

March 2011

Retrofitting State Owned Buildings, Can we make our money back?

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Retrofitting State Owned Buildings

Can we make our money back?

Rachel Heller

3/6/2011

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Abstract

This Major Qualifying project will examine if by taking out bonds to make all state owned buildings in Massachusetts energy efficient, if the saving in energy costs will be able to cover the cost of the project by the time the bonds mature. Furthermore this project will utilize system dynamics to model the situation.

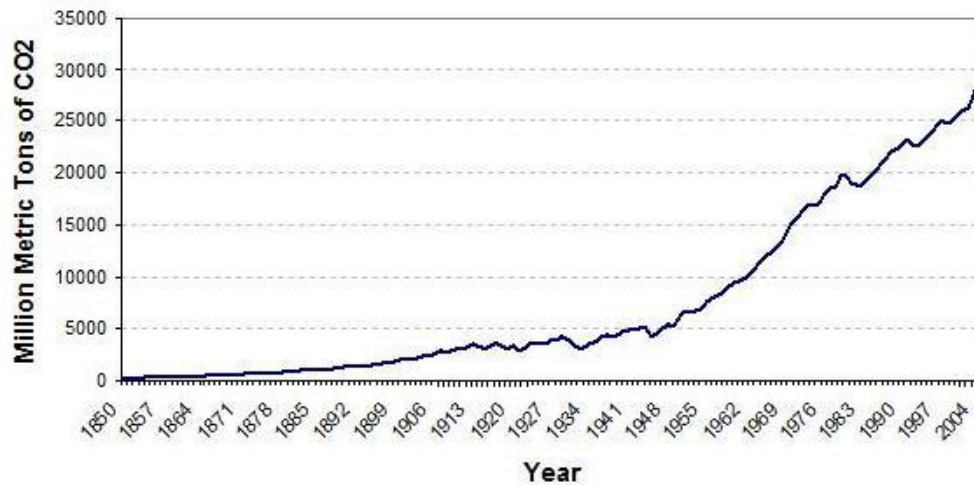
Introduction

Global warming has become a topic that has gained a lot of notice over the past 10 years. With Al Gore publicizing the topic, he has gained support from many small interest groups around the United States and the World, along with the government and past and current presidents. President Bill Clinton even stated that, "Al Gore has been warning us of the dangers of climate change for more than 20 years. His landmark book, "Earth in the Balance" made a deep impression on me and was one of the reasons I asked him to be my running mate in 1992" (Al Gore on Environment). To be able to have a profound effect on a President of the United States truly shows his ability to lead and inspire people to become active in protecting the environment.

This movement has caused global warming to become a priority for the government. While this has become a priority, stopping global warming is not a simple fix and must be balanced with not hurting the United States economy. Determining a way to stop global warming without affecting the economy has caused many debates, over various proposed solutions.

As seen in Figure 1 the general trend of global CO2 emissions has been exponentially increasing since the early 1850s.

Historical Global CO₂ Emissions* (1850-2004)



*from Fuel Burning, Cement Manufacture, and Gas Flaring

Source: Marland et. al (2007) Global, Regional, and National CO₂ Emissions. In Trends: A Compendium of Data on Global Change. CDIAC U.S.A.

Figure 1: Historical CO₂ Emissions

Whether the units are in parts per million as seen in Figure 2: predicted CO₂ emissions, or in metric tons in Figure 1 the general trend is then predicted into the future continuing to increase exponentially. If this path is continued it will have major environmental effects. As noted on the website of an environmentally friendly company, "If current warming patterns continue and average global temperatures rise even by a few degrees Celsius [...] The changing climate would alter forests, crop yields, and water supplies, and could lead to famine," (EcoSmart Concrete). Because of these drastic consequences to increased carbon emissions it is fundamental to start addressing this issue. However, while there are many articles discussing the negative effects of global warming, there are many people who oppose this point of view and believe that global warming does not exist.

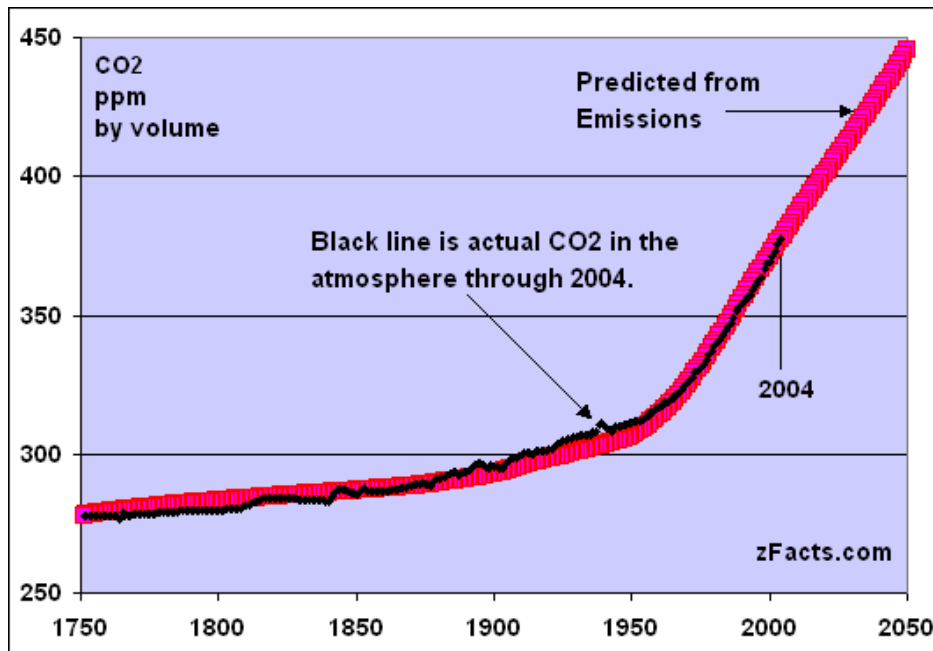


Figure 2: predicted CO2 emissions

Recently the Massachusetts chapter of the Sierra Club, a non-profit that works on environmental issues, proposed an idea that they believe not only will lower CO2 emissions, but will not negatively impact the economy. Through taking out bonds to pay for renovating state-owned buildings to be more energy efficient, the costs associated with renovation will be covered by the amount in energy savings by the time the bonds mature.

This Major Qualifying Project (MQP) will examine if retrofitting the state owned buildings will produce enough savings in terms of energy costs to equal the amount borrowed in bonds to pay for the retrofitting and the accrued interest in the next 50 years, through the use of system dynamics. System dynamics, defined by Erik Pruyt, as “a ‘theory of structure’ ... that tells us how the concepts of feedback loop and stock should be used to construct models, which is at most a structural epistemological theory or language’ ...with which system dynamicists see and describe reality “ (Pruyt 3). This method will show how changes in policy, in terms of making state owned buildings more energy efficient, will affect CO2 emissions, along with the ability of the state to pay back the cost of the bonds based off of energy savings by the time they mature because of the current constraint on the State budget.

This information will then be used by the Sierra Club to help not only guide the parameters of the law which is being written to allow the renovations, but also in showing lawmakers the overall effectiveness of implementing these changes.

Error! Reference source not found. Below, shows the hope or best case scenario if changes in our government policy are ideal and have a great effect on CO2 emissions. The goal is that carbon emissions, from state owned buildings, will quickly level out and stop growing exponentially. However the worst case scenario, or fear, of what could happen with our changes is that emissions from state owned buildings would increase even faster once the changes are made.

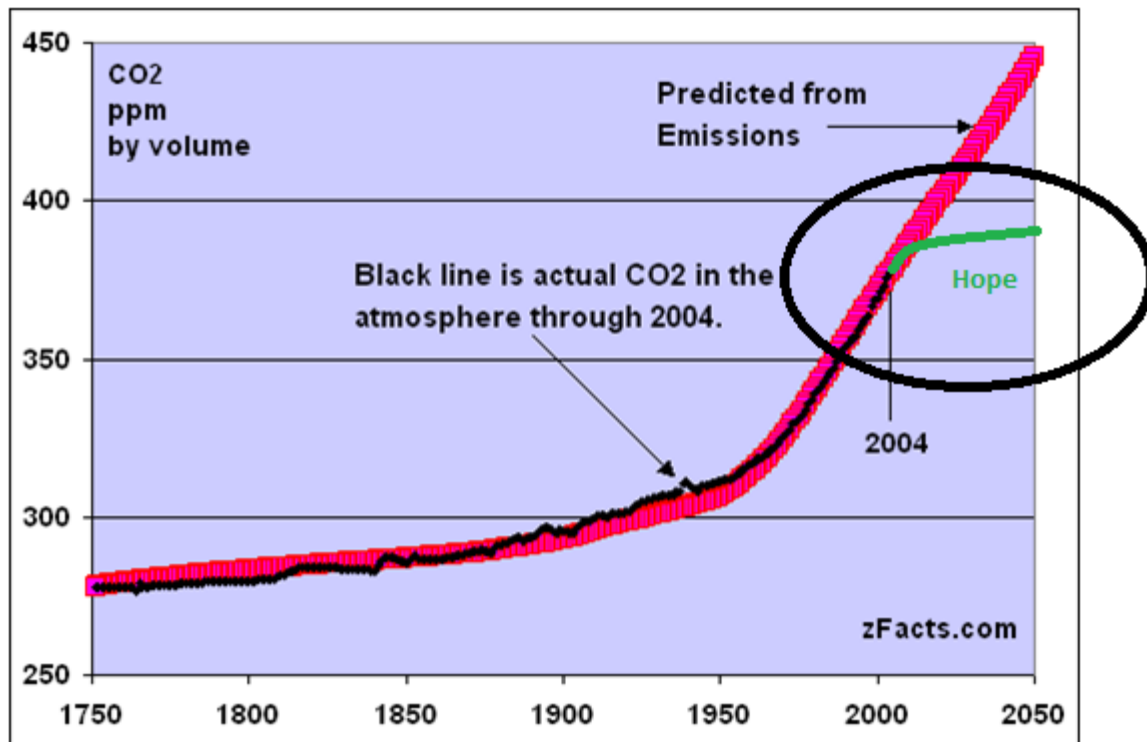


Figure 3: Hope/fear

These figures will help to keep the modeler aware of whether the overall results will tend to follow more of the Hope path than Fear or if it will not make enough of a difference to move the emissions away from its predicted growth. Even more than that it is important to note that not only

lowering the emission rate only in Massachusetts will enable the emissions to lower to that extreme on a world level, but it will need to be a world effort to get to that point.

Reference Mode

When creating a system dynamics model it is important to know the reference model for the time period you are looking at. A reference mode is described as, “a fabric of trends representing a complex pattern rather than a collection of historical time series.” (Saeed) . By knowing the reference mode it allows you to see the behavior of the situation and to predict what will currently happen in the future. This knowledge allows you to create a model that has a similar trend and enables you to be aware if the changes you make in the model will affect the system in a beneficial way.

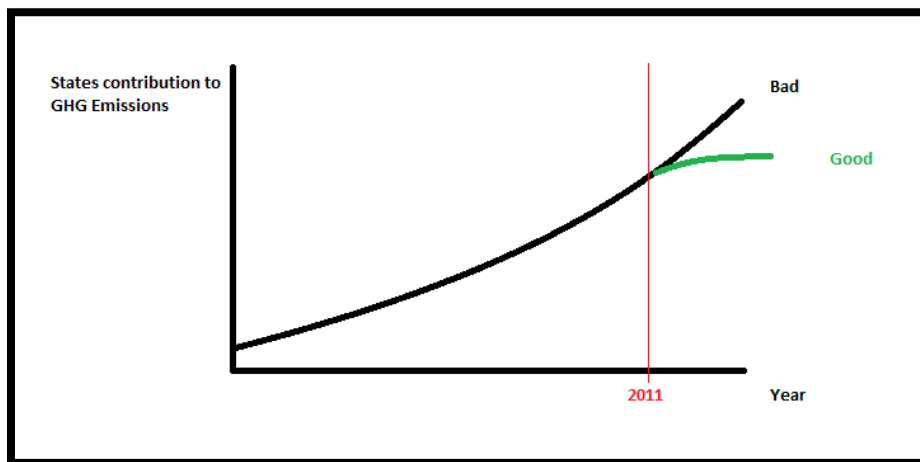


Figure 4: Reference Mode of states GHG Emissions

The trend seen in Figure 4: Reference Mode of states GHG Emissions, was derived from the graphs in the introduction. This graph is representative of the general trend of Massachusetts CO2 Emissions, dependent on the fact that all countries and states are equally adding to the CO2 in the atmosphere. This reference mode shows what a good and bad result of changing the model would be. A bad result would be to either not affect the CO2 emissions or increase the amount of CO2 in the atmosphere. While a good result, which is the goal of implementing the policy in the short term, would be to have the amount of CO2 in the atmosphere to level out. The overall long-term goal would be to decrease CO2

emissions. This however is beyond the scope of this MQP and would be the next step to be modeled after CO2 levels had successfully leveled out.

