	1.452	1.4054	1.2055	1.0721	1.097	0.9941	0.8816	0.9591	0.9771	1.0471	1.151	1.12	1.1673

Figure 1. Scale of new dwelling construction in the Netherlands (CBS 2011)

It is intuitive and commonly accepted that the quality of the existing dwelling stock is important, and an energy transition would be very slow due to the inertia caused by this stock if policies only focus on new dwellings. However, the extent of such an inertia has not been analyzed explicitly for the Dutch residential sector. Although recognizing the importance of the existing stock is important, we believe that the extent of this importance should be made much more clear in order to conduct a healthier policy discussion. In that respect, we aim to conduct a preliminary study in order to demonstrate the importance of the existing dwelling stock, and the inertia it can cause during an energy transition process. Besides, we also aim to explore effectives of certain policy options that can alleviate this inertia

One of the reasons for the fact that the above mentioned inertia has not been studied in detail can be about the analytical difficulty of the task considering the interrelated processes of dwelling ageing, new construction, demolition and renovation. Especially, the renovation process is directly related to the social dynamics in the system, which is rarely studied at a system level (Santin, Itard et al. 2009). Considering these, we utilize a dynamic simulation model in which physical processes such as ageing, and social processes such as renovation are incorporated. The simulation model, which will be introduced in the following section, is developed in order to represent the Dutch residential sector, and is used as an experimental ground in our analyses on the extent of inertia and the effectiveness of some policies in alleviating it.

As mentioned above, in the following section of the article we discuss the scope, structure and validity of our simulation model. The third section is about the experiments we have conducted with the model. The final section of the paper is devoted to discussion about the observations, general conclusions and future work.

2. Model Description

The objective of the model is to simulate the aggregate energy consumption in residential buildings in the Netherlands. The energy consumption we are focusing in this work is directly related to the physical state of the dwelling, such as *space heating*, *cooling*, *ventilation*, *domestic hot water* and *lighting*. Among these, space heating and domestic hot water constitute a major portion of approximately 70-80% (Klunder 2005; Beerepoot 2007). Therefore, the model mainly focuses on these two energy-consuming activities; i.e. space and domestic water heating.

Considering the above mentioned scope of the model, final energy consumption in a dwelling is the joint outcome of the following factors;

a. (*Energy-related*) Dwelling quality (incorporating efficiency of the heating systems and insulation level)
b. Household's demand for energy services (incorporating space and water heating demand)
c. Climate conditions (corresponding to the number of heating-days)

In very simple terms, socio-economic factors as well as climatic conditions influence the demand of a household. This demand coupled with the quality of the dwelling determines the final energy consumption at that dwelling. In that respect, the model covers the following aspects in order to simulate the aggregate energy consumption from residential buildings;

a. Housing stock: Quantity aspect of the housing stock (the number of dwellings), and the quality aspect of the housing stock (i.e. energy efficiency of the dwelling)
b. Household behavior: Behavior of the tenants related to energy consumption, as well as to dwelling quality such as renovation.

The model description will be structured according to these aspects, which are discussed in the following subsections.

a. Housing Stock

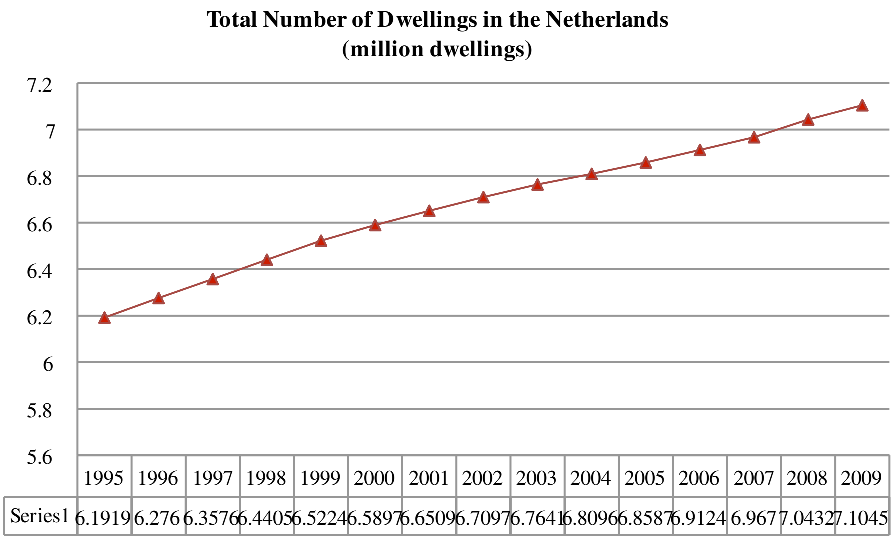
Most important challenge in representing the housing stock is the vast diversity of the dwellings. On the one hand, assuming that the Dutch housing stock is composed of identical houses (i.e.

homogenous stock assumption) may yield overlooking important dynamics. On the other hand, trying to capture the diversity in its full scale may result in a model that is of little use due to its detail level. In this trade-off, the main issue is to select the attributes that matter with respect to energy efficiency of the dwellings, and represent the diversity along these dimensions at a sufficient level. Looking at the issue from this perspective, one of the key aspects that is strongly related to the energy efficiency of a dwelling is its architecture. Although the Dutch dwellings show significant variety in architectural details, they can be grouped under three categories; terraced dwellings, (semi)detached dwellings, and gallery flats (Figure 2). These three dwelling types are commonly used as representative types, and the properties of a typical example of such dwellings are discussed in detail by Klunder (2005). The total number of dwellings in the Netherlands, as well as their distribution among these three dwelling types are given in Figure 3 and Figure 4, respectively.

Terraced Dwelling	(Semi-)detached Dwelling	Gallery Flat

Figure 2. Representative dwelling types in the Dutch dwelling stock

Apart from these three types having different physical properties (e.g. surface area, heat-loss surface, etc.), there is a strong coupling between different income groups and these dwelling types. Gallery flats are predominantly social housing units, which accommodate low income groups. On the other end of the spectrum, detached dwellings are most commonly occupied by high income households. In short, there is also a significant correlation between the dwelling types and the income level of their occupants.



	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Series1	6.1919	6.276	6.3576	6.4405	6.5224	6.5897	6.6509	6.7097	6.7641	6.8096	6.8587	6.9124	6.967	7.0432	7.1045

Figure 3. Total number of dwellings in the Netherlands (CBS 2011)

Considering the aforementioned issues, we utilized these three dwelling archetypes to model the architectural diversity in the Dutch dwelling stock. In other words, three different dwelling types are explicitly included in the model. Although some fundamental attributes of these archetypes are different, the processes through which these sub-groups change (e.g. renovation, ageing, demolition) are very similar. Therefore, the model sections related to the dynamics of different dwelling groups are identical in structure, but differ only in some parameters. In that respect, we will discuss the processes based on a single dwelling type, and mention the differences for the others when necessary.

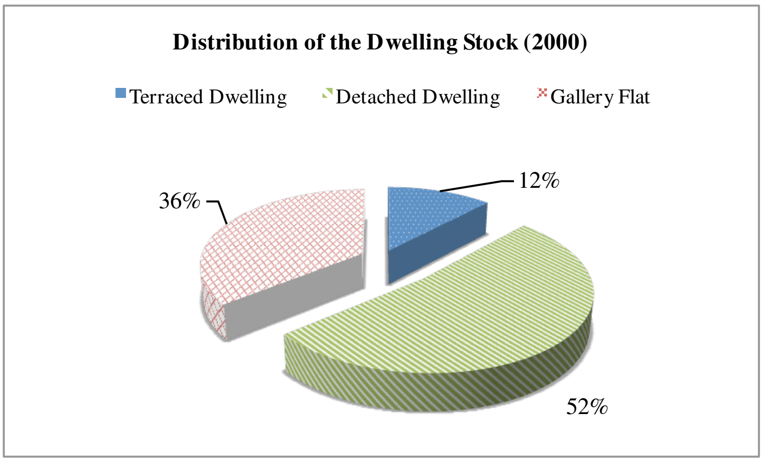
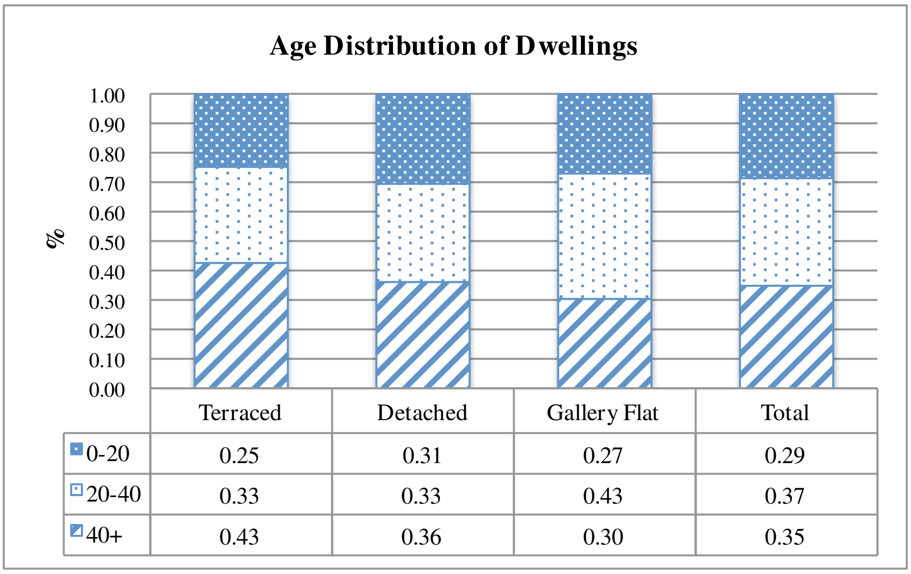


