Appendix A
Materials Published in the Electronic Supplements

Several materials were used in this study, which are either to voluminous to print or are only available in electronic form. The following materials are provided via an electronic supplement.[1]

- Documentation of the Interviews
- Codes used in the analysis of the interviews
- Testing intervention levers

[1] Additional material is available online from http://extras.springer.com

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Appendix B
Most Important Variables of the Large Simulation Model

In this appendix, the names of the main variables of the large simulation model are listed.[2] Further, I define what units it is measured in and I state over what rage the variable varies in the model. Finally, I state what kind of subscripts were used to further differentiate the variable. In particular, the following subscripts were used (also see Sect. 7.2 starting on p. 211):

- **by BO type** refers to the four subscripts used for building owners, namely *profit-professional*, *profit-non-professional*, *multicriteria-professional* and *multicriteria-non-professional*.
- **by tenant type** refers to the three subscripts used for tenant types, namely *cost-minimizers*, *evaluators* and *ecological*.
- **by strategy** refers to the two subscripts used for renovation strategies, namely *paintjob renovations* and *eeupgradings*.
- **by housing type** refers to the two subscripts used for *paintjob housing* and *eeupgraded housing*.

In this appendix, the main variables are grouped according to the four modules of the model and can be found as follows:

- Module 1: The Stock of Buildings Revisited (see p. 208)
- Module 2: Demand and Supply on the Housing Market (see p. 209)
- Module 3: Technology (see p. 209)
- Module 4: Civil Society and State Interventions (see p. 209)

Note that within the four modules, the variables are ordered according to the main sectors, as given in Fig. 7.1 on p. 209. Within the sectors, the variables are not ordered alphabetically. Instead, they are ordered in a way that is oriented toward when a variable is required to advance the understanding of the model's structure.

[2] Remember that the large model uses the small model as its first module. Alterations are only made in order to subscript the stock of buildings for the four types of building owners. Hence, module 1 of the large model contains basically the whole small model.

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B.1 Module 1: The Stock of Buildings

Table B.1 Key variables of module 1: The stock of buildings

Variable	Meaning	Unit [Range]	Subscripts
Buildings owned by BO type			
SHARE OF BUILDINGS OWNED BY BO TYPE	Gives the share of buildings that is owned by any of the four building owner types	dmnl [0–1]	BO
Building sector			
HEATED FLOOR SPACE	Gives the past empirical and future projected heated floor space of Switzerland's multifamily buildings	dmnl [0–1]	BO
Building stock state variables (e.g. EE BUILDINGS IN NEW CONDITION)	Contain the number of buildings in any of the 6 possible states shown in Fig. 4.2	buildings [0–∞]	BO
Building stock flow variables (e.g. AGEING OF EE BUILDINGS)	Give the number of buildings moving in and or out of any of the 6 possible states shown in Fig. 4.2	buildings/year [0–∞]	BO
YEARS NEE BUILDINGS IN BAD CONDITION ARE LEFT UNRENOVATED	Gives the number of years that buildings in non-energy-efficient buildings in bad condition are in average left unrenovated	year [0–∞]	BO
TOTAL SHARE OF EEUPGRADINGS	This variable aggregates the SHARE OF EEUPGRADINGS from the four building owner types into the total share of renovations that are renovated into an energy-efficient building design (see Fig. 4.2)	dmnl [0–1]	–
Floor space and energy coefficients			
ENERGY COEFFICIENT OF CONSTRUCTIONS	Gives the energy coefficient that constructions have to implement by law	MJ/m^2a [0-∞]	–
ENERGY COEFFICIENT OF EEUPGRADINGS	Gives the energy coefficient that eeupgradings have to implement by law	MJ/m^2a [0–∞]	–
AVERAGE ENERGY COEFFICIENT OF STOCK OF [NEE / EE / TOTAL] BUILDINGS	Gives the average empirical energy coefficient of the nee buildings, of the ee buildings or of all the buildings	MJ/m^2a [0–∞]	–
CO_2 emissions			
Diffusion rates of [oil / gas] heating systems in [construction, eeupgrading]	Give the share of energy provided by different heating systems, either in construction or in renovations	dmnl [0–1]	–

(continued)

Table B.1 (continued)