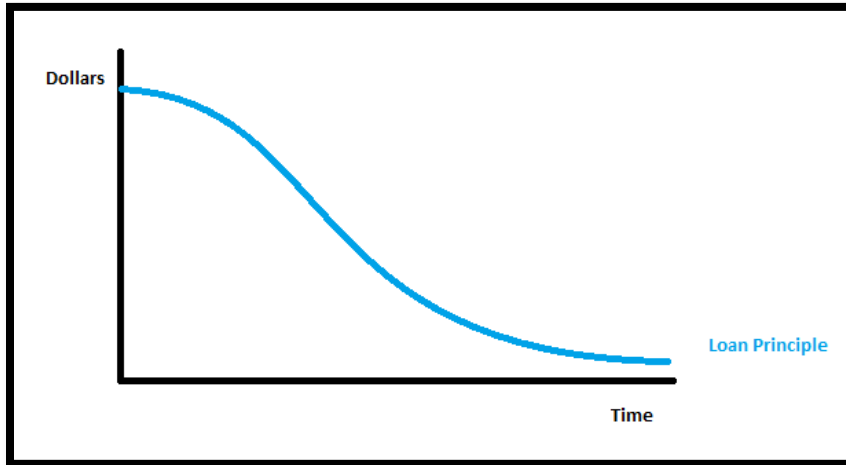


Figure 5: reference mode of the loan principle over time

In terms of paying off the principal of the loan, the two graphs (Figure 5 and Figure 6) below shows that as the savings from the buildings being energy efficient increase, the loan principal decreases because the money saved is used to pay back the loan.

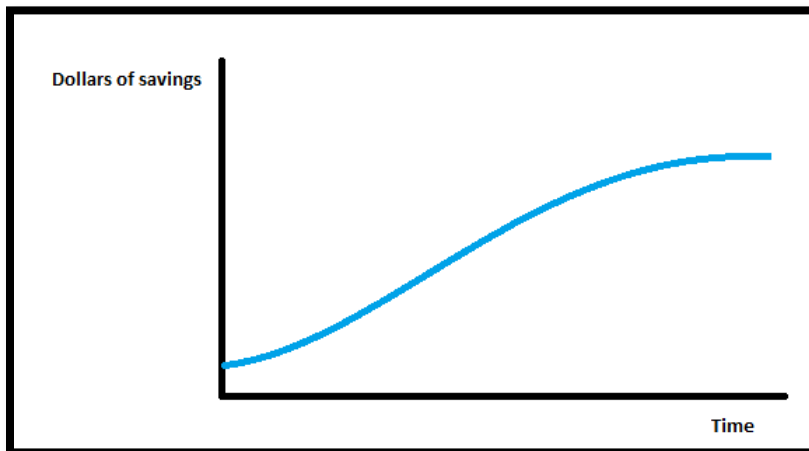


Figure 6: Reference mode of energy cost savings over time

These reference modes show the general trends the model will be making. By changing various factors in the model, it will affect not only how quickly the loans are paid back, but also the rate. Essentially by

adjusting various factors in the model through possible policy changes it will affect the slope of the lines and the length of time.

Literature Review

This model is being produced for the Boston chapter of the Sierra Club. The Sierra Club was founded in 1892 and is the oldest grassroots environmental organization in the United States. The organization works on environmental issues such as preserving national parks and clean air projects. Because of their mandate the Boston chapter of the Sierra Club has been working on ways to improve the CO2 emissions in Massachusetts for the past few years.

Specifically the organization as a whole has been looking at the larger issue of global warming and how the US carbon footprint plays a part in it. Global Warming is defined as “an increase in the earth's atmospheric and oceanic temperatures widely predicted to occur due to an increase in the greenhouse effect resulting especially from pollution” (Merriam-Webster). Being concerned with global warming follows the Sierra Club’s mission statement:

“To explore, enjoy, and protect the wild places of the earth;
To practice and promote the responsible use of the earth's ecosystems and resources;
To educate and enlist humanity to protect and restore the quality of the natural and human environment; and to use all lawful means to carry out these objectives.” (Sierra Club)

Specifically the second line which talks about inhabiting the earth responsibly. Along with looking at the global foot print the Sierra Club is also investigating how to create more Green jobs and at increasing the amount of laws created about protecting the environment. Both of these topics also fall in line of our project of lowering carbon emissions through financing retrofitting state owned building through bonds. Part of the model deals with looking at the impact of green jobs through this initiative. Green jobs are defined as, “jobs that create, run and support a clean energy economy and which pay decent wages and provide benefits that can support a family” (Sierra Club) . Essentially a green job is one that pays as well as the average job, yet is done in a way that benefits the environment.

The Sierra Club opted to look at the problem of using bonds to retrofit state-owned buildings through the use of system dynamics (SD). “SD attempts to illustrate complex interplay between hard or

tangible aspects (such as machines, materials, money, people) and soft or intangible aspects (such as morale, policies, processes, structures) of a given situation.” (BusinessDictionary). This model that is being built will specifically look at the tangible aspects such as the amount of money being built along with the number of buildings being retrofitted.

Jay Forrester

System dynamics is a relatively new area. It was founded in the 1950's by Jay Wright Forrester. Forrester was born in 1918 in Nebraska. After majoring in electrical engineering at the University of Nebraska he moved on to Massachusetts Institute of Technology, better known as MIT. There he worked as a research assistant working with Gordon Brown who was a pioneer in feedback control systems. This base later led him to form the modeling technique known as system dynamics. System Dynamics is based off of systems thinking. “Systems thinking is a way of understanding reality that emphasizes the relationships among a system's parts, rather than the parts themselves” (Pegasus communication). Essentially, systems thinking involves identifying how different aspects affect not only the problem at hand, but each other too. “A system is a group of interacting, interrelated, and interdependent components that form a complex and unified whole,” (Pegasus communication). Systems thinking is then represented in system dynamics modeling. The modeling portion deals with using a program such as Vensim that allows the user to visualize how the various aspects interact along with adding mathematical equations. The model then produces graphs and information about how changing certain parts of the model will affect the overall situation. System dynamics models have been used in the past to look at everything from environmental effects to the economy and even the population of fish in a pond.

John D. Sterman

Two of the models we will be looking at were created by John Sterman, and another one he was the thesis advisor for. Sterman is currently a professor at MIT teaching system dynamics. Additionally he

has the title “Jay W. Forrester Professor of Management” for all of the work he has done to carry out Forrester’s work in the field of system dynamics. Sterman’s “research includes systems thinking and organizational learning, computer simulation of corporate strategy and public policy issues, and environmental sustainability” (MIT Sloan Management). It is especially his work in public policy issues and environmental sustainability that was a great foundation to this model and report.

The New York Times

Sterman’s work on the “bathtub” effect has greatly helped in portraying to the public the environmental issue at hand. As Sterman explains it, “the atmosphere is like a bathtub with a partially opened drain. Carbon dioxide from burning fuels and forests is flowing in twice as fast as it is being absorbed by plants and the ocean, and some of those “sinks” are in fact getting saturated, it appears, meaning that the “drain” is clogging a bit.” (New York Times opinion pages). Being able to communicate and explain what is occurring in a system through system dynamics is a major reason for the system dynamics field being created.

In his article for the New York Times, Sterman talks about “‘The erroneous belief that stabilizing emissions would quickly stabilize the climate supports wait-and-see policies but violates basic laws of physics,’ Dr. Sterman concluded.” (New York Times opinion pages). This is a major belief people have about global warming and CO2 emissions that people are working hard at to explain the reality of the situation to others.

“Our mental models suggest that if we stop the growth of emissions, we will stop global warming, and if we cut emissions, we’ll quickly return to a cooler climate. We tend to think that the output of a process should be correlated with — look like — its input. If greenhouse gas emissions are growing, we think, the climate will warm, and if we cut emissions, we imagine that the climate will cool. In systems with significant accumulations, however, such correlational reasoning does not hold. Rather, it’s more like filling a bathtub. The amount of carbon dioxide in the atmosphere is like the level of water in a bathtub. The level grows as long as you pour more water in through the faucet than drains out. Right now, we pour about twice as much CO2 into the atmospheric tub than is removed on net by natural processes.” (New York Times opinion pages)

Through the example of the environment being a bathtub people are able to explain that “The long lifetime of carbon dioxide in the atmosphere, and the long lifetime of sources like coal-burning power plants once built, mean that the “faucet” for CO₂ is getting cranked open just when it should be going in the opposite direction.” (New York Times opinion pages). Through using visual models with modeling programs such as Vensim it becomes a great tool for visualizing CO₂ emissions filling up the atmosphere and staying there through being able to see “water levels” in the tub rise and fall along with graphs being produced.

The Effect of Energy Depletion on Economic Growth

The first model of Sterman’s that was an asset to this project was his paper on The Effect of Energy Depletion on Economic Growth. In this report he talked about a lot of the factors that have an effect on the economy that deal with energy resources such as the fact that:

“Depletion of energy resources has emerged as one of the major problems facing the world for the remainder of the century. At the same time, the economy of the United States has not fared well. The '70s saw economic growth falter from the 3.7% per year rate of the '50s and '60s to 2.7% per year. The nation experienced the deepest recession since the Great Depression, rising unemployment, and the most severe peacetime inflation in U.S. history.” (J. D. Sterman, THE EFFECT OF ENERGY DEPLETION ON ECONOMIC GROWTH 4)

While this model will not explore the various forms of energy it will look at using energy more efficiently which will lower energy consumption and therefore somewhat counteract the scenario above.

Additionally Sterman discussed that:

“As the price of energy rises, the cost of producing every good and service in the economy rises (including the costs of energy production). Higher costs are passed into prices, possibly triggering a wage-price spiral, reducing the standard of living, and adding to the demand for credit and to government deficits; each of these adds to inflationary pressure.” (J. D. Sterman, THE EFFECT OF ENERGY DEPLETION ON ECONOMIC GROWTH 10)

Thereby, noting another reason that lowering our energy use is beneficial to the economy in addition the environment which will be positively impacted through a decrease in CO₂ emissions.

In his report Sterman also touches on the issue with waiting to replace the old capital until it breaks:

“The delay in substituting new capital for old is one of the most important sources of the more severe intermediate-term impact. In the base run, two decades (the average life of capital) are required to replace old capital with energy-efficient capital. Thus, even though the price of energy reaches its equilibrium value by about the 60th year of the simulation, the energy/GNP ratio continues to decline for half a century before reaching equilibrium (Figure 6). Because of the long life of capital, energy demand is relatively inelastic in the short run, resulting in a transient increase in the fraction of national income devoted to energy production.” (J. D. Sterman, THE EFFECT OF ENERGY DEPLETION ON ECONOMIC GROWTH 49)

Our model will not include this because the goal of the project is to update the capital on the basis of the savings that will be made by replacing the capital now versus doing it over the long term and losing those savings through running inefficient capital.