Figure 4. Distribution of dwellings according to dwelling-types (ten Donkelaar, Boerakker et al. 2006)

Although the architecture of the dwelling is important, a much more important aspect with regard to the energy efficiency is the age of the dwellings. The technology, construction material, and also the construction techniques are strongly determined by the period in which a dwelling was built. This is one of the reasons why capturing the age distribution of the dwelling stock is important. The second reason is more about the turnover rate of the housing stock. The age distribution of the dwelling stock is not uniform, which is mainly due to the changes in the demand for housing over the years, and the massive demolition during the Second World War. The age distribution of the Dutch stock as of year 2000 is given in Figure 5 (ten Donkelaar, Boerakker et al. 2006; Thomsen and Meijer 2007).



	Terraced	Detached	Gallery Flat	Total
0-20	0.25	0.31	0.27	0.29
20-40	0.33	0.33	0.43	0.37
40+	0.43	0.36	0.30	0.35

Figure 5. Age distribution of Dutch dwellings in 2000

Due to the non-uniform nature of the age distribution, the rate of dwellings reaching the end of their service times will most likely be fluctuating. Capturing such fluctuations is of primary importance while analyzing the possible pace of change in the existing dwelling stock. Due to these reasons, the age distribution of the dwellings is captured by using three stages (i.e. age categories) during the life cycle of dwellings in the model; early, medium and late stages. The change in the distribution is modeled by using an ageing-chain structure, which is given in Figure 6[2]. Construction time is initialized to be 2 years. Once a dwelling is completed, it is considered as an early stage dwelling, and after an ageing delay of 20 years, it becomes a medium stage dwelling. Eventually, dwellings older than 40 years are considered as late stage dwellings.

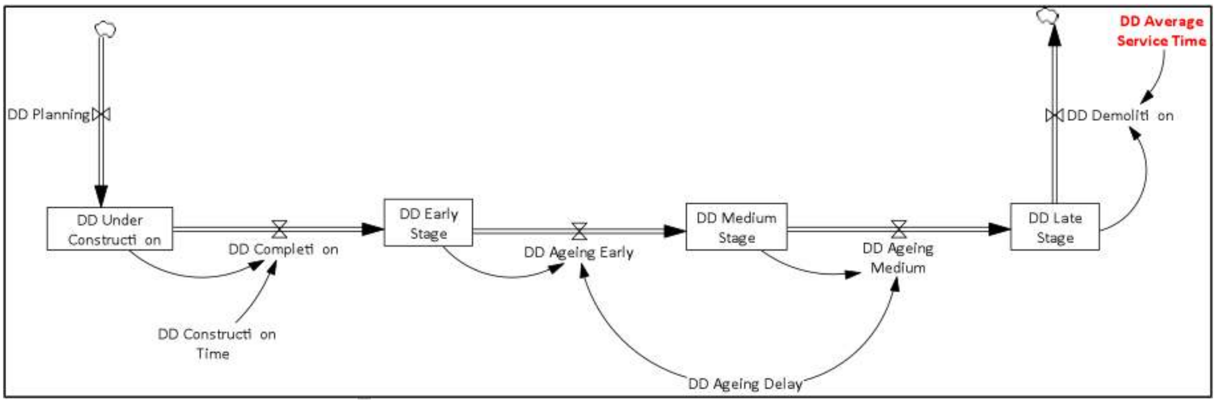


Figure 6. Ageing-chain structure used for life cycle of dwellings

Besides intuitive *completion* and *ageing* flows, the other two flows of the ageing-chain structure are of primary importance; i.e. *planning* and *demolition*. The current version of the model does not cover the construction industry endogenously. Instead, we assume that the planning will follow the housing demand in the Netherlands. Using the most likely national population projections of CBS (CBS 2011) as an exogenous parameter in the model, demand for dwellings is calculated over time. The difference between the existing dwelling stock and this demand figure constitutes the *expansion part* of the planning flow. The other part of the planning flow is the *replacement part*, and is equal to the number of dwellings being demolished. Eventual number of dwelling being planned is equal to the sum of the expansion and the replacement parts.

A dwelling is expected to be demolished upon completing its useful service time. Theoretical useful service time of a dwelling ranges between 75 to 100 years according to several sources (Klunder 2005). However, as several researchers have already pointed out, the actual service times depart from these theoretical figures significantly in the Netherlands (Sunikka 2006; Boonekamp 2007; Itard, Meijer et al. 2008). Looking at the historical figures, it is seen that the fraction of dwellings being demolished annually ranges between 0.15 and 0.35% (Figure 7). With a very rough estimation, these figures suggest an average service times even higher than 200 years. Based on these historical figures, the average service times for detached dwellings, terraced dwellings, and gallery flats are initialized to be 200, 125, and 80 years, respectively.

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[2] DD stands for Detached Dwelling. The same structure is also used for terraced dwellings and gallery flats in the model.

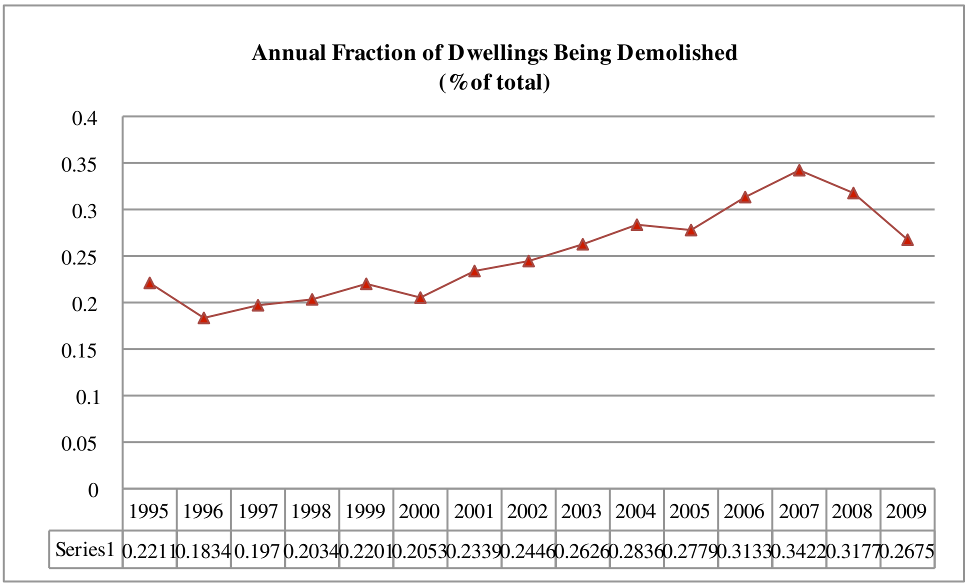

Figure 7. Percentage of Demolished Dwellings

In other to represent overall quality level of the dwellings (with respect to energy consumption), we use a general metric that summarizes the energy efficiency of a dwelling considering its architecture, installed equipment and its insulation level; i.e. energy performance coefficient (EPC). EPC is an indicator that has already been used in the Netherlands in building regulations and policy discussions. Briefly, given the identical household behavior, a dwelling with a high EPC will result in a higher final energy consumption than a dwelling with a lower EPC. There were no EPC standards before 1996. Therefore, there is some uncertainty about the EPC level of the dwellings built before 1996. The EPC levels of the residential buildings that were built after 1996 are given in the table on the right.

Period	EPC level
1996-1998	1.4
1998-2000	1.2
2000-2006	1.0
2006-2010	0.8

We used a second ageing-chain structure to simulate the changes in the EPC levels of the dwelling sub-groups. As can be seen in Figure 8, co-flows are implemented along this second ageing chain in order to trace changes in EPC levels due to the dwelling ageing process (Sterman 2000). The average EPC level of dwellings at different stages of their life cycle are altered mainly through these co-flows. Besides, as can be seen in the figure, the EPC levels may also be altered through renovation (see vertical flows which represent EPC change due to renovation). Renovation process, and the formulation regarding the total number of dwellings being renovated will be discussed while we introduce household behavior. Finally, the EPC level of the dwellings being planned is determined according to a policy variable (i.e. *New Const EPC*). This variable is altered during simulation experiments to test different governmental policies.