Variable	Meaning	Unit [Range]	Subscripts
Efficiency of [oil / gas] heating systems	Gives the share of energy that is converted from useful energy to final energy for oil and gas heating systems	dmnl [0–1]	–
CURRENT CO_2 EMISSIONS	Amount of CO_2 released each year as a consequence of heating with oil and gas heating systems	tons CO_2/year [0–∞]	–

B.2 Module 2: Demand and Supply on the Housing Market

Table B.2 Key variables of module 2: Supply and demand on the housing market

Variable	Meaning	Unit [Range]	Subscripts
Building owners' decision-making			
SHARE OF EEUPGRADINGS	Gives the share of buildings under renovation that are renovated into an energy-efficient building design for each type of building owner (see Figs. 4.2 and 7.6) Note that this variable only applies to the buildings that are under renovation in the current year. Hence, even with a very high share of eeupgradings, only a very small percent of the total stock of buildings is transformed every year	dmnl [0–1]	BO
Tenants' decision-making			
SHARE OF TENANTS DEMANDING EEUPGRADED HOUSING	Gives the share of tenants that demand eeupgraded housing	dmnl [0–∞]	tenants
Demand, supply and cumulated renovations			
CUMULATED NUMBER OF EEUPGRADINGS	This variable accumulates the eeupgradings of each year into a stock, and could also be called "installed base". This variable allows to derive learning effects as a function of the installed base	buildings [0–∞]	–

(continued)

Table B.2 (continued)

Variable	Meaning	Unit [Range]	Subscripts
Calculating market price component			
MARKET PRICE COMPONENT OF THE RENT OF HOUSING	Part of the rent that is not related to construction costs. Is used to calculate mark-ups for housing types that are in high demand and calculate discounts for housing types that are in low demand	CHF [–∞–∞]	housing type
Calculating heating costs			
AVERAGE HEATING COST	Gives the average heating costs of the two housing types	CHF [0–∞]	housing type
Calculation of rental prices			
YEARLY COST OF RENTING HOUSING	Gives the cost that tenants must pay in order to use and heat a flat	CHF [0–∞]	tenants
Share of Tenant Types			
DISTRIBUTION OF TENANTS	Gives the share of tenants that belong to any of the three tenant types	dmnl [0–1]	tenants

B.3 Module 3: Technology

Table B.3 Key variables of module 3: Technology

Variable	Meaning	Unit [Range]	Subscripts
Technological quality			
TECHNOLOGICAL QUALITY OF EEUPGRADING DESIGNS	Measures the technological quality of the eeupgrading renovation strategy	quality units [0–1]	–
Construction costs			
CURRENT REAL CONSTRUCTION COST FOR PAINTJOB RENOVATIONS	Gives the cost of implementing the paintjob renovation strategy	CHF [0–∞]	–
CURRENT REAL UNSUBSIDIZED CONSTRUCTION COST FOR EEUPGRADINGS	Gives the cost of actually implementing the eeupgrading renovation strategy, without considering subsidies	CHF [0–∞]	–
Architects' reaction to technological change			
PROBABILITY THAT ARCHITECTS PROMOTE ENERGY EFFICIENCY	Gives the likelihood that a building owner encounters an architect who promotes energy efficiency	dmnl [0–1]	–

B.4 Module 4: Civil Society and State Interventions

Table B.4 Key variables of module 4: Civil society and state interventions

Variable	Meaning	Unit [Range]	Subscripts
Civil society			
POWER OF THE ADVOCACY COALITION WHICH DEMANDS FURTHER PUBLIC POLICY INTERVENTIONS	Measures the share of members of parliament who in principle support further interventions in support of energy efficiency in the stock of buildings	power units [0–1]	–
Reactions of the state			
INTENSITY OF PUBLIC POLICY INTERVENTION INTO THE STOCK OF BUILDINGS	Measures the actual level of state intervention	Intensity units [0–1]	–
EFFECT OF PUBLIC R&D EXPENDITURES ON THE TECHNOLOGICAL QUALITY OF EEUPGRADING DESIGNS	Measures the contributions public R&D expenditures have on the technological quality of eeupgrading designs	quality units [0–1]	–
AMOUNT OF SUBSIDY FOR EEUPGRADINGS	Measures the financial support given to buildings owners who implement energy-efficient building designs	CHF [0–∞]	–

Appendix C
Model Testing

Model testing is a crucial element in research based on System Dynamics. In this appendix, I provide more detail on this topic than I could in the main text. Due to space limitations, only the main results from model testing could be reported there (see Sect. 7.9). In this appendix, I provide greater detail on the work that was done to increase and document the quality of the two models.