Economic Vulnerability and the Energy Transition

Sterman’s second paper we will be basing our model off of is his report on Economic Vulnerability and the Energy Transition. This report touched on using subsidies

“The model is used to analyze the effects of government subsidies for energy technologies. The effects of subsidies for long-lead time, capital intensive centralized technologies are contrasted against subsidies of short lead-time, labor intensive, decentralized technologies; the latter are found to be far more effective in reducing the vulnerability of the economy during the transition.” (J. D. Sterman, ECONOMIC VULNERABILITY AND THE ENERGY TRANSITION)

While we will not be looking at subsidies, but taking out bonds in our model, we will not be dealing with subsidies. However, this model did set the base for looking at the government’s interaction in becoming more energy friendly and there for environmentally friendly. Additionally this model examined factors such as the labor market which our model will also touch upon. Most importantly though Sterman talked about the fact that:

“The economy is likely to face a prolonged period of economic vulnerability due to the continued depletion of nonrenewable resources, slow development of alternative sources, and lags in the adjustment of energy consumption to higher prices” (J. D. Sterman, ECONOMIC VULNERABILITY AND THE ENERGY TRANSITION)

These fact add to the overall point that their needs to be a change made in the amount of energy consumed not only because of the environmental impacts the Sierra Club is concerned with, but because of the economic ramifications of not adjusting our energy use.

Juan Francisco Martin Aguirre

Climate change was the main topic in the dissertation of his doctoral student Juan Francisco Martin Aguirre. Aguirre's paper was on Improving Understanding of Climate Change Dynamics Using Interactive Solutions. This goes back to the earlier point Sterman made in his new article that by having a visual aid that is interactive it will help to improve people's understanding of both dynamic and complicated situations. In Aguirre's paper it states:

Low public support for mitigation policies may arise from misconceptions of climate dynamics rather than uncertainty about the impact of climate change. Misconceptions of climate dynamics are associated with a weak intuitive understanding of the concept of accumulation (Sterman and Booth Sweeney, 2007). The principle of accumulation refers to the ability to determine the level of a resource or stock, such as greenhouse gas (GHG) concentration in the atmosphere, when the rate of change in the stock level varies as determined by the difference between its inflow and its outflow (GHG emissions released into the atmosphere minus the amount removed by natural processes).

(Aguirre 16)

The past passage explains a very important part about why there has not been a large following on lowering CO2 emissions.

It is not because people are unaware, but more so that they are not fully able to grasp the situation at hand, especially the basic principals dealing with the amount of GHG in the atmosphere.

Aguirre then continues on to discuss the fact that:

The first objective of our interactive simulation is to improve understanding of climate change dynamics. We have learned from prior work that people struggle when making decisions in the presence of dynamic complexity¹. Sterman and Booth Sweeney (2007) concluded that subjects involved in their experiment failed to respond correctly because of the prevalence of a pattern matching heuristic. The idea that people often use dynamically deficient mental models to guide their decisions is also referred to as *misperceptions of feedback* (Sterman, 2000). It represents the notion that people fail to appreciate time delays between cause and effect, do not understand the relation between stocks and flows, and are insensitive to non-linearities that could abruptly affect the outcome of an evolving system. (Aguirre 19)

This aspect that people often do not realize the time delay effect is a reason that they do not always fully grasp the system and what is occurring. Time delays, are an important part of any model and is one of the main reasons that models are able to show what is occurring in the real world. Because in practice there are many time delays that effect every system.

Thomas S. Fiddaman

Tom Fiddaman finished his Ph.D. in system dynamics at MIT Sloan School of Management. His dissertation, along with his research has centered around environmental work and business strategy which is why he has done a lot of important research related to making state owned buildings energy efficient. Fiddaman most importantly has done a lot of work with, “the application of modeling to group problem solving and negotiation and the development of better tools for the analysis of complex simulation models.” (Fiddaman, Tom Fiddaman's Homepage). It is this concentration on using modeling to help people understand the system which the Sierra Club hopes this model will do when introducing this bill into legislation.

In addition to Fiddaman’s philosophy on using system dynamics modeling to help educate the general public his paper, A Feedback-Rich Climate-Economy Model, is also very relevant to our work. In this paper he talks about his ‘FREE’ model which looks at the Feedback-Rich Energy-Economy. “The purpose of the FREE model is to explore the impact of climate policies, focusing on a carbon tax” (Fiddaman, A Feedback-Rich Climate-Economy Model 10). While our model will not examine carbon tax

much of this research will deal with looking at the financial aspect associated with becoming more energy efficient.

More specifically Fiddaman's model shows that, "The energy-economy systems in the model draw heavily on Sterman's energy-economy model and the System Dynamics National Model (Senge 1978; Sterman 1980; Sterman 1981). In general, the structures for capital investment and embodiment of energy requirements in capital have been closely copied," (Fiddaman, A Feedback-Rich Climate-Economy Model 9). This point emphasizes that the work between Fiddaman and Sterman, along with Aguirre are all closely related and therefore is a natural launching point for this model.

Richard Musgrave

For the model it was necessary to look at the work done by Richard Musgrave. Musgrave worked on revolutionizing economics in the public sector. He accomplished research and revolutionary work in the public finance sector. His work was so well known that after his death that economists such as, Max Sawicky at the Economic Policy Institute in Washington stated Musgrave, "... basically drew the map for public finance in terms of how the subject should be organized," (Hall). This is praise not easily found for many economists and proves how great his contribution was to public finance.

Musgrave's work in the public sector has been seen in forms of financing projects. As stated by McNulty, "Musgrave described the setting of tax policy as a delicate orchestration of factors including employment, inflation, economic growth, and the fair distribution of the tax burden" (McNulty) Current projects that are occurring dealing with a similar theme of balancing taxes and continuing growth is seen in a program in Minnesota where they are offering tax-exemption for state agencies or schools that are making their buildings energy efficient. This combines Musgrave's theory of using taxation as a way to help orchestrate the economy. By making these buildings energy efficient it will allow the schools to

save money through becoming more energy efficient and then use that money to benefit their organization and spur spending.

The work accomplished by Forrester, Sterman, Aguirre, Fiddaman, and Musgrave has been an integral part of setting the base for this project MQP. Additionally their work, in the public sector and the environment, has most likely indirectly influenced current projects that have been undertaken by schools to lower their emissions.

Current Massachusetts Efforts

In terms of the current work being done towards improving the carbon footprint, Massachusetts towns have already been making an effort towards becoming more energy efficient. As noted in the Sun Chronicle, the town of Norfolk has been working on adding solar panels to, “expand the area where solar panels could be installed at the old landfill off Medway Branch Road.” (PETERSON). The town is worked on improving its foot print by adding solar panels, which is not necessarily an easy task. Currently the town of Norfolk has called an emergency town meeting in order to change some zoning codes to allow the solar panels to be installed.

With individual towns working towards improving their footprint and organizations such as the Sierra Club working on investigating cost effective ways for the state to accomplish this it has become a prevalent topic at the state level. Even internationally work has been done to increase the efficiencies of companies.

While adding green design elements to a building, such as solar panels and wind turbines have added costs that may not be anticipated, reports have come out from, “Cambridge University [that] estimated that the world could save 73 percent of its energy through efficiency measures. Much of that gain could come from deploying basic, already-available technologies such as thicker building insulation and triple glazed windows.” (Luoma). This approach would involve making the decision when

retrofitting, repairing, or building to spend a little more money presently, but to save both energy and money over the life time of the products.

Green Businesses

Paul Rak a Canadian citizen decided when his first child was born that he was going to make VeriForm Inc, his steel fabricator business more energy efficient to create a better world for her. While this could have negatively affected his business it had the opposite effect. “Between 2006 and 2008, he told the trade magazine *Green Manufacturer*, he spent about \$46,000 on energy efficiency, an investment that immediately began returning about \$90,000 in reduced energy bills annually, a nearly 200 percent return on the investment. Meanwhile, VeriForm had cut its energy costs by 58 percent and its greenhouse gas emissions by 233 metric tons per year.” (Luoma). Saving \$90,000 a year drastically increases profit through lowering their variable cost of production. This is a great example to show that becoming more energy efficient can not only benefit individuals, but the overall economy too.

The previous models and research completed about the energy efficiency of retrofitted buildings and various system dynamics model dealing with energy use do not look purely at the carbon emissions of buildings as our model will. We will also expand looking at the carbon emissions of state owned building to examine how this can financially be done through taking out bonds and potentially be cost free to the state within the next ten to twenty years. This added sector in the model will add in an important part of determining the feasibility of this project, the aspect of money.

The pressure has started to make the average US citizen’s life more energy efficient. “President Obama set a goal of improving U.S. energy efficiency by 20 percent over the next 10 years” (Luoma). This means there are more subsidies and savings for people who decided to use energy efficient products. So far the US has been able to lower its energy use “According to the American Council for an Energy Efficient Economy (ACEEE), [...] the U.S. would be consuming 80 percent more energy than it

does now if it was using as much energy per dollar of GDP generated in 1975.” . This shows that it is possible to decrease our energy use without changing the way we live. Most people do not even realize that the way we use energy now is that drastic from 1975.

In terms of state energy use, which is what we are concerned with in this report since we will be looking at the carbon footprint of Massachusetts, “California became the first state to confront that issue in 1982, when, in the throes of the energy crises of that era, it found a way to decouple profits from the amount of energy used, allowing the utilities to encourage efficiency while guaranteeing a profitable return. Utilities, essentially, were allowed to charge more for each unit of energy, as long as efficiencies improved”. While we will be looking more at using state bonds to pay for retrofitting buildings, this is just another example how there are many creative and inventive ways to make our world more energy efficient.

Performance Contracting

Performance contracting is a new method of enticing people to go green which started in Europe. Essentially a private energy source company or ESCO completes a cost-benefit analysis of, “energy-saving opportunities and then recommend a package of improvements to be paid for through savings” (ECS Resources and Information). The next step is for the person who owns the property to enter in to an agreement that if they implement the retrofits and maintain the retrofits, then if they do not receive the savings the ESCO estimated they will pay the difference. An additional benefit of this program is that it allows multiple projects to be streamlined by combining all of the projects in one contract and making sure that the optimal savings are realized. The company will additionally teach the company how to maintain the new retrofits so that they will reach their potential savings and cover the cost of installing them.

Table 1: ESCO projects

Country	Total value of ESCO projects in 2001 (in USD)	Population size in 2005	Value of ESCO projects per capita (USD)
United States	1800-2100 Million USD	300 Million	6 USD
Germany	150 Million USD	82 Million	1,8 USD
Brazil	100 Million USD	185 Million	0,54
Japan	61,7 Million USD	127 Million	0,48
Canada	50-100 Million USD	32,8 Million	1,52-3
China	49,7 Million USD	1300 Million	0,03
Poland	30 Million USD	38,5 Million	0,77
Sweden	30 Million USD	9 Million	3,3
Australia	25 Million USD	20,7 Million	1,2
Korea	20 Million USD	49 Million	0,4
Switzerland	13,5 Million USD	7,5 Million	1,8
India	0,5-1 Million USD	1100 Million	0,0009
South Africa	10 Million USD	46,5 Million	0,21

As seen by the table above EPCO has not only had many projects overseas, but the number one in terms of the value of their project is the United States.

The Model

This model was based off of various conversations with the Boston Sierra Club along with a plethora of data and proven system dynamics modeling techniques.

The model has five sectors which are all affected by the policy changes that will be made in the building sector. The building sector keeps track of the number of state owned buildings and their status in far as whether they have been audited, retrofitted, or demolished. Additionally the building sector examines the number of auditors and builders along with their production rate.