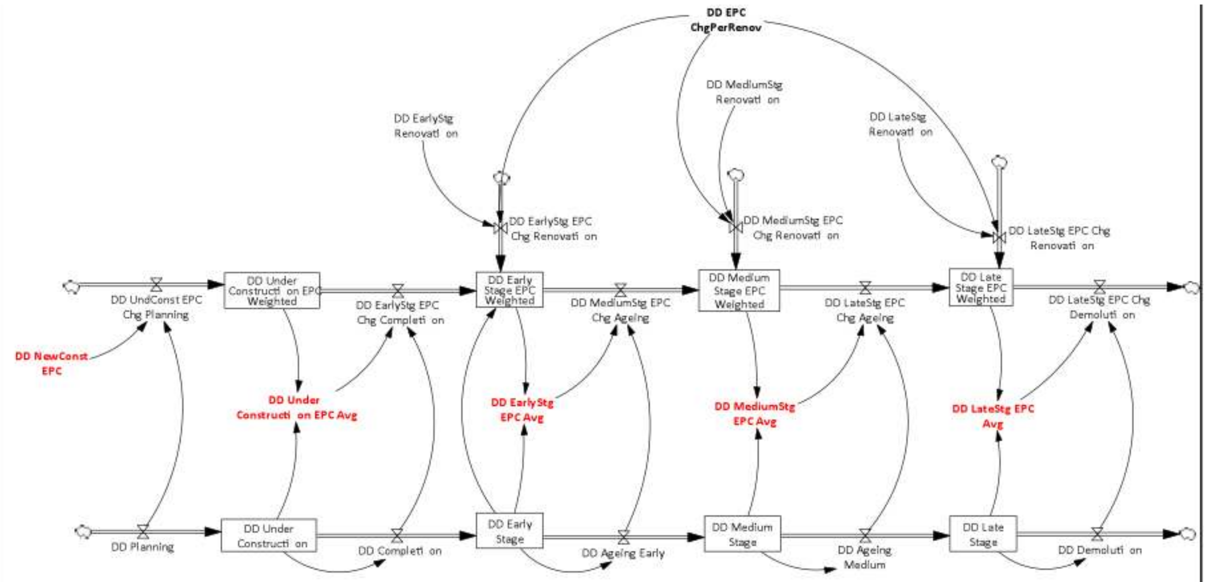

Figure 8

a. Household Behavior

As already mentioned, the final energy consumption of a household depends on two factors; intensity of the households energy consuming activities, and the energy efficiency of the dwelling. The model incorporates two fundamental household behaviors directly related to these two factors. A simple causal loop diagram that depicts these two behaviors is given in Figure 9.

In the short run, households can alter the level of their energy consuming activities (i.e. energy demand). For example, they can set the thermostat to a higher or a lower degree. The energy demand of a household changes from its normal level due to two factors in the model; changing climate conditions (i.e. a change in heating-degree days), and changing energy expenses. Very simply, it is assumed that the energy demand of a household will increase proportionally to an increase in the heating-degree days. On the other hand, a household can alter its demand as a reaction to a change in energy expenses. If the share of energy expenses in the total income of the household increases, *energy conservation* mechanism will be activated and the demand of the household will decrease. In the opposite case, it is assumed that the household will increase the intensity of energy consuming activities if the costs of those activities decrease. This tendency of increasing consumption as a result of increasing income (or decreasing cost of consumption) directly corresponds to the *rebound effect* widely discussed in the energy consumption literature (Haas, Auer et al. 1998; Greening, Greene et al. 2000).

Besides this, households can also change the energy efficiency of the dwelling they are using through renovations, which is considered as a longer-term action in the model. The tendency of the households to renovate depends on two factors. The perceived level of energy expenses-to-household income serves as the trigger of action. In other words, as expenses rise, so does the willingness of the household to renovate. A household is assumed to review the economic advantages of a renovation action when it is willing to take such an action. Therefore, for a renovation to take place, the household should be willing to renovate, and renovation action should be economically profitable, which is the second factor that influences the number of renovations taking place. The profitability of a renovation depends on the amount of fuel consumption avoided as a result of renovation, and the price of that fuel at the decision point.

A feedback loop that counteracts the renovations is about diminishing rate of return; as the energy efficiency level of a dwelling increases, cost of further increasing the efficiency also increases (energy saving per renovation spending diminishes). This feedback mechanism is also shown in Figure 9.

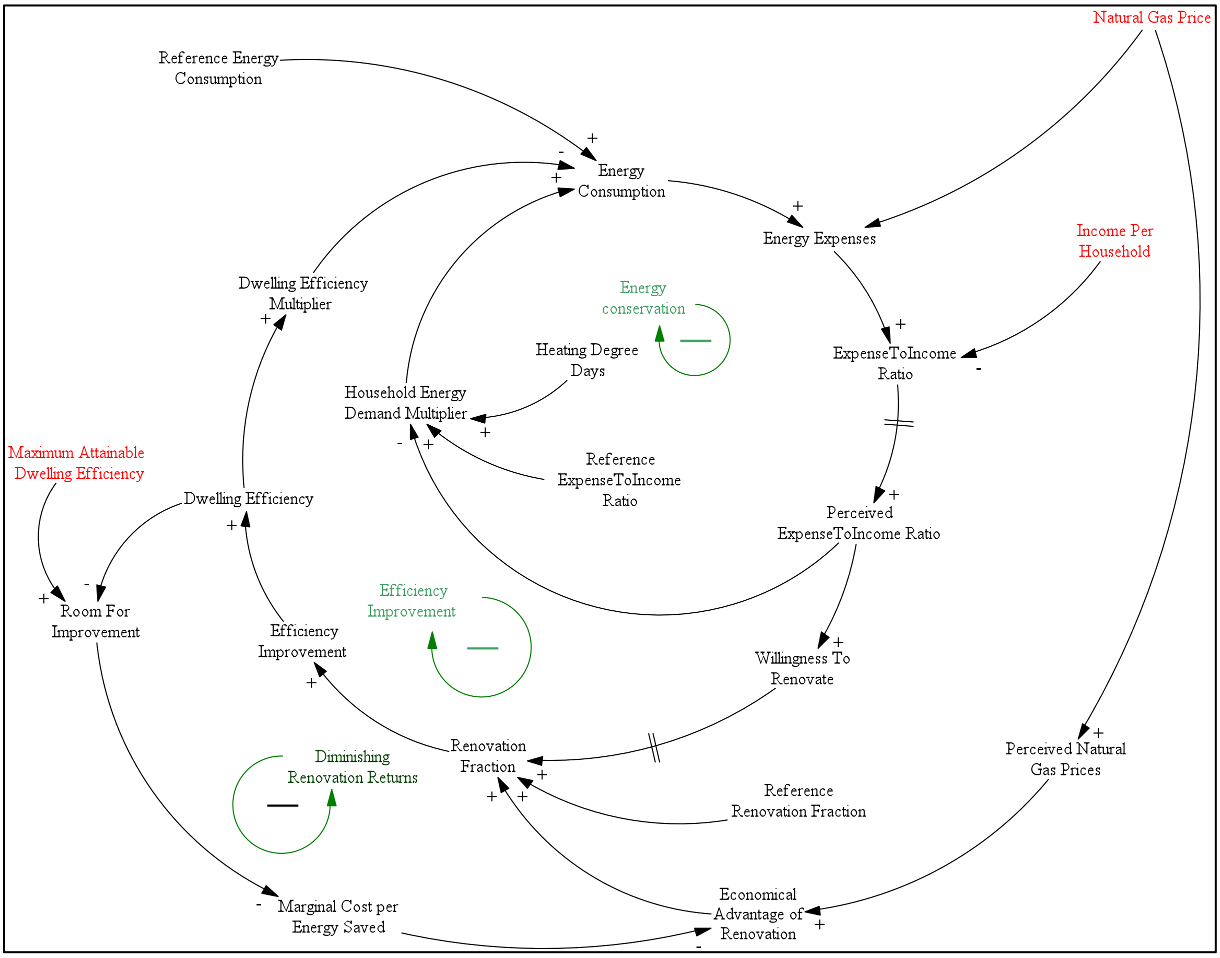

Figure 9

As it should be clear from the description given above, renovation rates depend on income level of the households, as well as the state of the dwelling. In that respect, low-income families living in an old dwelling is expected to have a different renovation behavior than a high income family living in a medium stage dwelling. We aim to explicitly represent that heterogeneity at a level that is consistent with the model scope and assumptions. Therefore, the structure given in Figure 9 is used to model the renovation behavior of a subset of households. There are 9 household subsets in the model. Based on the correlation between the income levels and the type of dwelling, the first dimension that differentiates the subsets is the type of dwelling (terraced, detached, gallery flat). The second dimension is the condition of the house, which is related, with the age of the dwelling (early, medium or late stage). These two dimensions are used to define the nine household subsets (e.g. households in late stage gallery flats, households in early stage detached dwellings, etc.), and a copy of the aforementioned structure (with different parameter values) is used to capture the behavior of these household subsets.