By applying a wide range of tests to the model and its behavior, the validity of the model is increased. However, validity in an absolute sense can not be achieved—certainly not in the social sciences. Nevertheless, the iterative process of model testing, model adaptation and retesting somewhat mirrors the evolutionary mechanism, and it is thought to yield a robuster model compared to an untested model. The tests reported here were selected from the literature (Schwaninger and Groesser 2009; Sterman 2000).

The structure of this appendix is as follows: First, I discuss tests that apply to both models (see Sect. C.1). Second, I report on the testing of the small model (see Sect. C.2). Finally, I report on the testing of the large model (see Sect. C.3). I only reported on tests I deem applicable to my models.

C.1 Tests Applying to Both Models

Issue Identification Test

Schwaninger and Groesser (2009, p. 9004) demand that System Dynamics models be applied to "the right problem". In the introduction (see Chap. 1) and the analytical chapters (particularly in Chaps. 3, 4 and 5), I very clearly showed thats energy-efficient renovations are indeed a very important problem. What is more, once the limitations of the role of energy efficiency in buildings became clearer, I slightly expanded the focus and investigated the role of heating systems. Hence, I conclude that this study indeed addresses the right problem.

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Adequacy of Methodology Test

Schwaninger and Groesser (2009, p. 9004) argue that System Dynamics is suited best for dealing with issues characterized by "dynamic complexity, feedback mechanisms, nonlinear interdependency of structural elements and delays between causes and effects". Throughout this study I have shown that System Dynamics is an adequate methodology for the specific issue under study.

Structure Examination Test

This test refers to whether a model contradicts knowledge or evidence about the situation under study (Schwaninger and Groesser 2009, p. 9005). Sterman (2000, p. 859) points to several questions regarding the structure of models. I can respond to them as follows:

- The structure of both models is consistent with current knowledge about the system. I tried to describe the model as explicitly as possible and I labored hard to show how the model is grounded in the empirical and the theoretical literature.
- The level of aggregation is in my opinion the correct one. The current state of knowledge favors an aggregate perspective. However, further research might lead to more disaggregated modeling. Yet the work reported here can serve as a framework within which disaggregated work can take place.
- As far as I can see, both models conform to basic physical laws, such as the conservation of mass.
- As far as I can see, the decision rules of actors adequately explain *changes*. In Chap. 5, specifically in Sect. 5.4, I extensively justify the decision rules implemented into the model.

I conclude that the simulation models used in this study are exceptionally rigorously grounded in the theoretical and empirical knowledge currently available.

Parameter Examination Test

This aim of this test is to "evaluate a model's parameter against evidence or knowledge about the real system" Schwaninger and Groesser (2009, p. 9006). This test showed that there is probably some uncertainty about the correct value of parameters. Most parameter in the model were set so that they produced a behavior which—in light of theoretical and empirical knowledge—seemed the most reasonable. However, future research could aim to empirically estimate parameter and contribute to further reduction of uncertainty.

Boundary Adequacy

Sterman (2000, p. 859) points to the importance of the boundary adequacy. Regarding my models, I think that the boundary adequacy has been thoroughly established. Chap. 3 clearly sets the context. The small model described in Chap. 4 showed the need to develop a endogenous explanation, as presented in Chaps. 5 and 6. In this study, a building stock model, the market, technology, drivers of policy change and state interventions were brought together in order to provide an interdisciplinary account of the diffusion of energy-efficient renovations.

However, there is one aspect, where the boundary could be criticized as too narrow. This concerns the question of heating systems. However, the focus of this study was from the begin on the role of efficiency in the hull rather than the question of low energy use and low emission heating systems. I therefore refer to future work to integrate an endogenous explanation of the diffusion of low energy use and low emission heating systems.