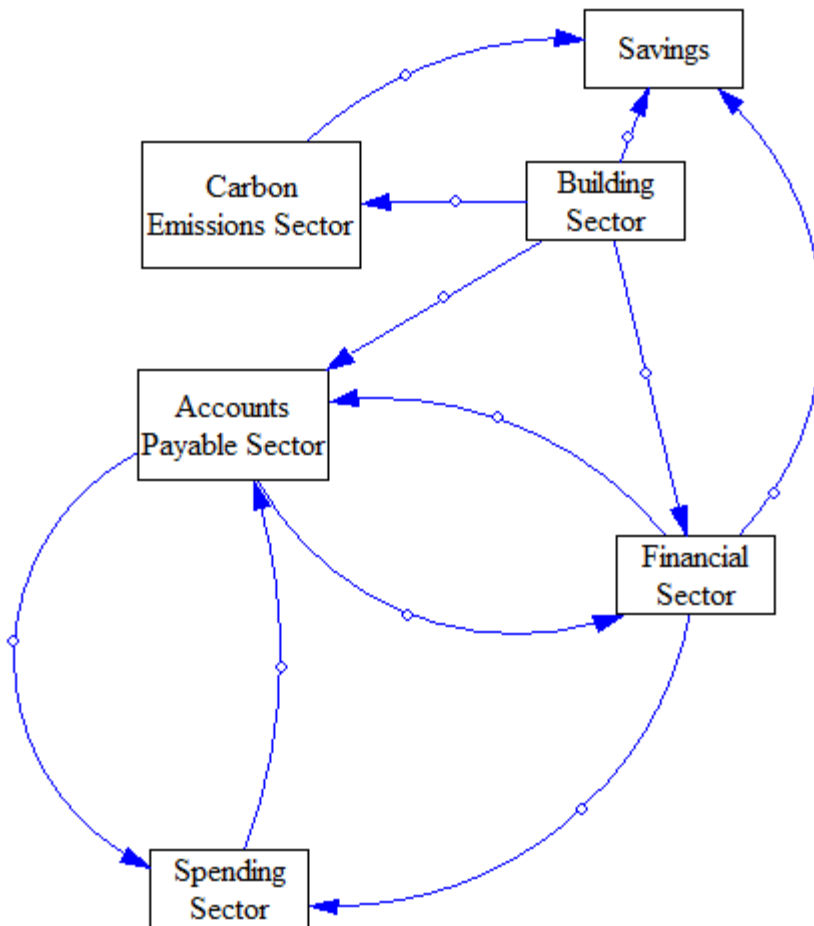


Figure 7 Sector Model

The building sector shapes the financial sector in terms of how much money needs to be borrowed in order to retrofit the remaining buildings. The financial sector then impacts the accounts payable sector in terms of when the scheduled debt repayment is, since that is a part of the overall amount that needs to be paid. Finally the financial sector affects the spending sector because the rate of borrowing in the financial sector counts towards the current amount of borrowed cash in the spending sector.

The spending sector consists of aspects such as the cumulative debt, money borrowed and the total cost. This sector essentially keeps track of the total spending. The spending sector then affects the accounts payable sector in terms of the overall liquidity value.

The accounts payable sector records the costs of retrofitting the buildings along with the general upkeep and maintenance of the buildings. This then in turn affects the spending sector such as when the scheduled payments are from the money borrowed. Additionally the accounts payable sector is not only affected by the number of retrofitted buildings, but it also affects the desired amount to borrow in the financial sector.

Accounts Payable Sector

The accounts payable sector keeps track of the costs associated with the buildings maintenance and upkeep, along with any added costs of retrofitting the building.

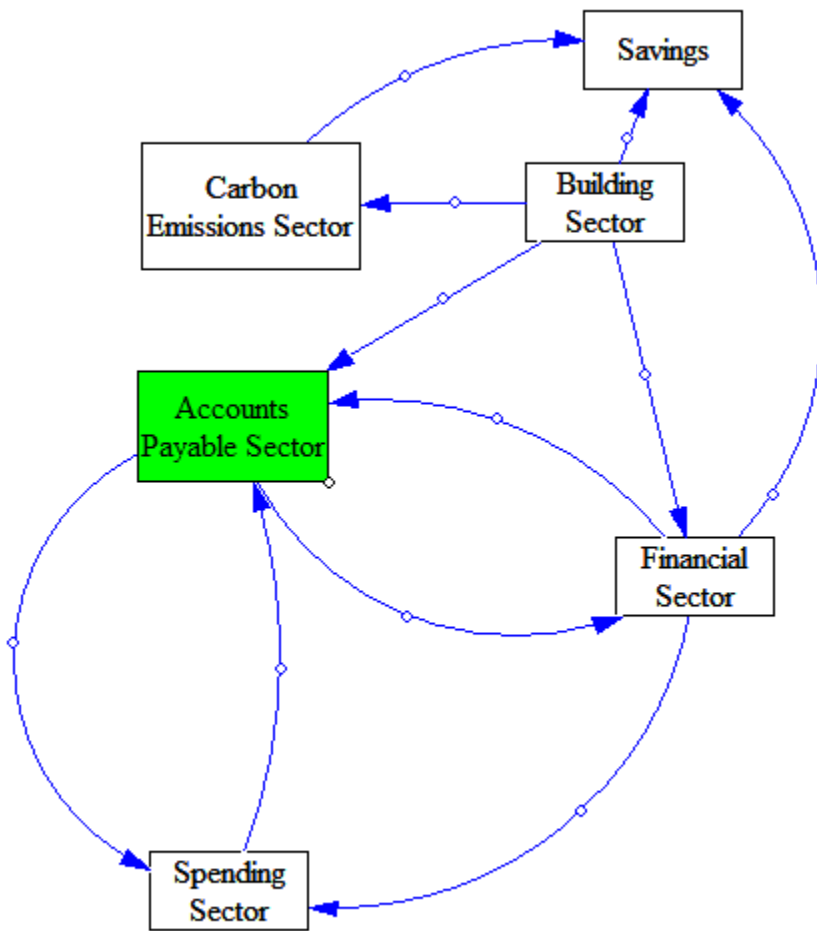


Figure 8: Sector Model: Accounts Payable

As seen in [Figure 9](#) there are 11 main equations for this model which will be explained in this section.

These equations allow us to see financially in terms of operation costs if due to the retrofitting if the cost of operation decreases.

Sum of the Spending

In order to determine that amount of money needed to support the operations of the buildings and retrofit them we will need to use Equation 1.

Equation 1: Sum of all the Spending

$$\text{sum up all the spending} = \text{INTEG (Accounts Payable Auditors + Accounts Payable Building maintenance + Accounts payable contractors + Accounts Payable Building Operations + Accounts Payable Raw Materials, 0)}$$

This Equation adds up all of the costs for hiring auditors, contractors, and supporting maintenance, operations and any materials that need to be bought. Essentially it adds all of the costs for not only retrofitting the building, but also the day to day costs. Additionally there is an aspect to this equation that keeps it from going below zero cost.

Scheduled Payments from Tax Revenue

We then look at the equation scheduled payments from tax revenue. This includes the day to day costs of a building along with the amount that is scheduled to be paid back for the bonds. This equation, Equation 2, is important because it will show the amount of money saved after buildings become energy efficient, essentially how much money it will save the tax payers.

Equation 2: Scheduled payments from tax revenue

$$\text{Scheduled payments from tax revenue} = \text{Scheduled Retired Accounts Payable Buildings Operation + Scheduled Debt repayment + scheduled Retired Accounts payable maintenance}$$

As seen above, this number is calculated through summing up the amount paid for building operations, the amount of debt from the bonds that must be paid back, along with the maintenance costs.

Scheduled Retired Accounts Payable Maintenance

For Equation 2 it is necessary to keep track of the retired accounts payable for the building maintenance. This includes such aspects of fixing something in the building when it breaks and keeping everything up to code.

Equation 3: scheduled Retired Accounts payable maintenance=

$$\text{Scheduled Retired Accounts payable maintenance} = \frac{\text{Accounts Payable Building maintenance}}{\text{Time to pay Accounts payable maintenance}}$$

In order to calculate this amount we made it a cost per year number by dividing it by the time to pay back.

Scheduled Retired Accounts Payable Buildings Operation

Likewise for Equation 2, Equation 4 is necessary to understand. The scheduled retired accounts for building operations include costs for electric and other bills that need to be paid. This is where a decrease should be seen after the buildings are retrofitted, since this account includes the cost of electricity.

Equation 4: Scheduled Retired Accounts Payable Buildings Operation

$$\text{Scheduled Retired Accounts Payable Buildings Operation} = \frac{\text{Accounts Payable Building Operations}}{\text{Time to pay Accounts Payable Buildings Operation}}$$

Looking at Equation 3 and Equation 4 are important because it shows the effect that the new policy will have of making the buildings more cost effect.

Retired Accounts Payable Buildings Operation

After looking at the scheduled payment for building operations, it is important to look at the equation dealing with the retired accounts, or the equation that pays the bill so to say. In this case it is

Equation 5.

Equation 5: Retired Accounts Payable Buildings Operation

$$\text{Retired Accounts Payable Buildings Operation} = \text{Effect of Liquidity on Accounts Payable Buildings Operation} * \text{Scheduled Retired Accounts Payable Buildings Operation}$$

In order to determine if the bill is able to be paid, the liquidity must be taken into account. This is important since if there is no cash the bill cannot be paid for and retired. If that number is something different than 1 the full amount of the bill will not be paid for.

Scheduled Payments from Borrowing

To calculate the payments from the amount borrowed it is necessary to sum up the money used from the borrowed debt. This model assumes that when money is borrowed it is automatically used.

Equation 6: Scheduled Payments from borrowing=

$$\text{Scheduled Payments from borrowing} = \text{Scheduled Retired accounts payable auditors} + \text{Scheduled Retired accounts payable contractors} + \text{Scheduled Retired Accounts Payable raw materials}$$

As seen in Equation 6 the variables that the borrowed money pays for are the auditors, contactors, and materials needed to retrofit the buildings. While there are many equations in this sector only a few were discussed because they have the same theory repeated for all of the retired accounts ect. A full list of the equations is listed in the Appendix.

Building Sector

The Building sector examines the actual implementation of the policy. The policy that is being executed in this model is to increase the energy efficiencies of state owned buildings in order to decrease carbon emissions. The aspects of paying back the bonds with the money saved and the overall effect on carbon emissions will be examined in other sectors.

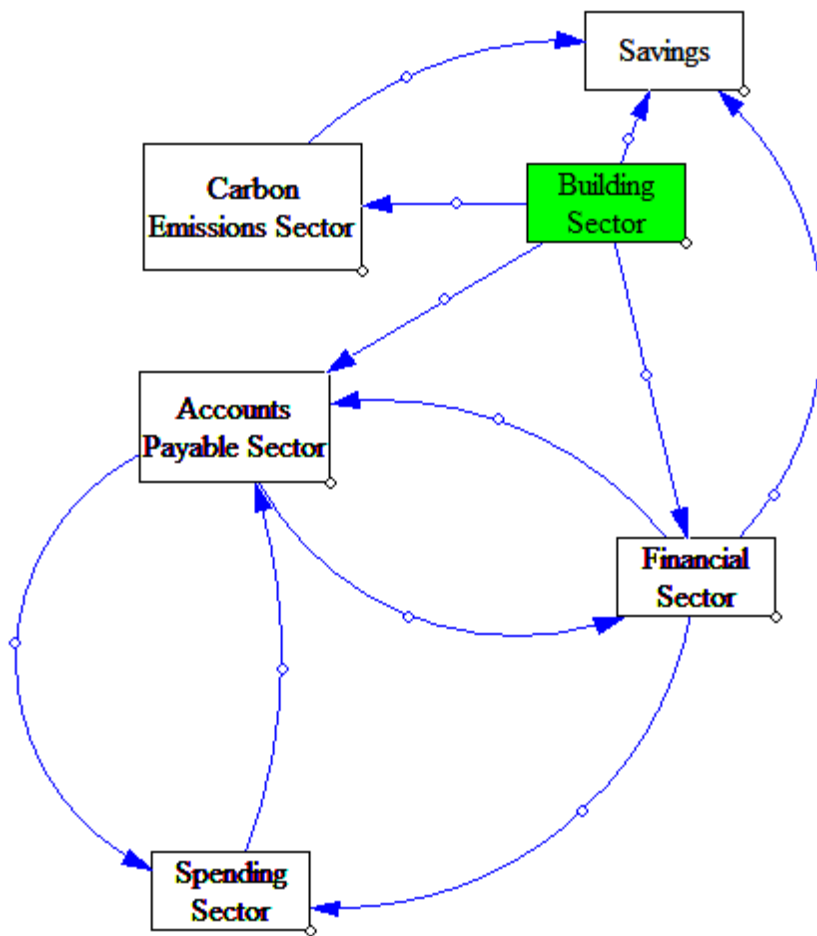


Figure 10: Sector Model Buildings

As seen in Figure 11 there are five main equations we will be examining in this section. Not only do these equations look at the buildings, but also deal with the number of auditors needed. Originally a concern expressed by the Sierra Club was that they were worried a lack of available auditors once there is an increase in demand by the state. However through research we found that it is not a long process to receive a certification to be an auditor. That means that the auditors, along with the construction workers who have a short education before they are able to build, are not a possible bottle neck in this model.