3. Simulation Experiments

As mentioned in the first section of the article, the main objective of this study is to develop a better understanding about the inertia posed by the existing dwelling stock, and to lay down some explicit figures to demonstrate this inertia. Additionally, we aim to study the interaction of some very basic processes related to the residential sector (e.g. ageing, renovation, etc.) and the resulting impact on the aforementioned inertia. These objectives naturally condition the way we use our model and the type of experiments to be discussed below. Simply, we used the model as a dynamic test ground and in some cases explored even unrealistic situations in order to picture the interactions of various processes better. While doing so, we also kept a loose correspondence with the Dutch residential sector with regard to the size of the dwelling stock and socio-economic characteristics. Considering the model-use typology proposed by Yücel (2010), the way we use the model can be seen somewhere in between *model-use for case-specific insight development*, and *model-use for generic insight development*.

Before proceeding into the experimentation phase, the model is tested for the validity of its structure for the task at hand. Considering established verification and validation procedures proposed in the field (Barlas 1996; Sterman 2000), we tested the model structure and equations, and concluded that the model is appropriate and reliable for the purposes of this study.

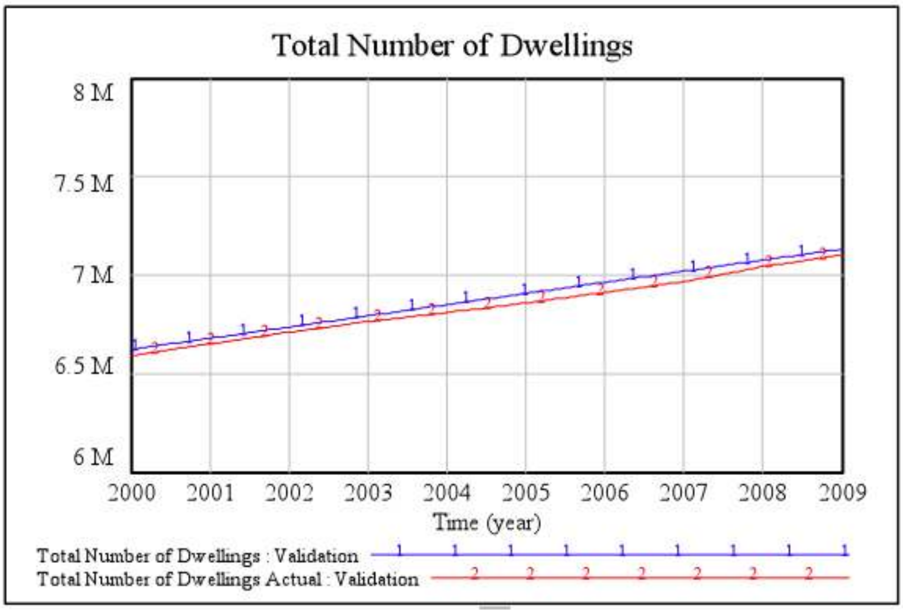

Figure 10

Besides, we also compared the basic behavior of the model with available data. For that purpose, we initialized the model based on actual data corresponding to year 2000, and used the 2000-2009 period (a period about which reliable data is accessible) for behavioral comparison purposes. Model generated behavior for key variables compared with the actual dynamics can be found in Figure 10 through Figure 12. As can be seen from the plots, the model is able to capture the general trends. Considering the fact that the model does not cover the housing and construction market dynamics, the deviations seen in the new dwelling construction are expected. However, the ability of the model in capturing the overall trend in this variable is what matters mainly for this study. As a result, we concluded that the model has a good degree of correspondence with the Dutch case, and has a valid structure for our purposes.

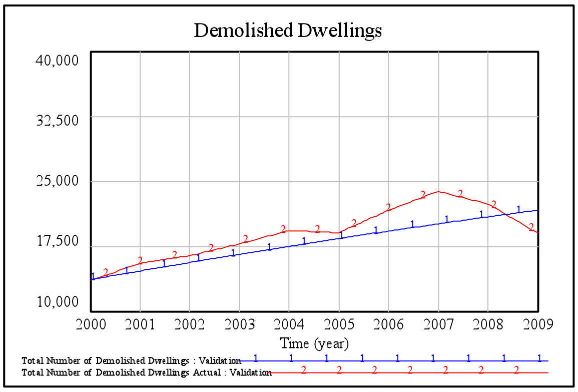

Figure 11

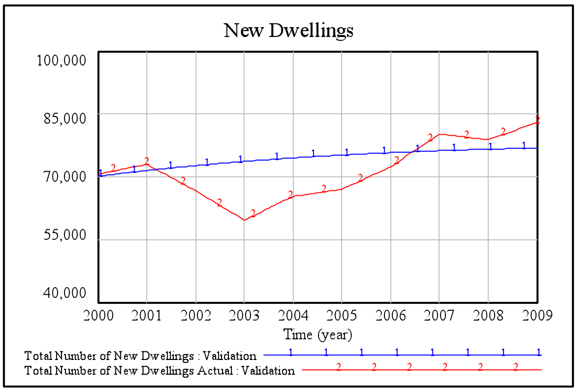

Figure 12

a. Reference case

As mentioned earlier, the primary objective of this work is to develop a better understanding about the extent of inertia caused by the existing dwelling stock. In that context, our reference experiment is a totally hypothetical case that helps to draw a baseline for an energy transition in the residential sector. In this experiment, it is assumed that households do not invest in energy-related renovations, and they do not conserve energy. In other words, the dwellings continue to exist as they were built, and households continue to consume their normal/reference level of energy in their dwellings. This way we aim to isolate the extent of energy consumption change due to the changes in the dwelling stock; i.e. new constructions and demolitions. In a way, this reference experiment shows the potential impact of policies purely focusing on the newly constructed dwellings.

In this experiment, we assumed that the EPC regulations will get tighter in the future. Although there is no certainty regarding changes in EPC regulations, we assumed a reasonable (not very radical and/or rapid) change pattern. The EPC regulations imposed on the new constructions in this reference experiment are given in the table on the right.

Period	EPC level
2010-2014	0.8
2015-2020	0.7
2020-2030	0.6
2030-2040	0.4

Figure 13 demonstrates the change in the energy efficiency of the three dwelling age-groups, as well as the average of the whole stock (the thick line). As a result of more efficient dwellings being constructed, and less inefficient old ones being demolished, the EPC levels are on the decline.

Although these trends are good news, the more important thing is the impact of these trends on the total energy consumption. In order to demonstrate the change in total energy consumption better, we used the total energy consumption in year 2000 as the reference, and plotted the total energy consumption as a fraction of 2000-level. Figure 14 demonstrates the change in total energy consumption during the 40 year time horizon.

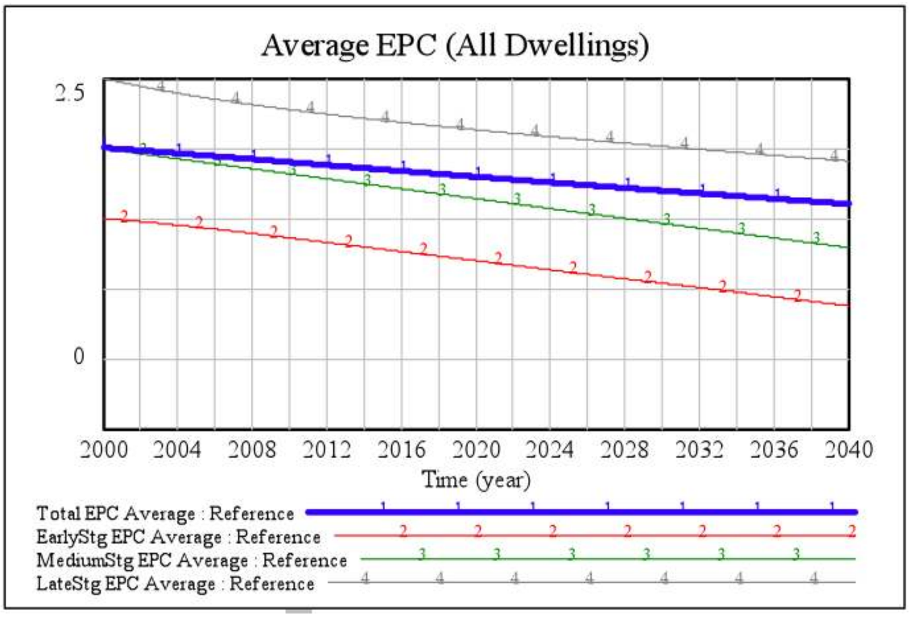

Figure 13. Change in EPC levels – Reference run

Despite all the improvements in the quality of the dwelling stock, total consumption even increases slightly above the 2000-level, and then decreases to level 1 towards the end of time horizon. At the first glance, these trends suggest a sort of inconsistency. However, when we consider the change in the total number of dwellings, the picture is clear (Figure 15). Although there is an improvement in the individual dwellings, the level of this improvement is not sufficient to compensate the increase in the total number of dwellings. Therefore, the result of the conjoint trends in the housing stock and the EPC-levels is as it appears in Figure 14.