Testing the Integration Time Step

I found that both models are stable for both, a time step of one and the smallest time step proposed by Vensim, set to 0.007812. Between the two runs only absolutely minor differences exist. Due to the widespread lack of precise data put into the model, minor computing errors from integration can be ignored as not meaningful. I therefore conclude that both models show nearly the same behavior and that they are stable also when the integration time step is changed.

Dimensional Consistency

Dimensional consistency refers to a situation, where the units in an equation are consistent to each other. In order to check dimensional consistency, I used Vensim's *units check* function. Initially, the software showed that several unit errors existed. However, by manually inspecting equations where Vensim found unit errors, the number of unit errors could be reduced to zero.

Testing the Time Horizon

In order to ensure that the models do not show unrealistic behavior or fluctuations outside the time horizon, I set the model time from 1975 to 3000 and ran the baserun scenario for that long time period.

In the small model, the nee stream of buildings continues to deplete and begins to fall below 1000 buildings in bad condition after the year 2336. This long duration is because in the baserun scenario, 45 % of nee buildings in bad condition are renovated with paintjob renovations. Similarly, the yearly CO_2 emission rate stabilizes to 2.9 million tons of CO_2 in the year 2200 and 2.7 million tons in the year 3000. This behavior is within what was expected. I therefore conclude that the model is stable and converges to a long-term steady state.

In the large model, the same dynamic pattern can be seen. The non-energy-efficient aging chain is depleted in the long run. And the CO_2 emission rate stabilizes at around 2.5 million tons of CO_2. Both, the building owners' SHARE OF EEUPGRADINGS and the SHARE OF TENANTS SEARCHING EEUPGRADED HOUSINGS converge towards a stable value. Both, the TECHNOLOGICAL QUALITY OF EEUPGRADINGS as well as the construction costs for both renovation strategies converge towards a stable long term value.

Testing the Time Horizon of the Large Model

In order to ensure that the model did not begin to show unrealistic behavior outside the time horizon, I set the model time from 1975 to 3000 and ran the baserun scenario for that long time period. All the drivers of policy change as well as the POWER OF THE ADVOCACY COALITION DEMANDING (FURTHER) PUBLIC POLICY INTERVENTIONS converge to a stable value. The fact that the EMISSION GOAL GAP does not converge towards zero is a sensible result. It represents the fact that energy-efficiency measures are not capable of bringing down the emission rate towards the goal rate. Further, all three public policy interventions (public R&D, subsidies, energy coefficient) converge towards a stable limit. I therefore conclude that both models show stability also in the long run.

Family Member Test

Often, simulation models can be described as belonging to a typical class of models (Schwaninger and Groesser (2009, p. 9010). My models probably best are described as diffusion models, which are generally characterized by s-shaped diffusion processes.

C.2 Testing the Small Model

The following work was carried out in order to increase the trust in the small model presented in Chap. 4 and used as the basis for the large model's building stock module (see Sect. 7.4).

C.2.1 Model Structure

In the validating interviews, one of my interviewees suggested that I use a fixed delay function in order to calculate the aging behavior of the stock of buildings. In such a case, the number of buildings constructed in the year 1 would become buildings in good condition in t+10 years. I experimented with several operationalizations (including Vensim's DELAY FIXED function) and a combination of the operationalization described above with fixed delays. I found that it proved impossible to find a satisfactory operationalization. In order to have a well calibrated aging chain, the initial year of the model would have to be postponed by the number of years a building needs to be renovated (55 years in my case). Starting the model at the year 1920 would pose the problem of data availability, and extending the time horizon of the model would carry a series of further implications for my study. However, experimenting with fixed time delays made me aware of the fact, that my operationalization probably underestimates the speed of transformation. Because the number of buildings under renovations is calculated as NUMBER OF NEE BUILDINGS IN BAD CONDITION divided through YEARS A BUILDING IN BAD CONDITION IS LEFT UNRENOVATED, it may take more time until the non-energy-efficient aging chain is drained.