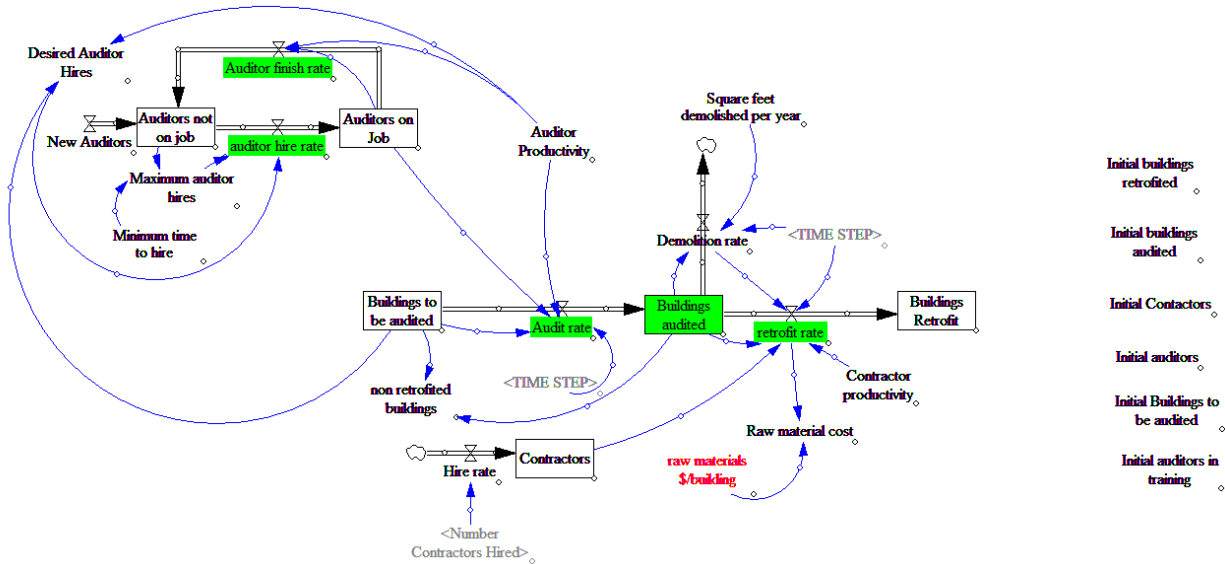


Figure 11: Building Sector

Auditor Hire Rate

In terms of the auditor hire rate, that expresses the amount of auditors that needs to be hired for the number of available jobs, which is expressed by Equation 7. To calculate the number of auditors to hire Vensim takes the desired Auditors Hires and the maximum auditors hires and finds the minimum of the two.

Equation 7: auditor hire rate

$$\text{auditor hire rate} = \min(\text{Desired Auditor Hires}, \text{Maximum auditor hires})$$

This way there are not too many auditors hired for the job. Additionally the way the equation was written keeps the number from going below zero.

Auditor Finish Rate

The Auditor finish rate is calculated so that the auditors are only hired for the amount of time they are used and then are essentially put back in the pool to be used for the next building.

Equation 8: Auditor finish rate

$$\text{Auditor finish rate} = \text{Auditors on Job} * \text{Auditor Productivity}$$

This was calculated as seen in Equation 8 by multiplying the number of auditors on the job by their productivity as the rate to be taken out once finished.

Audit Rate

Additionally to calculate the Audit rate we look at Equation 9.

Equation 9: Audit rate

$$\text{Audit rate} = \min(\text{Auditors} * \text{Auditor Productivity}, \text{Buildings to be audited} / \text{TIME STEP})$$

There we see that to calculate the audit rate the equation multiplies the number of auditors by their productivity and then compare that to the buildings to be audited divided by the time step. This equation is one of Fiddaman's first order control functions which will make sure the equation is robust.

Buildings Audited

Additionally to keep track of buildings audited is an important aspect. This stock keeps track of the number of buildings that need to be audited. Once a building is audited it is then removed from the stock and either demolished or retrofitted.

Equation 10: Buildings audited

$$\text{Buildings audited} = \text{INTEG}(\text{Audit rate} - \text{Demolition rate} - \text{retrofit rate}, \text{Initial buildings audited})$$

When determining the demolition rate a number was used based off of the average number of buildings demolished per year.

Retrofit Rate

The rate at which the buildings would be retrofitted took the difference between the number of buildings to be audited and those that are demolished. Those are then divided by the rate the contractors can work.

Equation 11: Retrofit rate

$$\text{Retrofit rate} = \min((\text{Buildings audited} - \text{Demolition rate} * \text{TIME STEP}) / \text{TIME STEP}, \text{Contractors} * \text{Contractor productivity})$$

This essentially makes the number of contractors a constraint of how many buildings can be retrofitted at any given time.

Spending Sector

The spending sector interacts mainly with the accounts payable sector and the financial sector. As seen in Figure 12.

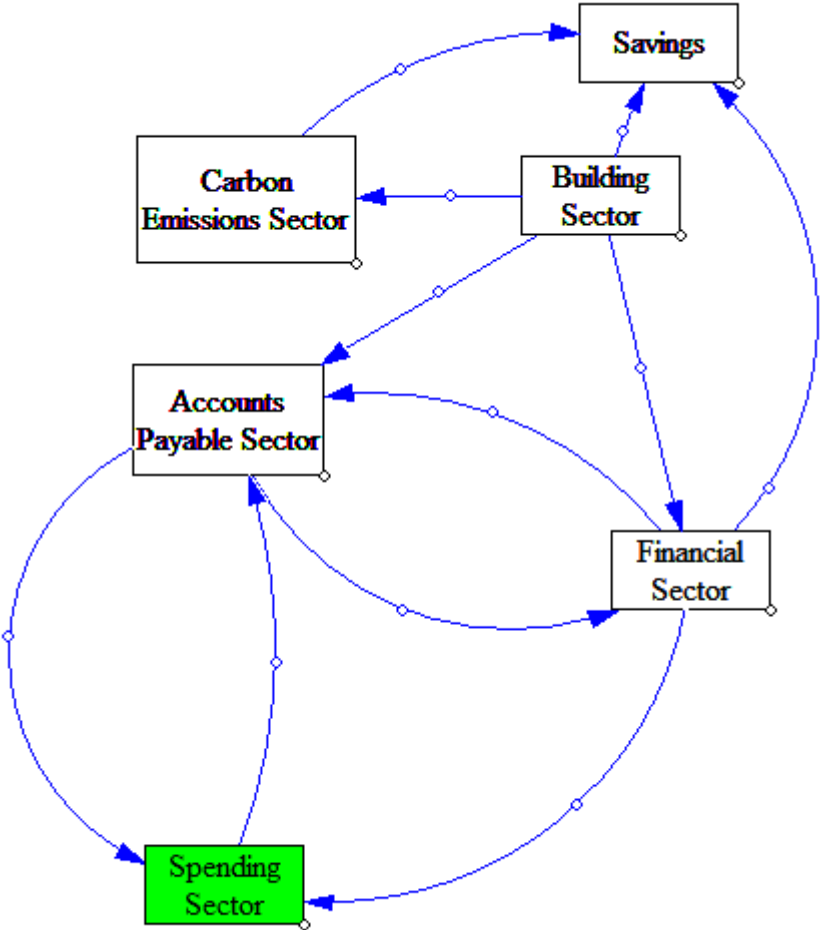


Figure 12: Sector Model Spending

The spending sector examines the cumulative debt, costs, liquidity, and borrowed cash in the system as seen in Figure 13 as the highlighted variables.

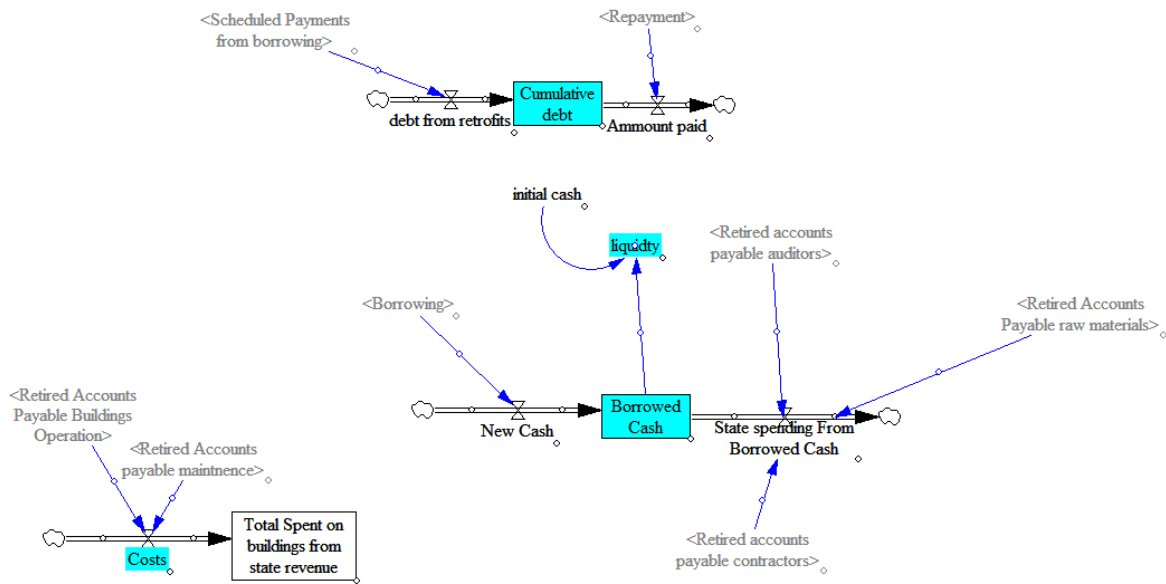


Figure 13: Spending Sector

Costs

When looking at the flow of cost into the “total spent on buildings from state revenue” the equation that produces that stock is Equation 12.

Equation 12: Costs

$$\text{Costs} = \text{Retired Accounts Payable Buildings Operation} + \text{Retired Accounts payable maintenance}$$

Through adding the amount paid for building operations and the maintenance repairs it produces the cost of upkeep and running the buildings. This allows the user to see if once a building becomes more energy efficient if the base costs decrease.

Borrowed Cash

It is also important to note the equation used to determining the borrowed cash. In order to find this number we used Equation 13.

Equation 13: Borrowed Cash

$$\text{Borrowed Cash} = \text{INTEG}(\text{New Cash} - \text{State spending From Borrowed Cash}, \text{initial cash})$$

This equation integrates the difference between the rates of new cash, minus the state spending from the cash borrowed starting at the initial amount the state had borrowed.

Cumulative Debt

It is then necessary to examine the cumulative debt. This is an important value to be aware of because it shows the state's current standing in paying off its debt as seen in Equation 14.

Equation 14: Cumulative debt

$$\text{Cumulative debt} = \text{INTEG} (\text{debt from retrofits} - \text{Amount paid}, 0)$$

This equation integrates the difference between the debts from retrofitting the building and the amount paid back. This allows us to be aware of when and how long it will take to pay back the full amount.

Liquidity

Another important aspect of paying back the debt is being aware of the states liquidity. Liquidity is, "The ability to convert an asset to cash quickly " (Investopedia). So it shows the ability of the state to pay back its loans, based on how liquid it is, or the amount of cash they have.

Equation 15: liquidity

$$\text{liquidity} = \text{Borrowed Cash} / \text{initial cash}$$

We calculated liquidity by dividing the borrowed cash by the initial cash. These equations are important because they keep track of the amount of money spent.

Financial Sector

In the financial sector you will see that the main point of it is to keep track of the amount of debt accrued because of the bonds being taken out and to determine how many bonds need to be taken out too.