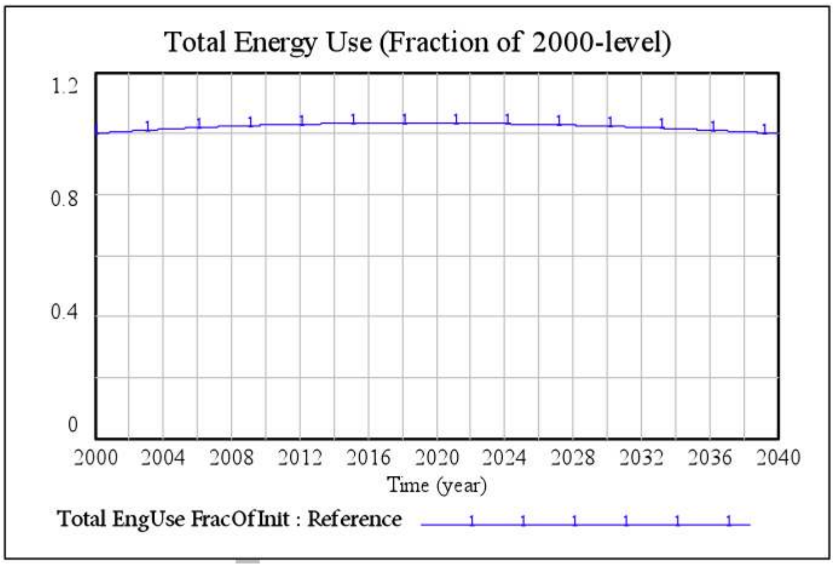

Figure 14. Total energy consumption – Reference run

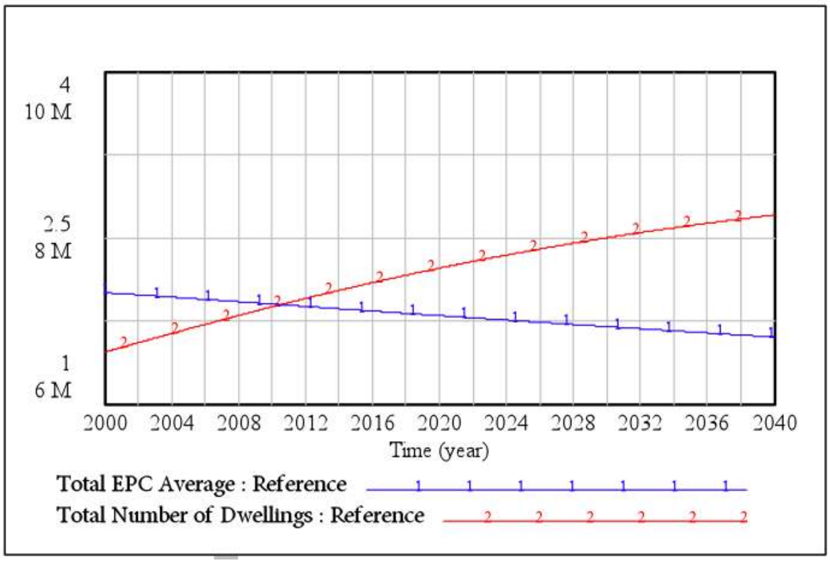

Figure 15. Average EPC-level vs. total number of dwellings

The results suggest that through regular measures purely aiming at new dwellings, it is possible to stop the growth trend in the energy consumption. However, almost no progress can be achieved in terms of reducing the total energy consumption in the residential sector. In the following two experiments, we will further analyze this point with some alternative policy measures.

b. Lower EPC regulations

Period	EPC level
2010-2014	0.7
2015-2020	0.6
2020-2030	0.4
2030-2040	0.2

In order to extend the previous experiment, we simulated the case where future EPC regulations are much lower than the reference case. The EPC-levels imposed in this run are given on the right. Although the new EPC levels are significantly lower than the ones in the previous run, there is almost no change in the total energy consumption trends. The reason for such lack of change is clear when we analyze the change in average EPC-levels. Figure 16 compares the average EPC-levels in this run with the reference run. As can be seen, despite lower regulations, the change in the average EPC-level of the dwelling stock is minimal. Since new constructions are around 1% of the existing stock, the marginal impact of even a significant change in the EPC regulations is minimal.

Another issue is related to the share of new dwellings with the low EPC levels in the total stock. Figure 17 depicts the changes in the shares of different age groups. As can be seen, the share of new dwellings is getting lower, as the stock is dominated by old dwellings. Parallel to the expected trends in the population, the growth in the total number of dwellings stagnates in the second half of the run. This translates into a decreased number of construction, which generally corresponds only to replacement of demolished dwellings. In other words, the share of new construction is getting lower towards the end of the run. Therefore, the impact of even very low EPC regulations beyond year 2020 have very limited impact, since the rate of construction of houses with such standards are even lower than 1%. This observation makes us explore the following case, which is an intuitive policy proposal to a problem such as the one discussed here.

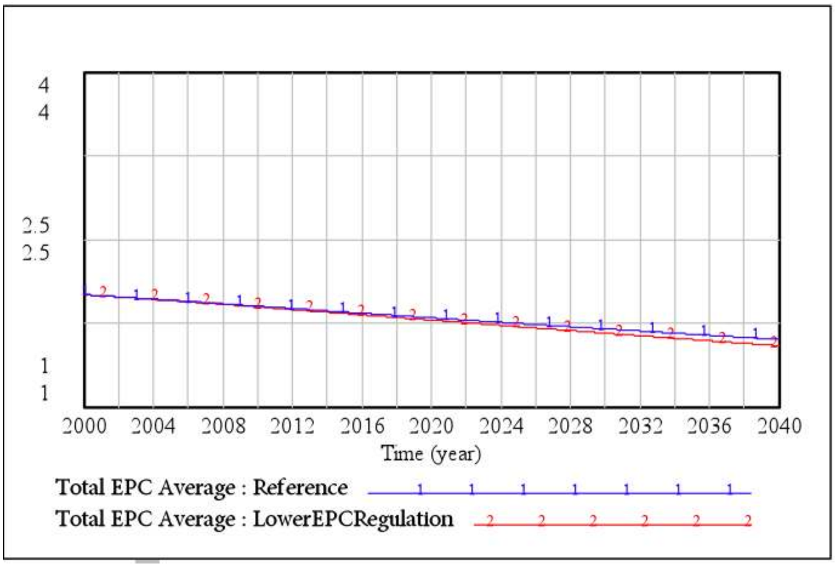

Figure 16. Average EPC-levels (reference run vs. lower EPC regulations run)

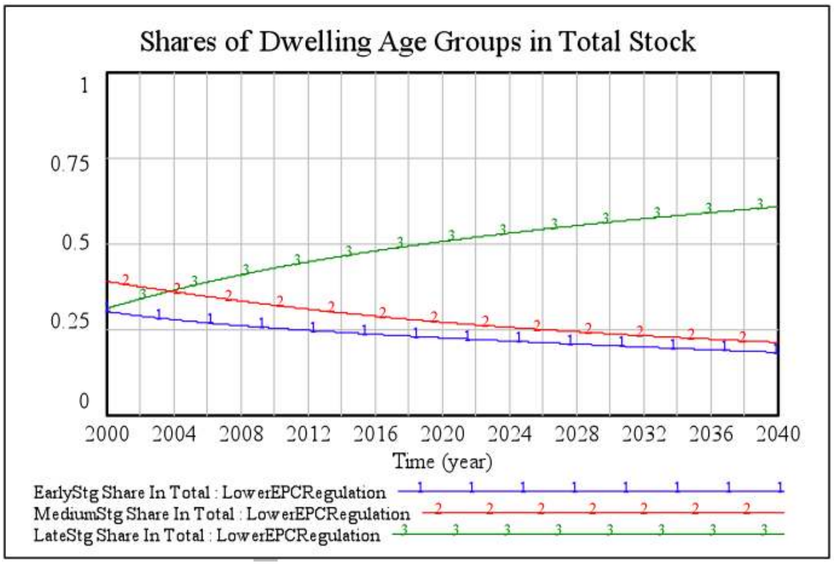

Figure 17. Shares of different dwelling age-groups

c. Increased stock turnover

The previous two experiments demonstrate that the rate of turnover is slow in general, and it gets even slower as the increase in the Dutch demand for houses stagnates. A quick fix to such a problem would be, independent of its applicability, to increase the rate of turnover via increasing the rate of demolishing. This is a debated topic in the form of major urban restructuring/renovation projects. In order to see the potential effectiveness of such a policy, we doubled the demolishing rates of all dwelling types after 2010 (see Figure 18).