C.2.2 Parameter and Numerical Assumptions

Testing the Number of Buildings

As described above, the past and projected total heated floor space for residential multifamily buildings (rather than the actual number of buildings) are put into the model as exogenous inputs. The number of buildings is then calculated by dividing the current total floor space through the average floor space per building (=1000 m^2). Table C.1 shows, that the empirical data on the number of buildings and the number of buildings given by the simulation model are not identical. The reason might be that the average heated floor space of multifamily buildings changed over time. Also, different data sources use slightly different definitions of multifamily

Table C.1 Comparison of empirical data and model values, for the number of buildings with at least 3 apartments

Year	Empirical data	Simulation model
1970	138 637	n.a.
1975	154 682	137 784
1980	170 727	155 654
1990	197 666	191 392
2000	220 426	227 130

The value for 1975 was interpolated from the years 1970 and 1980. All data was retrieved from Switzerland's federal office for statistics STAT-TAB database (BFS 2010) buildings. In conclusion, I deem the deviation acceptable. This particularly holds, because all energy-related calculations are anyway based on the total heated floor space rather than the number of buildings.

C.2.3 Model Behavior

CO_2 Emissions

Since the CO_2 emissions are the reference mode of this model, I carefully tested the fit of the model with the empirical data. This proved to be less straightforward than expected as I found the data not to be available in the desired specifications. For example, (Schulz 2007, p. 46) only provide values for the total stock of residential buildings, whereas I need values for the stock of multifamily buildings only. Nevertheless, I found two approaches to obtain approximate values for the yearly emission rates.

BAFU (2010) reports Switzerland's emissions from motor and heating fuels.[3] Obviously, the heating fuels include all building types. Therefore, in a first step the share of multifamily buildings in the total emissions needs to be approximated. According to BFE (2004, A8), multifamily buildings account for roughly 30 % of total heated floor space. However, I assume that multifamily buildings only account for 20 % of the emissions. This is because also process heat for industry is in the data and because multifamily buildings have a smaller surface to volume coefficient than one- or two-family homes, which makes them more energy-efficient.

The second approach relies on data from Switzerland's energy statistics (BFS 2010). There, time series for final energy demand from fossil heating fuels (heating oil) and gas are available from 1910 to 2009. By multiplying the final demand with the corresponding emission factors, the emissions can be approximated. By attributing 20 % of those emissions to multifamily buildings, the corresponding emissions can be approximated.

Figure C.1 shows the two time series obtained from official statistics and the model behavior in the baserun scenario. Comparing the model output with the data, it becomes evident that the model reproduces the empirical data sufficiently well. This can be also demonstrated quantitatively, by regressing the baserun time series onto any of the two empirical data series. As a result, an adjusted R^2 of more than 0.99 is obtained in both cases (ordinary least squares, no constant estimated). Pearson's correlation coefficient for the baserun time series and the BAFU data is 0.12. For the baserun time series and the BFE data it is –0.29.

Some caution however must be given, as the empirical data was calculated on the assumptions made above. In addition, I find it important to state clearly that the model was specifically calibrated to approximately reproduce the empirical data by including the flow variable INCREMENTAL EFFICIENCY GAINS IN THE STOCK OF

[3] The corresponding terms in German are "Treibstoffe" and "Brennstoffe".

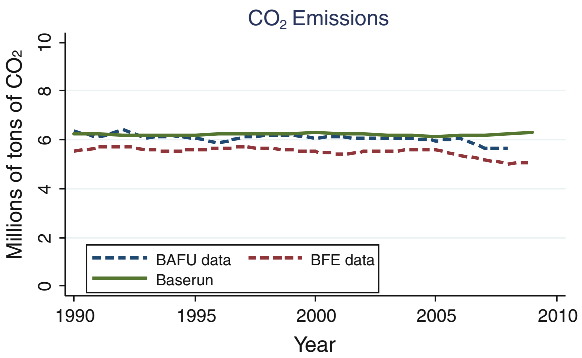

Fig. C.1 Comparison of emission data and model output in the baserun scenario

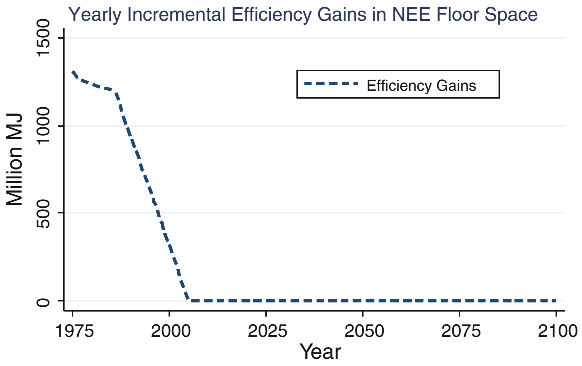

Fig. C.2 Incremental efficiency gains of nee floor space in millions of MJ per year

NEE BUILDINGS (also see Fig. 4.6 on p. 128) to reduce the energy demanded by the stock of nee buildings. Figure C.2 shows how this outflow was set in order to calibrate the model.