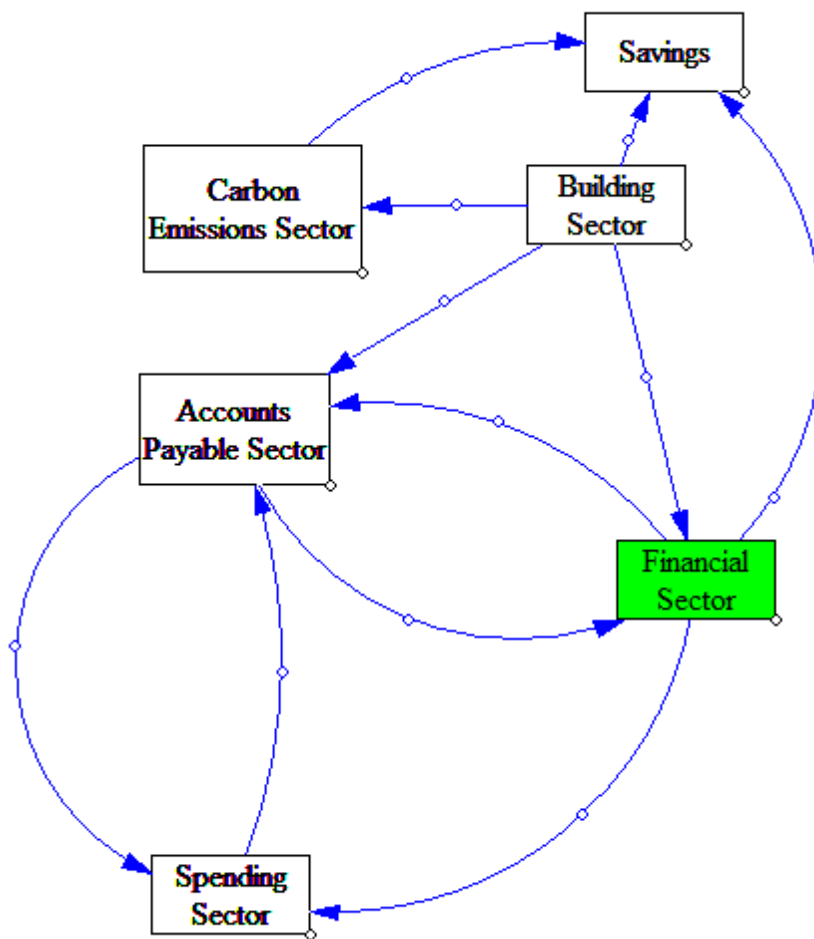


Figure 14: Sector Model Financial

As seen in Figure 15 we will be examining the debt, change in maturity for the bonds and the change in the average interest rate.

Debt

To calculate the debt Vensim finds the sum of the variables borrowing and interest generated, this is necessary because it is the true amount that is owed. It then subtracts the amount paid and integrates; this is all based off of the initial debt which our model has starting at zero.

Equation 16: Debt

$$\text{Debt} = \text{INTEG} (\text{Borrowing} + \text{Interest Generated} - \text{Repayment}, \text{Initial Debt})$$

Equation 18: Change in maturity

$$\text{Change in maturity} = (\text{current maturity} - \text{Average Maturity rate}) * \text{Fractional Borrowing Rate}$$

As seen in Equation 18 the change of maturity follows the same structure as the equation for change in interest rate because they are the same process for different aspects of the model.

Carbon Emissions Sector

The Carbon Emissions Sector is an important part which give us incite into the effectiveness of making the state owned buildings energy efficient has on the environment.

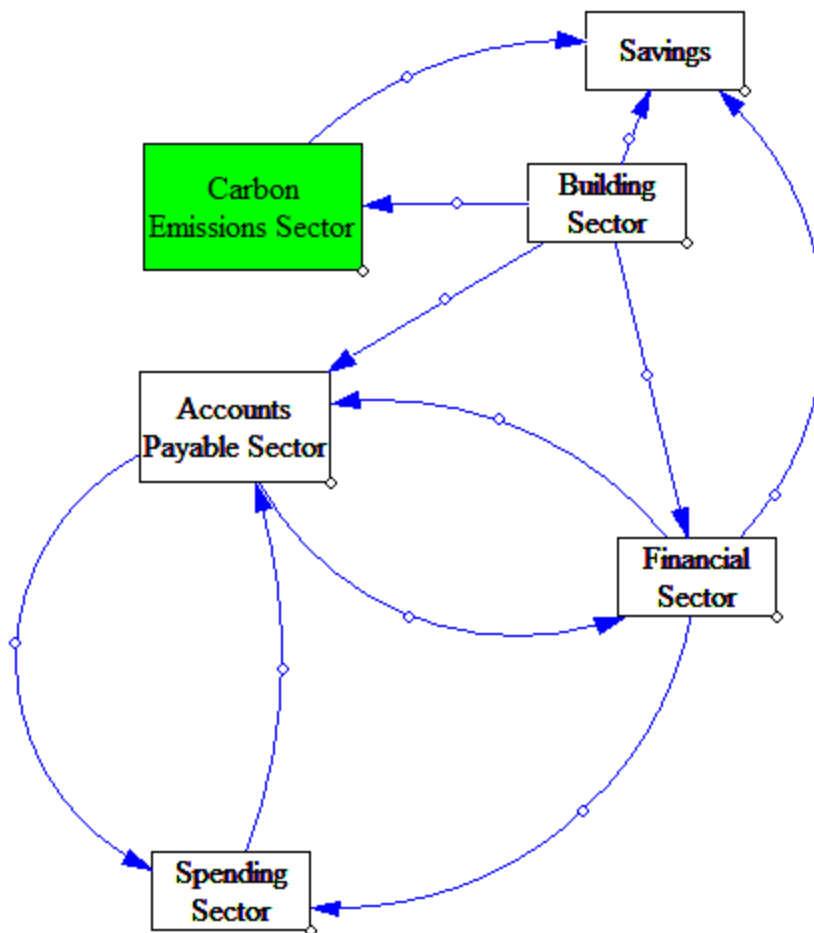


Figure 16: Sector Model Carbon Emissions

As seen below in Figure 17 the carbon emissions sector not only looks at the environment, but how decreasing the carbon emissions affects the health care sector too.

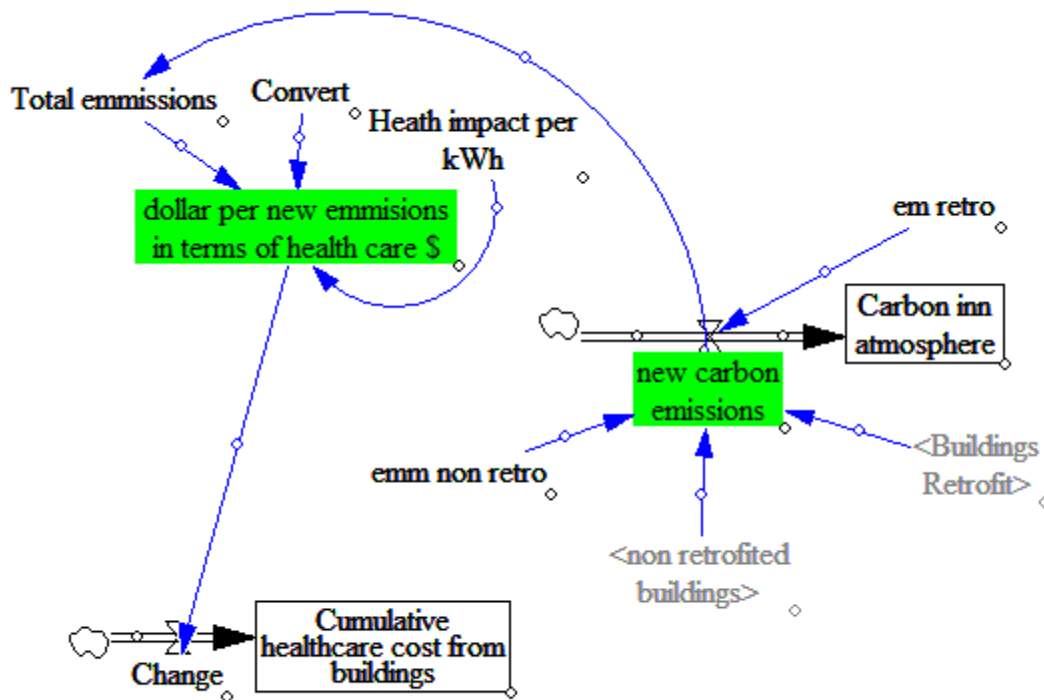


Figure 17: Carbon Emissions Sector

Dollar per New Carbon Emission In Terms Of Health Care Dollars

When looking at the overall effect of savings of this program it is important to see the savings in terms of health care are too. The equation to determine this is Equation 19. In order to determine the “dollar per new emissions in terms of health care \$ we divided the health impact, which is in dollars/kilowatt hours by a converting factor in order to have it in terms of Dollars per lbs of CO2. This number is then multiplied by the emissions of CO2 which is measures in lbs CO2 per square. This in the end will tell us the cost of health based on the emissions in terms of dollar per square foot.

Equation 19: dollar per new emissions in terms of health care \$

$$\text{dollar per new emissions in terms of health care \$} = \text{Heath impact per kWh} / \text{Convert} * \text{Total emissions}$$

This allows us to graph this over time and see if there is substantial decrease overtime.

New Carbon Emissions

In addition to the healthcare cost Equation 20 examines the new carbon emissions. The reason we are not looking at the total carbon emissions is because the goal of the policy change is to lower the amount of carbon buildings emit, not to also subtract previous emissions.

Equation 20: new carbon emissions

$$\text{new carbon emissions} = \text{Buildings Retrofit} * \text{emissions of retrofitted buildings} + (\text{non retrofitted buildings} * \text{emissions of non retrofitted buildings})$$

As you can see in Equation 20 in order to calculate the new CO2 emissions we took the number of buildings retrofitted and multiplied them by the average emission rate for a building that is retrofitted and added that to the product of the emission rate of a non retrofitted building and the average emission rate for a building that has not been retrofitted. Much like tracking health care cost we will be able to graph this overtime and see if the general trend decreases substantially.

Savings

The savings sector will be examining if the savings in energy costs will cover the costs of the retrofit.

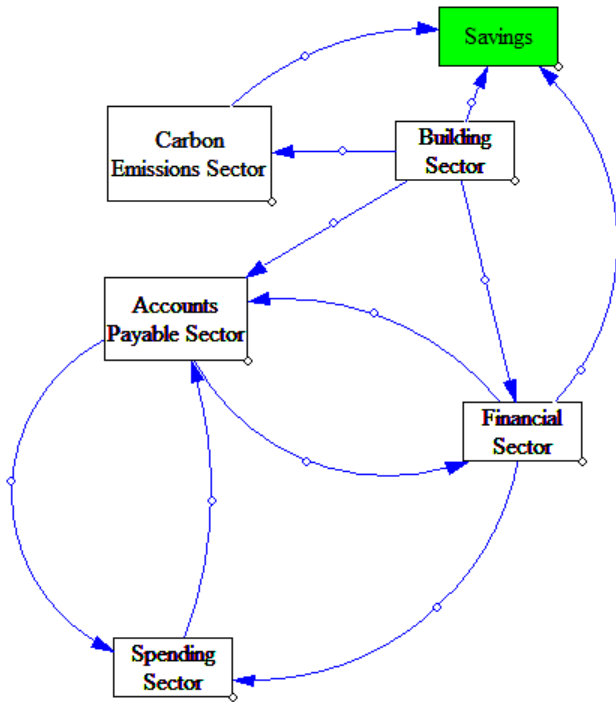


Figure 18: Sector Model Savings

This portion of the model which is seen in Figure 19 allows us to see if the costs associated with retrofitting are offset by the energy savings.