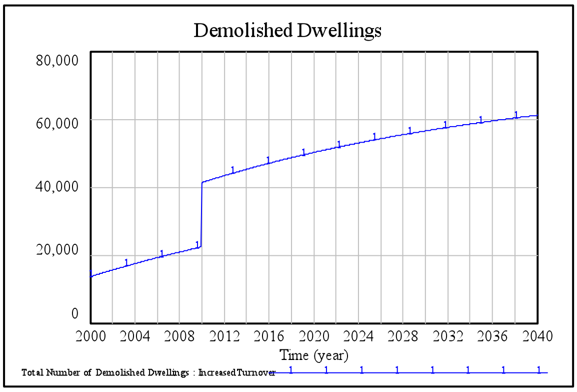

Figure 18

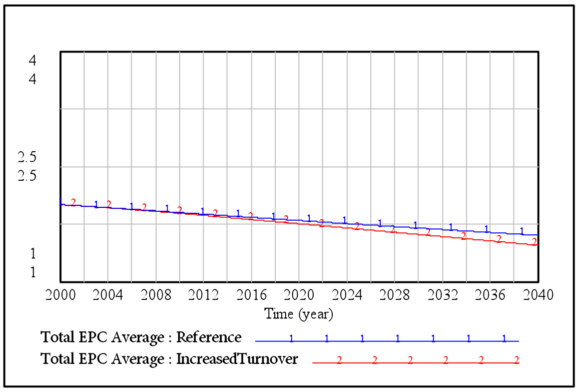

Figure 19

The increased rate of demolishing, and lower EPC standards seem to yield better results both in terms of attaining lower average EPC-levels (Figure 19), and decreasing the total energy consumption in the residential sector (Figure 20).

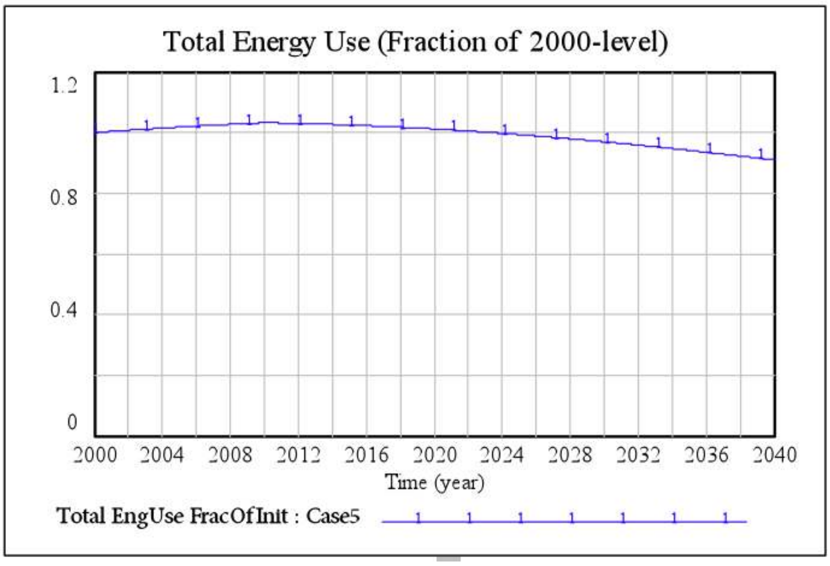

Figure 20

As a result, these three hypothetical cases help to clarify the importance of renovation processes with respect to an energy transition. Even under extreme conditions in terms of dwelling turnover and EPC regulations, the extent of change in the overall energy consumption is clearly limited. The above mentioned results stand as concrete demonstration of this fact in terms of quantitative figures. This turns our attention to the renovation processes, which we explore in the following experiments.

d. Renovation

In this experiment, we take into consideration possible energy-related renovations on the dwellings. It is quite difficult, if possible at all, to find reliable information about the number of renovations and more importantly the final improvement in the dwelling achieved through renovation. Therefore, we initialized the model so that the annual rate of renovations in the order of 100.000 renovations per year, and with each renovation we assume that the EPC of the dwelling is reduced by 0.2. This is slightly optimistic, in terms of renovation rate, than the figures reported by Sunikka regarding the renovation activity in the Netherlands (Sunikka 2005).

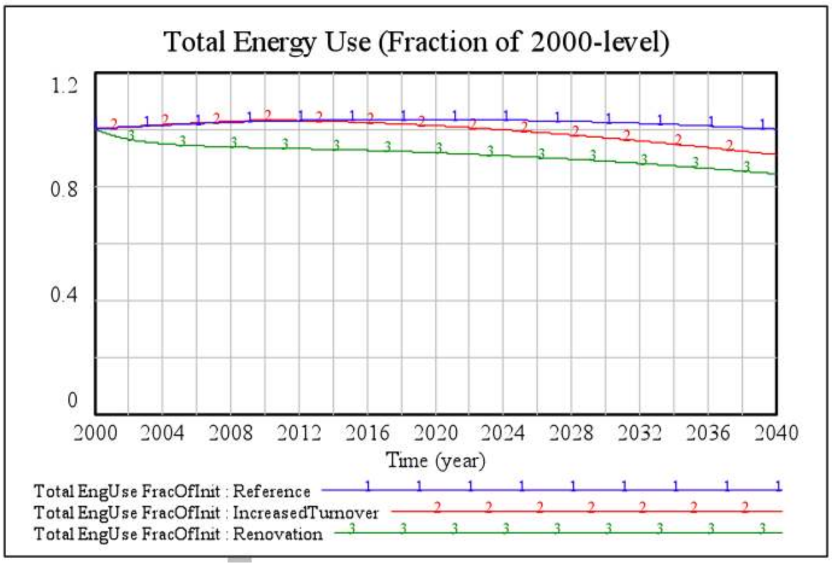

Figure 21. Total energy consumption – Renovation run

Compared to the previous experiments, renovation process yields the best outcome in terms of total energy consumption (see Figure 21); the total energy consumption declines to a level that is around 80% of the level observed in year 2000. As a result of renovations, the change in the quality of the existing dwelling stock is more compared to the previous cases. The average EPC level of the dwelling stock declines with a higher rate of change, and reaches a lower level Figure 22. When we observe the renovation behavior of tenants in different dwelling types and age groups (see Figure 22 through Figure 25), there are some understandable differences. Since income determines the ability of a household to renovate its dwellings, we observe higher renovation rates in detached dwellings, whose occupants have the highest income. Another factor that differentiates the renovation behavior is tenure; under current settings the cost of renovation is on dwelling owner and benefits are enjoyed by the renters. Therefore, the tendency of renovation in rented dwellings is lower than owner-occupied ones. When we consider that fact that the majority of gallery flats are rentals (mostly in the form of social housing), and the majority of detached dwellings are owner occupied, having higher renovation rates for detached dwellings is understandable.

Another point that makes a difference in renovation behavior is age of a dwelling. The age of a dwellings relates to a couple of issues; first of all the younger a dwelling is the lower its EPC level, since more recently constructed dwellings are better in terms of energy efficiency. Therefore, attaining a given amount of improvement in a younger dwelling (a further 0.1 EPC improvement) costs more compared to an older dwelling in worse condition (i.e. diminishing returns on renovation). Also due to this reason, a general decline trend is observed in renovations as the overall dwelling quality increases. Secondly, if the remaining lifetime of a dwelling is not long enough, a renovation investments may not payback. Therefore, renovation tendencies are lower among the late stage dwellings. This latter point seems to dominate the overall renovation behavior.