C.2.4 Sensitivity Analysis

All the sensitivity analysis was carried out with Vensim's standard sensitivity simulation setup. I set the number of simulations to 200. I used multivariate sampling with a random uniform distribution unless stated otherwise. The reason for using a uniform distribution (rather than a normal one) is that it is easier to identify sensitive behavior with this distribution. Normal distributions could be used to analyze the stability of the model under various normally distributed errors.

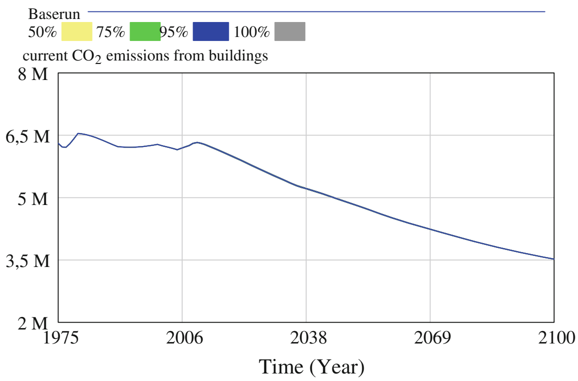

Fig. C.3 Sensitivity analysis of the initial distribution of buildings over the three quality categories

Initial Distribution of Buildings Over the Three Quality Conditions

In the model, I assigned the initial total number of buildings to three states. Now, I want to test whether variations in the initial distribution of buildings influence the CO_2 emission rate. Ideally, the outcome of this test should be that the CO_2 emission rate is robust to variations in the initial distribution.

It set the permissible range of SHARE OF BUILDINGS INITIALLY IN NEW CONDITION between 0 and 0.2 and the permissible range of SHARE OF BUILDINGS INITIALLY IN GOOD CONDITION to 0.2 to 0.6. The SHARE OF BUILDINGS INITIALLY IN BAD CONDITION is ten calculated as the difference to 1. I found that the the CO_2 emission rate is almost completely insensitive to variations in the initial distribution of buildings (see Fig. C.3). In fact, only when one zooms heavily into Vensim's sensitivity graph do the differently colored surfaces become visible (not shown in figure). I therefore conclude that this initial values are sufficiently well set when used as explained above.

Aging Parameters

The aging parameters used to calculate after how many years a building moves down to the next condition were set in accordance to expert judgment rather than hard data. In order to test how sensitive the CO_2 emission rate is to changes in those aging parameters, I performed the following sensitivity analysis. For each of the three aging parameter which control the stream of nee buildings, I allowed a variation of plus or minus 10 years around the model value. Figure C.4 shows the resulting sensitivity graph. According to that figure, 95 % of the 200 runs Vensim calculated remained reasonably close to the baserun line (expressed as the green surface and further encapsulated surfaces. Obviously, simulation runs where all aging parameters take a high value transform the stock of buildings slower to energy-efficiency than

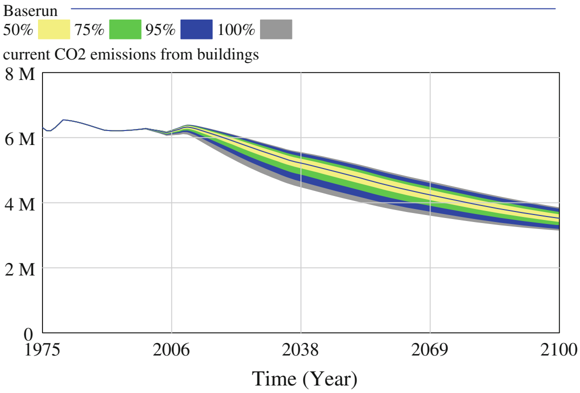

Fig. C.4 Sensitivity analysis of aging parameter

simulation runs where buildings have a comparatively short service life. In the long run, however, all the runs seem to converge. This is, because eventually all non-energy-efficient buildings are moved to the stream of energy-efficient buildings. I interpret the result of this analysis to strengthen the credibility of my model.