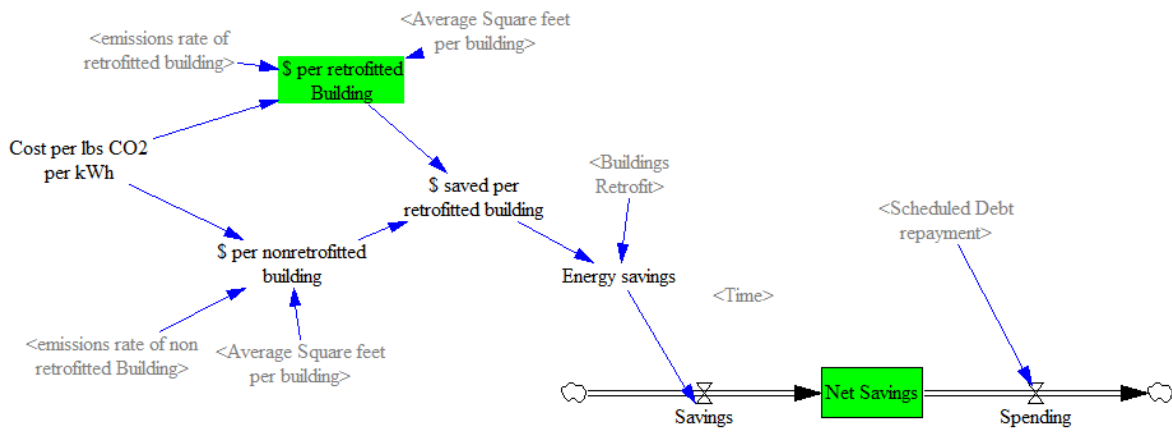


Figure 19 Savings Sector

To calculate this we looked at certain aspects such as the amount of carbon emission emitted from a retrofitted building and then use that information along the number of retrofitted building to calculate \$ per retrofitted Building as seen in Equation 21: \$ per retrofitted Building.

Equation 21: \$ per retrofitted Building

"\$ per retrofitted Building" = Average Square feet per building * Cost per lbs CO2 per kWh * emissions rate of retrofitted building

This information is then used to calculate net saving.

Equation 22: Net Savings

Net Savings = INTEG (Savings - Spending, 0)

Through looking at then net savings it shows if the policy put in place has savings equal or greater to zero.

Tests and Results

After creating the model it was necessary to go through and test different situations in the model. In total there were 30 variables that were able to be adjusted to be adjusted as seen in Table 2.

Table 2: Variables and Initial Values

Variable	Unit	Original Value
Auditor Productivity	Units: buildings/auditor/year	2.00
Average maintenance costs	Units: \$/year	10000.00
Average operation costs	Units: \$/year	100.00
Contractor productivity	Units: buildings/year	100.00
Contractor's hourly wage	Units: \$/year	20000.00
Current Interest Rate	Units: Fraction/year	step
Current Maturity of bonds	Units: year	0.08
FINAL TIME = 50	Units: year	50.00
Fraction Borrowed	Units: Dmnl	1.00
Heath impact per kWh	Units: \$/kWh	0.14
Initial auditors	Units: auditors	10.00
Initial Buildings to be audited	Units: buildings	0.00
initial cash	Units: \$	100000.00
Initial Contactors	Units: Workers	4.00
Initial Debt	Units: \$	0.00
New Auditors	Units: auditors/year	200.00
Number Contractors Hired	Units: workers	1000.00
Utility rate non retro	Units: \$/year	3000.00
Utility rate retro	Units: \$/year	1000.00
people years	Units: auditors/year	5.00

After reviewing the list however, it made the most sense to adjust only the variables in Table 3. This table shows the variable, the value used in the base run and then the high and low value that was used to see the sensitivity of the variable in the model. The sensitivity refers to the impact of changing a value has on the whole system. The benefit of checking the sensitivity is that it shows that aspects of the model that have the biggest impact so that you can make policy changes that affect those aspect to truly effect the model rather than writing a policy about one that has little impact.

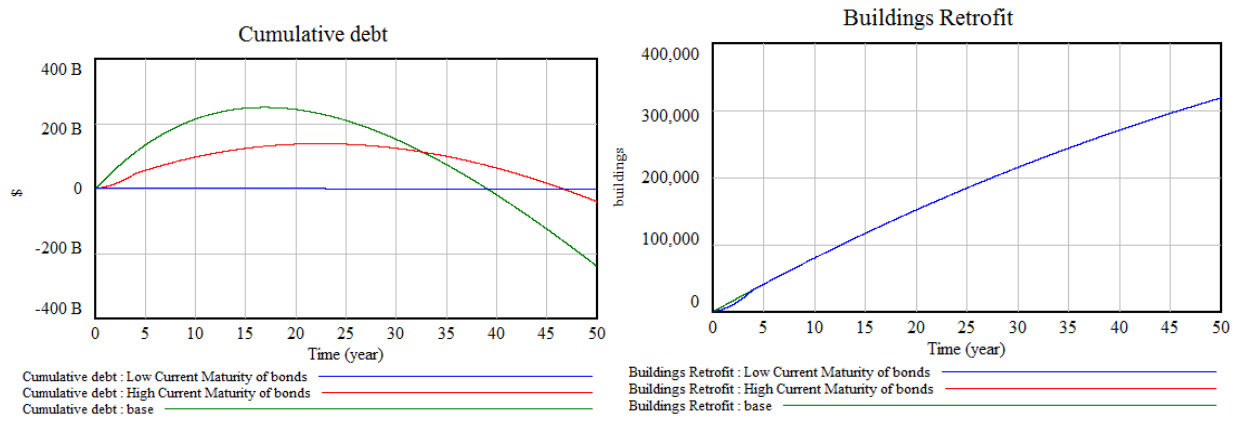
Table 3: Changed Variables

Variable	Base Value	High Value	Low Value	Other
Auditor Productivity	125.00	175.00	75.00	-
Contractor productivity	6.00	8.00	4.00	-
Contractor's hourly wage	69,870.00	90,000.00	50,000.00	-
Current Interest Rate	0.04	0.06	0.02	.02-.06
Current Maturity of bonds	0.08	1/24	20.00	1-20
Initial auditors	1,000.00	1,200.00	800.00	-
Initial Buildings to be audited	500,000.00	1,000,000.00	200,000.00	-
initial cash	100,000.00	500,000.00	50,000.00	-
Initial Contactors	400.00	600.00	300.00	-
New Auditors	200.00	250.00	150.00	-
Number Contractors Hired	500.00	800.00	400.00	-
people years	1.00	2.00	0.50	-

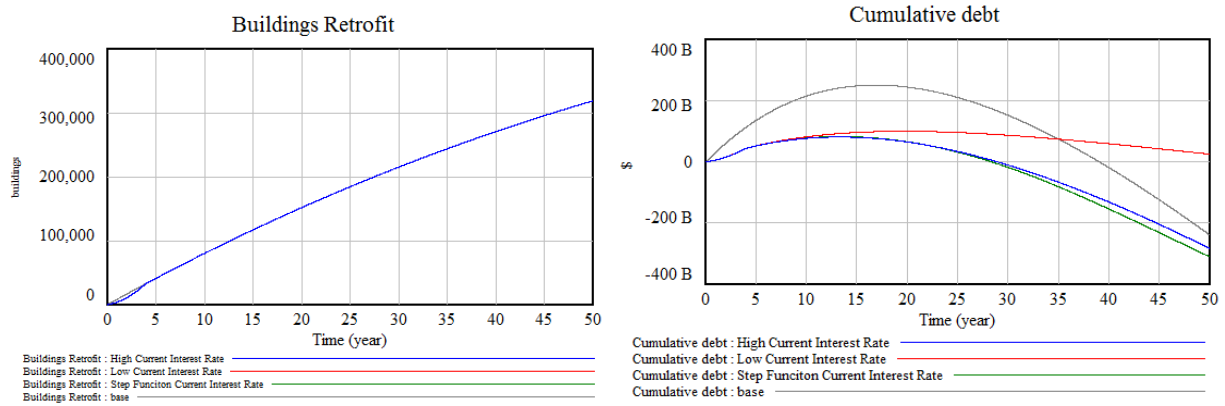
Upon completing all of these tests, they were then compared in terms of the cumulative debt and Buildings Retrofit to see which variables had the greatest impact on those two areas. The reason the Cumulative Debt and Retrofitted Buildings were the two areas looked at is because they are important on a state level to determine if this is a good financial decision and to see how long of a project they were undertaking.

The three top results, as seen in the graph below were Current Interest Rate, Current Maturity of Bonds, and People Years.

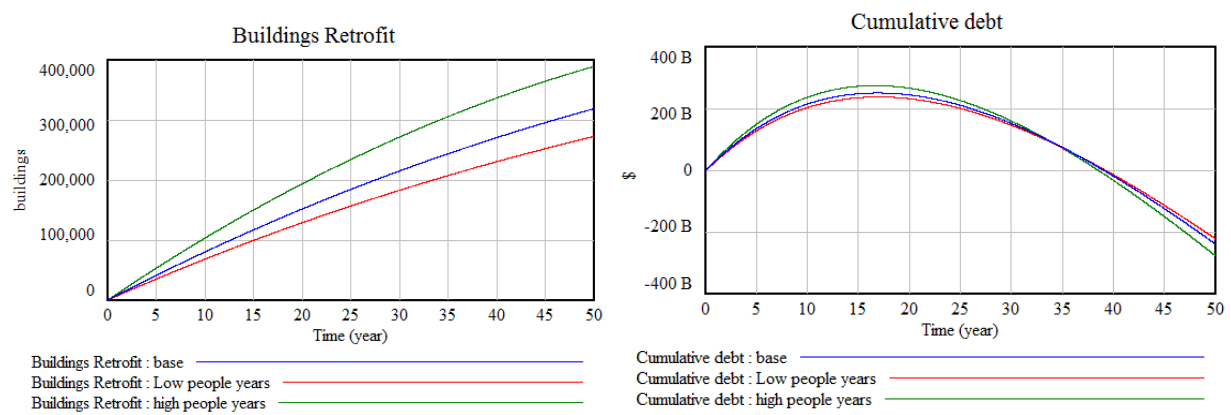
Current Maturity of Bond



Interest Rate



People Hours



The rest of the results can be seen in Appendix A-Results.

Additional information found from our results is:

1. The number of contractors and auditors available did not significantly impact the retrofitting of the buildings.
2. The amount of people hours did effect the number of buildings that were retrofitted

The following tests were then created to see which combination of these variables would have the greatest impact on the environment in addition to cumulative debt and buildings retrofitted.

Table 4: Final Tests

Variables Changed	Test 1	Test 2	Test 3
Auditor Productivity	125.00	125.00	125.00
Contractor productivity	6.00	6.00	6.00
Contractor's wage	69,870.00	69,870.00	69,870.00
Current Interest Rate	Step	0.04	Step
Current Maturity of bonds	step	0.08	Step
Initial auditors	1,000.00	1,000.00	1,000.00
Initial Buildings to be audited	500,000.00	500,000.00	500,000.00
initial cash	100,000.00	100,000.00	100,000.00
Initial Contactors	400.00	400.00	400.00
New Auditors	200.00	200.00	200.00
Number Contractors Hired	500.00	500.00	500.00
people years	3.00	3.00	1.00

Of these tests these were again the top three results based off of the same criteria of our previous test.

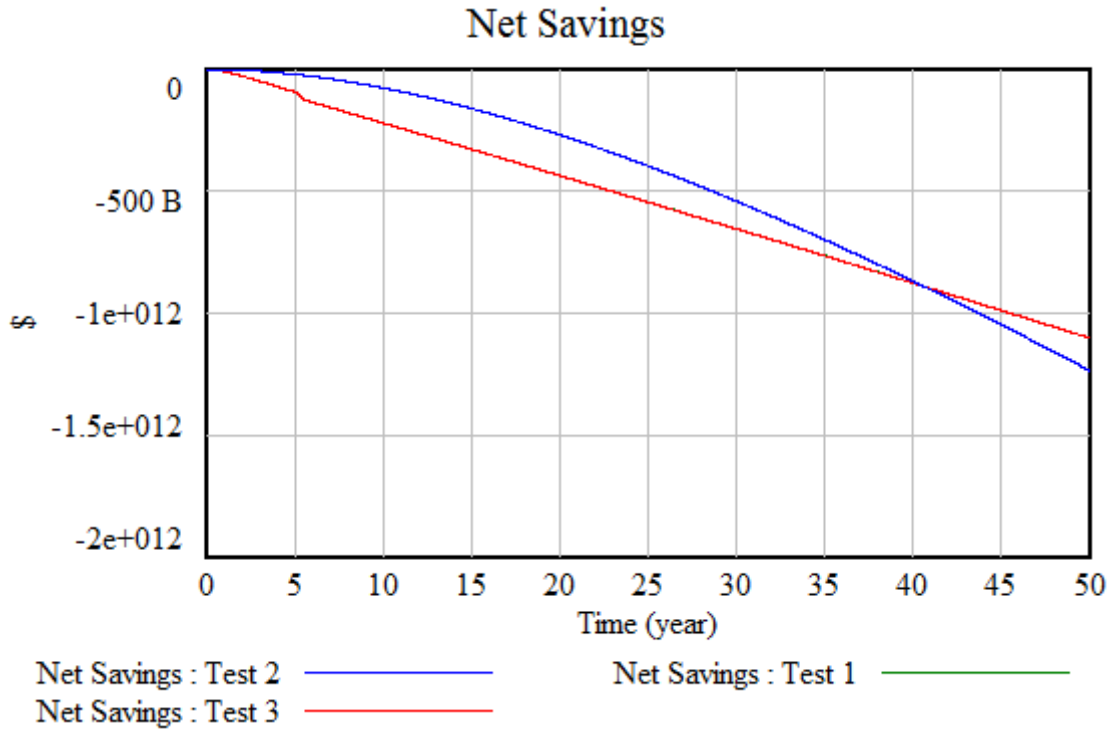


Figure 20: Results Net Savings

It is important to look at Net Savings when examining the 3 policies. Figure 21: Results Buildings Retrofit shows that test 1 and 3 (also known as policy 1 or 3) has the same effect on net savings. While policy 2 has greater savings than policy 1 and 3 by year 50 policies 1 and 3 have the greater amount of savings. In essence this tells us that policies 1 and 3 will have higher savings in the long run than policy 2.