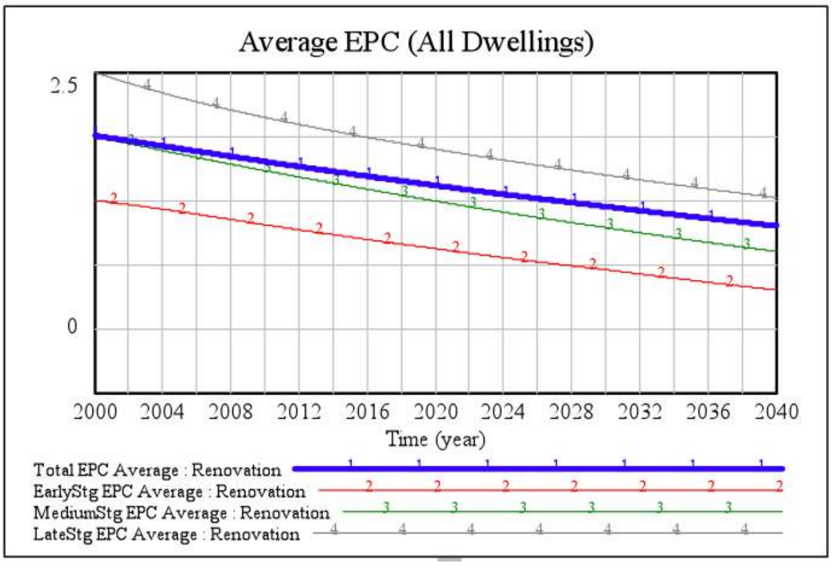

Figure 22

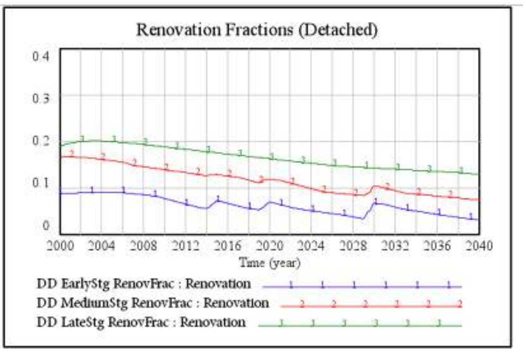

Figure 23

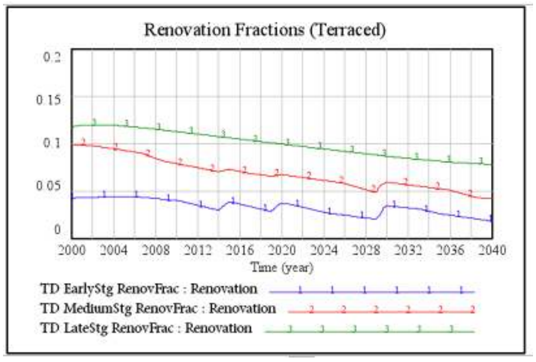

Figure 24

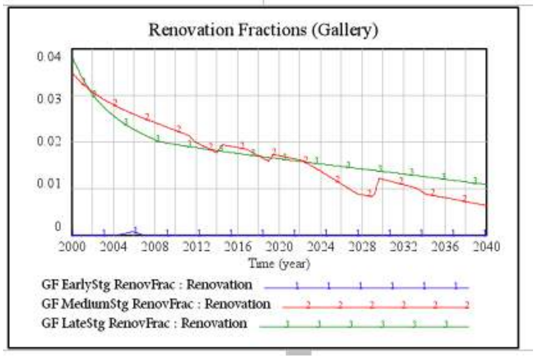

Figure 25

As a result, renovation process is observed to be much more effective than other changes that are solely aiming for new constructions. However, there is a caveat; despite being the best case over the conducted experiments, it should be kept in mind that this experiment depicts a sort of optimistic renovation behavior scenario. Once the outcome is interpreted in the light of this fact, the renovation efforts required to achieve significant energy savings seem to be much more than what we consider as normal today.

e. Renovation and Increased Turnover

Observing that increasing the rate of turnover in the dwelling stock, and speeding up renovations are two effective ways to reduce the overall energy consumption, an intuitive experiment is to try them together. In this experiment, we explore the joint impact of renovating existing dwellings, and also increasing the turnover rate of the stock (i.e. demolish younger, build faster).

The result of this experiment in given in Figure 26 with the plots of the related former experiments. As expected, the joint impact of these two mechanisms yields better results in terms of energy saving. This is not a surprising observation. However, deeper analysis of the interaction of these mechanisms reveal more interesting insights to be discussed below.

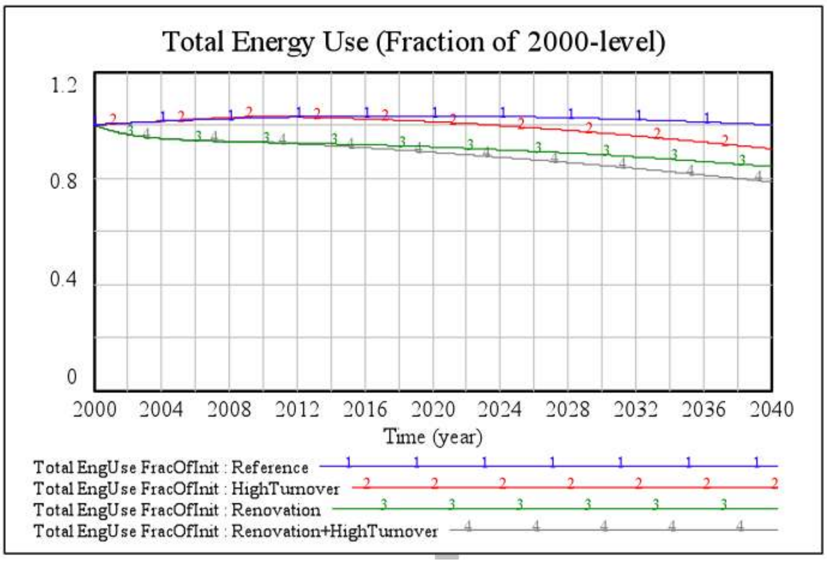

Figure 26

As already discussed, one of the factors that drive the renovation behavior of households is economic profitability. The cost of renovation is compared with the annual energy expense savings to be achieved. In order to conduct such a comparison, the renovation cost is converted into equivalent annuities using a market interest rate. Before making general conclusions about the joint impact of these two mechanisms, we have conducted a set of sensitivity analyses, which cover also the interest rate used in the reference case of the model.

Briefly, the results obtained from the sensitivity analysis regarding the interest rate confirmed our expectations regarding the parameter's importance. Although there is no significant change in the behavior pattern, the extent of energy savings through renovation are strongly related to the interest rate value. The most interesting point is that, some cases in this sensitivity analysis yielded energy consumption figures higher than the ones obtained with a slower turnover policy. In other words, increased turnover plus renovation yields worse results than just renovation. Such a result is observed especially in cases where the interest rate is high (e.g. 0.15-0.30).

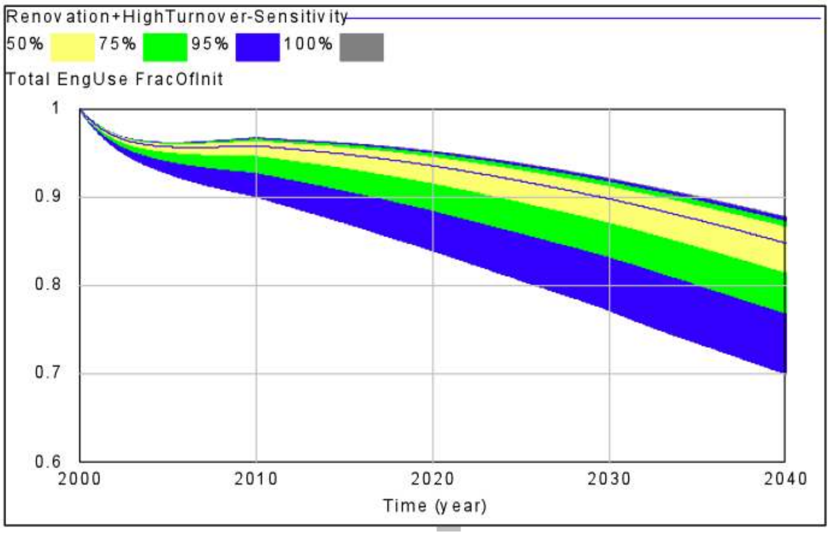

Figure 27

In order to demonstrate the aforementioned point better, a sample case is shown in Figure 28. In that plot, line 3 represents the simulation in which renovation mechanism active, but the dwelling demolishing rate is normal. When we increase the rate of demolishing (i.e. decrease the average service time of the dwellings), we get the results depicted by line 4. In short, the joint impact of these two mechanisms is not better than the individual impact of a single one. This seems to be a sort of counterintuitive result. The factor that yields this counterintuitive result is the indirect decrease in the remaining lifetime of the dwellings when their service times are decreased. For example, a 80-year old dwelling has 20 years more, if you plan to demolish it when it is 100-years old. It can be economically feasible to renovate such a dwelling, since 20 years is a long enough period during which the renovation can payback. Once the service time is changed to 85 years, the remaining lifetime of the dwelling is 5 years, which is not enough for a renovation investment to payback. This simple example depicts what causes the decrease in renovation rates as a result of increasing dwelling stock turnover policy.