C.3 Testing the Large Model

C.3.1 Model Structure, Parameter and Behavior

With some minor exceptions, module 1 of the large model (the stock of buildings revisited) corresponds to the small model. See above for testing issues of this module. No formal model tests can be carried out, due to a lack of data beyond what was presented in Chap. 7.

C.3.2 Sensitivity Analysis

Extensive sensitivity analysis of all intervention levers was performed (the electronic supplement). There, I concluded that the large model is remarkably stable.

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Appendix D
A Fictitious Example of the Immobility Business Model

In Sect. 8.5.3, I developed the idea of an association, that would support non-professional building owners to overcome the challenges of energy-efficient renovations. In order to illustrate and further substantiate the envisioned business model, I developed a (fictitious) example. Due to limitations, I provide this example in the appendix instead in the main text.

Imagine that a brother and a sister inherit a multifamily building from their parents, in the outskirts of a medium-sized city in Switzerland. The building was built in the year 1971 according to the construction standards of the time. It has 5 cm of insulation, which is not very much compared to the 25–30 cm of insulation materials used in current new buildings. Since its construction, the façade has been painted once, but no further insulation has been added. The windows were never replaced and neither the roof nor the basement were ever insulated. Currently, the building is starting to show wear and tear in several elements. The windows will need to be replaced sooner or later. Generally, maintenance was minimal during the last decades and the reserves set aside for future renovations were negligible. This was because most of the income from the tenants' rent went to interest payments for the mortgage, and whatever remained was drawn as income by the previous owners of the building.

The new owners were unsure how to proceed regarding their building and contacted the Immobility association to request an analysis of their building. Eventually, a specialist came to analyze the state of the building and produce a report. In addition to the results of the analysis of the building, the specialist compiled a report on the current housing market situation and reported on trends that might influence demand for housings at the specific location. Specifically, the report stated that the building's main structures had aged well. The report also stated that the size of the rooms was still big enough given current market trends. Further, while the bathrooms and kitchens were several years old, they still were functional and could be used for a further decade. However, important elements such as the heating system, the windows, the blinds, the tiles on the roofing and the pipings for the water supply were near or already past their service life. Further, the report identified a lack of balconies, too small windows and the awkward and sparse placement of electrical sockets as attributes that reduced the utility tenants drew from their housing.

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In contrast, addressing these attributes could increase the rent potential of housings. The report further identified the lack of financial reserves as a key impediment to a major renovation.

Based on that report, the specialist offered the building owners to become member of the association. Further, he proposed that in the next few years the building should be left as it is with just minimal repair and maintenance. However, instead of drawing the proceeds of the rent as income, the building owners should use what is left after interest payments and maintenance to accumulated some capital. They were given the choice to put the accumulated capital either into a bank account or into an account at the Immobility association. Comparing bank rates and rates from Immobility, the building owners found that Immobility offers better rates. This is because the association gives preferential mortgages to other members. In consequence, Immobility can offer higher interest rates for saving accounts compared to banks and it can offer lower interest rates for mortgages than banks.[4] The expert further proposed to apply the CCEMARC in about five to ten years to the building. This would ensure that an advanced energy-efficient building design would be implemented at comparatively low cost. This would allow to obtain the Minergie certificate. The expert further recommended to replace the roof with a prefabricated maisonette apartment and to install balconies for each flat. This would increase the value of the flats on the rental market. Through the façade, a ventilation system, power lines and new pipings could be brought to each flat. This would allow to replace the pipings and install a ventilation system without disturbing the tenants more than a few days. Further, solar panels will be installed for warm water generation, and the heating system will then rely on a new system that combines heat pumps that take heat from the air and a heat pump that accesses an insulated, warm water tank in the ground. The warm water tank will be heated during warm days in spring, summer and falls. It will be used conjointly with neighboring buildings, so that investment costs can reduced and the thermal efficiency increased. This would allow to implement carbon-free[5] systems for heating and warm water.

Seven years later, the building owners decided to initiate the renovation process. They met twice with the project manager at Immobility, updated information in the files and outlined the renovation strategy that would be implemented. It was found that the market situation at the building's location remained largely unchanged and that current market conditions would allow an increase of up to 30 % compared to current rents. Over the last few years, about 100,000 Swiss francs were accumulated in a fund for future renovation work. In addition, some 400,000 Swiss francs could be obtained as a long-term loan from the Immobility association. The association drew on savings from other members and hence could offer favorable conditions. Further,

[4] I compared interest rates for saving accounts at Comparis for a capital of 100,000 CHF I found a variance from 0.100 to 1.150 %. Interest rates for mortgages were not readily available at Comparis. Therefore, I checked the cantonal bank of Zürich (ZKB). I found a variance from 1.190 % for a 2 year mortgage and 2.530 % for a 10 year mortgage. This warrants the conclusion that banks generally pay less interest for savings than they take for mortgages.

[5] Switzerland's electricity mix is generated without any signifiant emissions of CO_2, this may be different in other countries, particularly when coal is used to generate electricity.

some funds were obtained from banks at favorable rates. Due to the large volumes of renovations and the fact that Immobility professionally manages renovations, banks considered the buildings of Immobility members to carry a smaller risk compared to the average market. Therefore, they demanded lower interest rates.

Based on the former report and in close consultation with the building owners, the project manager initiated the required steps. He charged a specialized company to obtain the required three-dimensional measurements, based on which an architect at Immobility developed a project and specified the elements for prefabrication. The project manager obtained a construction permit, informed the tenants and handled all the paper work. After getting confirmation from the building owners he charged a specialized construction company to build the elements.

Two months later, prefabrication of the façade modules and the maisonette apartment that will replace the roof was completed. In the meantime, preparatory work was carried out. One window in each apartment was taken out and replaced by a balcony door. Further, a staircase was built into the roof, such that the future maisonette apartment would be accessible. The day before the installation, a crane was brought to the building and mounted. Eventually, the installation was begun by removing the whole roof from the building. Next, the façade elements were mounted around the building, at the exact place they were foreseen for. Where necessary, the old windows were unmounted. The façade elements already contained the new windows were necessary. As the façade elements were mounted, the crane lifted the prefabricated elements of the maisonette apartment on top of the building, where they were mounted. Subsequent work consisted of connecting various elements to each other. For example, the solar panels on top of the roof had to be connected and the new heating system had to be put in. Finally, external balconies were mounted in front of the building and connected. Finally, inspection for quality control was carried out. Later that year, a team of experts came by to commission the building and give tenants some instructions regarding how to use the ventilation system. Throughout the renovation work would be supervised by a project manager at Immobility.

Glossary

Actor Real individuals or groups of individuals which act in the real world.

Agent A representation of actors in the System Dynamics model. Used to represent the most important behavioral differences between actors within a typology.

Energy coefficient (legal) This is a measure of the amount of energy one square meter of heated floor space may use in a building. This is defined in the building code. A building only gets a construction permit if it adheres to the legal energy coefficient.

Energy coefficient (empirical) This is an empirical measure of the amount of energy one square meter heated floor space actually uses. It is typically given as an average value for the stock of buildings.

Energy efficiency Energy efficiency improvements are "a reduction in the energy used for a given service (heating, lighting, etc.) or level of activity. The reduction in the energy consumption is usually associated with technological changes, but not always since it can also result from better organisation and management or improved economic conditions in the sector ('non-technical factors')" (WEC 2008, 11).

Energy index The energy index is the total of the final energy (in MJ) used for heating a building during 1 year, divided by the heated floor space (in m^2). It is defined as MJ/m^2a. The corresponding term in german is *Energiekennzahl* (Econcept and Amstein+Walthert 2007, A-110).

Minergie Minergie is the name of a label for buildings in Switzerland. In addition to higher levels of comfort, Minergie-certified buildings implement a level of energy-efficiency which is significantly above the legal standard.

Renovation Upgrading of a building by implementing construction work, such that the building changes its state as described in Sect. 4.4.1.2.

Renovation practices Activities, rules, norms, attitudes, knowledge, competencies and dispositions that accompany the renovation of buildings.

Renovation strategy A particular approach to the renovation of a building. In Sect. 4.4.1.2, I define three different renovation strategies (reconstruction, energy-efficient upgrading and paintjob renovation) which summarize the different approaches that can be applied to non energy-efficient buildings in bad condition.

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