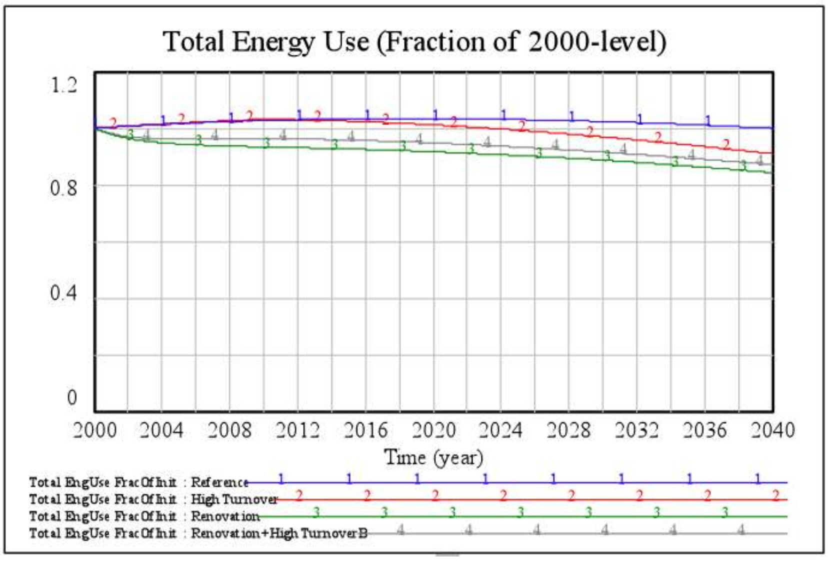

Figure 28

f. Reaching the targets

In the final set of experiments, we used the model to have a better understanding about what it takes to reach our targets in the residential sector in terms of reducing energy consumption. For this purpose, we defined a target trajectory for the total energy consumption in the residential sector. This trajectory being mainly imaginary, is inspired by general policy discussions on national energy sustainability. The key points in this trajectory are 2020 and 2040 points; we defined the target as reducing the energy consumption 20% by 2020, and 50% by 2040 (compared to 2000-level).

After some minor structural changes in the model, we tried to find the extent of renovation required over this 30-year period in order to achieve these targets. We utilized the optimization features of Vensim for this task. The result of our optimization runs reveal that following actions are necessary in order to reach the targets;

- Renovating 10% of the dwellings in the late stage annually, each renovation yielding 0.3 EPC improvement per dwelling; plus
- Renovating 5% of the dwellings in the medium stage annually, each renovation yielding 0.2 EPC improvement per dwelling

If these measures can be taken besides normal dwelling turnover policy and EPC regulations, it can be possible to realize the energy consumption curve given in Figure 29 (line 3). In short, this prescriptive experiment clearly indicates that significant energy savings are possible, but it will require an major renovation effort on the existing dwelling stock.

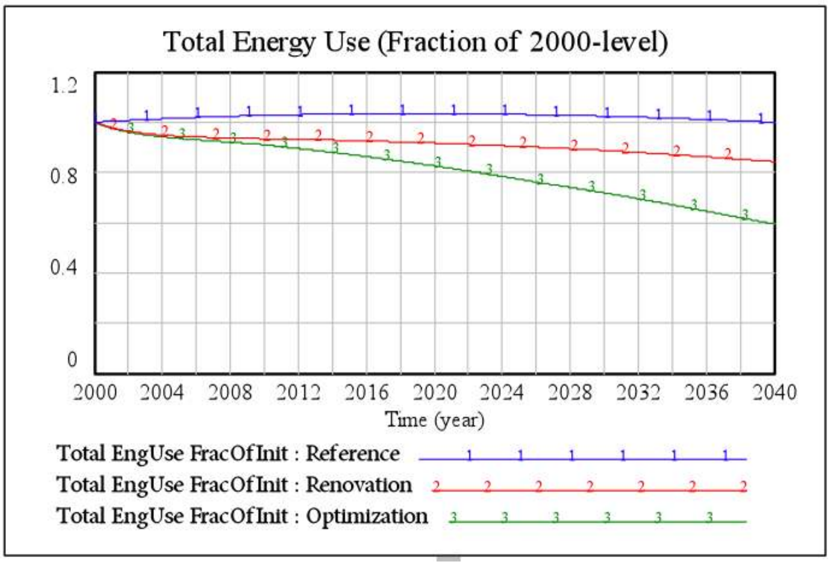

Figure 29

4. Discussion and Conclusions

In the face of global challenges like climate change, and finite fossil fuel reserves, energy transitions (i.e. significant changes in the amount of energy used, and also in the source of that energy). One of the most important frontiers of such a transition is residential sector. Transition to a more sustainable built-environment is a top priority policy issue for most European countries, such as the Netherlands. In order to realize such a transition, he Dutch government have bee using various policies, which mainly focus on new constructions and ignore existing dwelling stock. It is debated that more importance should be given to the existing dwellings, and only limited progress can be achieved through focusing on new dwellings. However, these debates seem to have no impact on the policies so far, most likely because of the fact that they lack an in depth exploration of the issue. This is what we primarily aimed at in this article; to explore the extent of inertia against transition caused by the existing dwelling stock.

For that purpose a simulation model is developed based on the actual figures of the Dutch situation. The model covers three different dwelling types, and three different age groups for each type. Apart from new construction, demolishing, and ageing processes related to the dwelling stock, the model also incorporates two crucial processes related to households; i.e. renovation and energy conservation.

In the first set of experiments, we aimed to show the extent of change in energy consumption, if the change comes only through old (inefficient) dwellings being demolished, and new (more efficient) dwellings being built to replace them over time. Although we tried extreme cases, such as doubling the rate of demolishing and construction, this set of experiments revealed that measures focusing just on new constructions fail to yield significant energy savings. To be more precise, it is seen that even with harsh EPC regulations, energy saved in the whole system only compensate the growth in demand due to increasing number of dwellings. In other terms, policies purely focusing on new dwellings do not seem to take the system to a better state, but only prevent it from going worse. Simulation experiments provide a very clear evidence of the importance of renovating the existing stock (at least in the Dutch case), which is the core issue in our second set of experiments.

As expected, an even normal level (taking the pace during 2000-2010 period as normal) of renovation activity yields total energy savings more than what is achieved even in extreme conditions during the first set of experiments. Still, renovations only yield 20% savings (compared to the year 2000-level) at the end of a 40-year time horizon, which falls short of ambitious sustainability goals. These experiments show that business-as-usual case for the renovation of the existing dwellings will not deliver what is needed for an energy transition.

A natural follow-up question to this observation is; what is required to achieve a significant change in the residential sector? We focused on this question in our last set of experiments. For this set of experiments, we modified to model in order to be able to use it in a more prescriptive manner, rather than a descriptive manner. Using the optimization tools of the simulation software, we searched for the rate of renovation required to achieve system-wide 20% energy saving by 2020, and 50% saving by 2040. The results show that the required rate of renovation is well above the current pace; i.e. every year improving the energy efficiency of 10% of the dwelling older than 40 years by 0.3 EPC renovating. These figures clearly indicate that conventional policy efforts will fail to take the Dutch residential sector to the desired more sustainable state, and more intense effort and more innovative policies focusing on the improvement of the existing dwellings are needed.

During our experiments, we also come across cases that clearly show the systemic nature of the problem at hand. In the first set of experiments, increasing the turnover rate of the dwelling stock is observed to be effective in increasing system-wide energy savings. In the second set of experiments, renovation is observed to be effective. Therefore, in some cases we explored the joint impact of these two processes expecting to get even more energy savings. However, in some cases these two processes, increased dwelling turnover and renovation, seemed to counteract; lowering the service times of the dwellings resulted the tenants having less tendency to renovate. The joint outcome was worse than what would be attained with a normal turnover policy. These cases show that even very simple processes related to the residential system may yield counterintuitive (at first thought) results, and such results these can be analyzed with a systemic perspective, rather than studying these processes in isolation.

Finally, when we consider potential limitations and drawbacks of the reported study, the model may appear as over simplistic at the first glance. Indeed the used model is quite simple, but we assess this simplicity as something essential to this study. Due to this simplicity, it is possible to solely focus on the major change processes about the dwelling stock and their interactions, which is our main objective, without being distracted with various elements that would be needed to take the model closer to the actual system in terms of behavioral replication. As a result, despite its appropriateness for conducting dynamic experiments to get general insights on the dynamics of dwelling stock, it would not be appropriate to go further and use the model for detailed policy analyses, and try to identify specific policy recommendations. The latter is a next step in our research agenda, which require the current model to be extended, or a new model to be built.

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