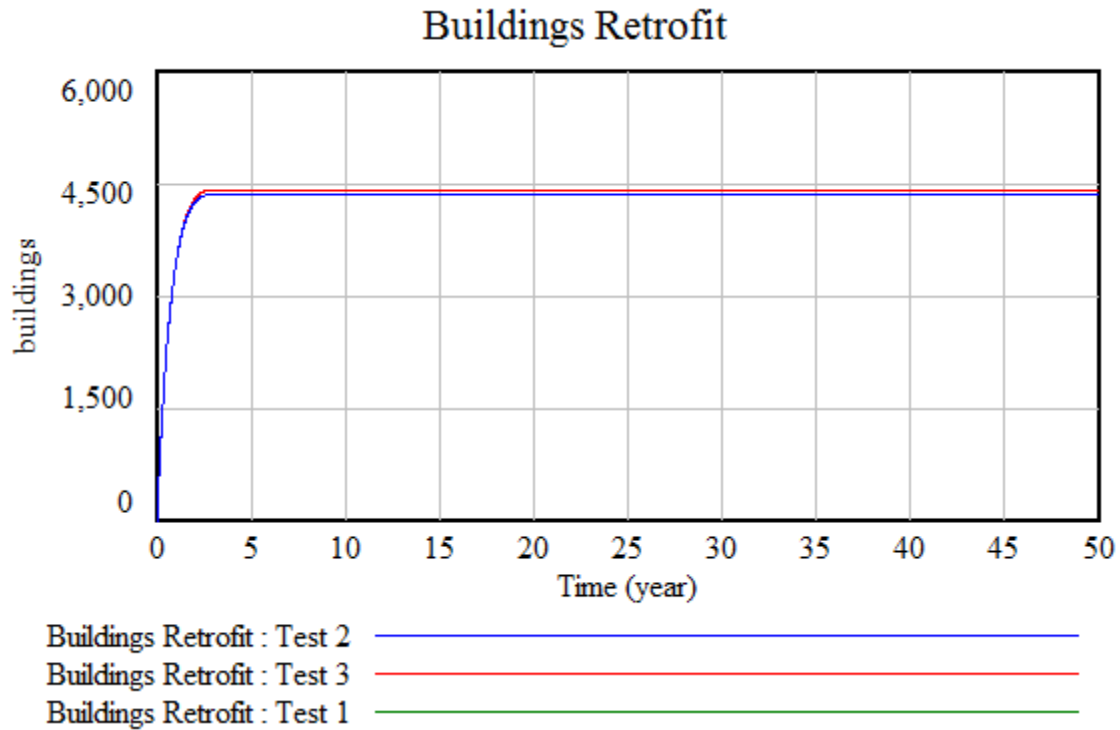


Figure 21: Results Buildings Retrofit

Examining the buildings retrofitted is important to show if a variable that has been changed slows down the rate of buildings being retrofitted compared to another policy. When looking at the three policies, in terms of buildings retrofitted, the results are similar enough that the time taken before all of the buildings are retrofitted that this is not a determining factor.

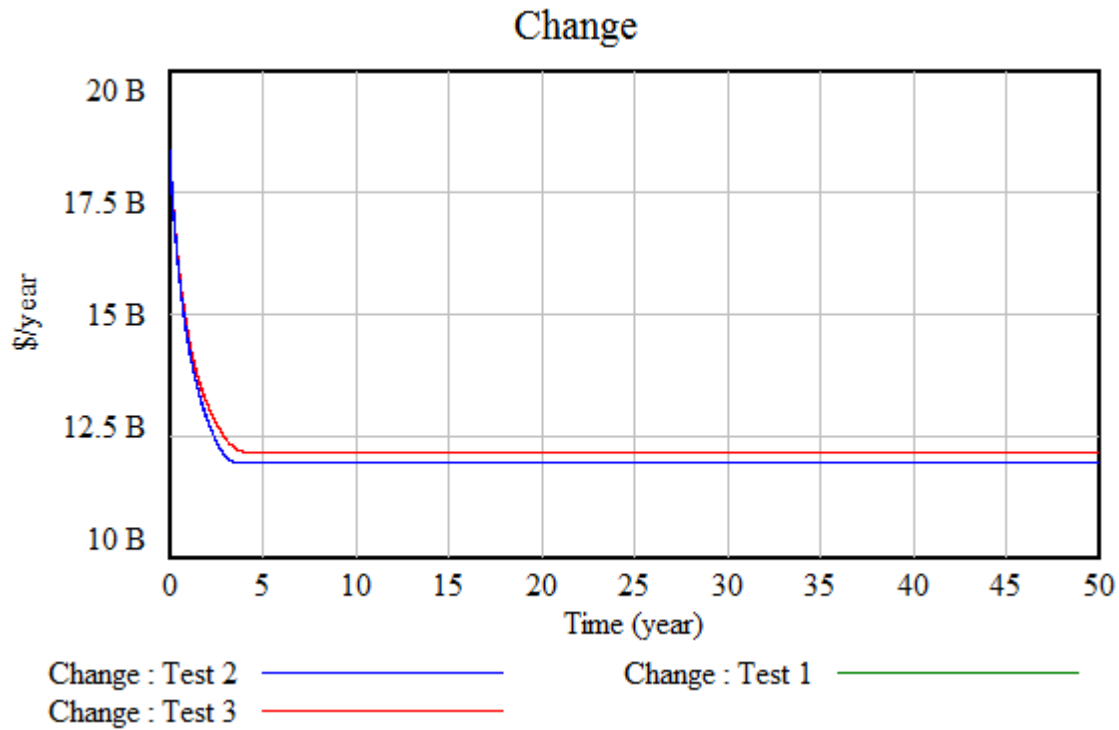


Figure 22: Results Change in environmental health care costs

Change in this graph refers to the change in the costs of healthcare. As seen in Figure 22: Results Change in environmental health care costs the initial healthcare costs starts around 17.5 Billion dollars per year and then drop to around 12 billion. However as seen in the graph policy 2 has a greater affect on the change in healthcare costs than policies 1 and 3.

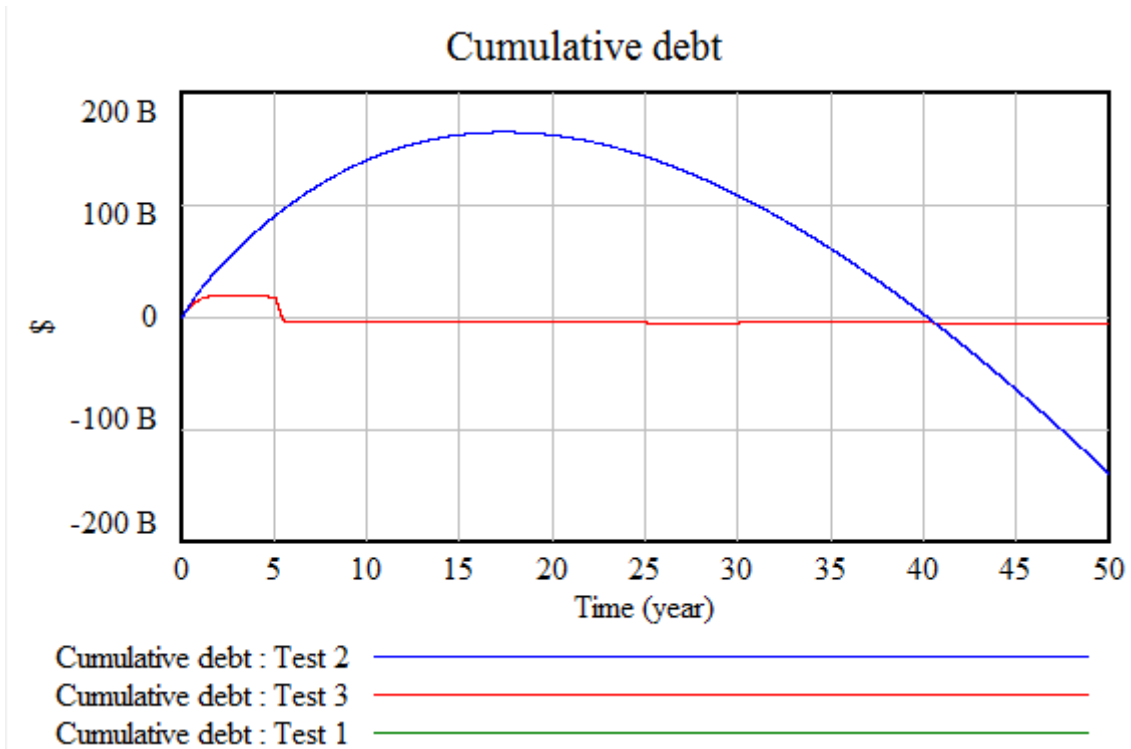


Figure 23: Results Cumulative Debt

When examining the cumulative debt in the short term Policy 2 has a greater amount of cumulative debt in the short term than tests 1 and 3. However, in the long run Policy 2 will have negative cumulative debt. Overall each of the options has its positive and negative points. In general options 1 and 3 produce the same results while option 2 creates more cumulative debt.

Recommendation

The general recommendation is for policy 1 or 3 to be put in place. The reason for this decision is because they both create the least amount of cumulative debt in the short-term. In the current economic state, while being energy efficient is important, being able to accomplish this with the least amount of cost is fundamental to this policy being enacted. So while it makes more sense in the long term to use policy 2, policy 1 and 3 will be easier to fund.

While there is very little difference between the amount of carbon Policies 1 and 3 produce versus the policy 2., there is a difference in the variables 1 and 3.

Policy 1 calls for a higher number of people hours, which results in more auditors being hired, while policy 3 does not affect the number of people hours. For this reason it makes more sense to go with option one since more people hours requires a greater rate of hire that will employ more individuals, which is better for the state since less people will need unemployment aid.

The added amount of auditors used will have many added benefits. In addition to fewer people needing unemployment aid, the state will also gain revenue from the income tax they will receive from those employed along with spurring the economy for local businesses since the newly employed will be able to spend money on goods and services.

Conclusion

Overall the results of this paper have led to the recommendation of policy 3. This is the best option because the debt is able to be repaid, however not purely based off of energy savings.

While the results of this model do not look particularly promising, I believe it is due to the fact that there are still many avenues left to examine for energy savings. The first would be to expand the model to incorporate more information on the retrofitting process and to meet with auditors and contractors to discuss potential financial benefits to retrofitting a building, that were not included in this model. Finally talking with an energy performing contracting group to discuss what they base their models off of would help to uncover even more ways to fine tune the model.

Along with savings in electric energy costs there are also other energy types to examine. Adding green energy sources into the model could increase the amount of savings to counter act the costs. Additionally adding these energy sources to the retrofitting would increase not only the number of people needed to construct it, but also lower the carbon emissions.

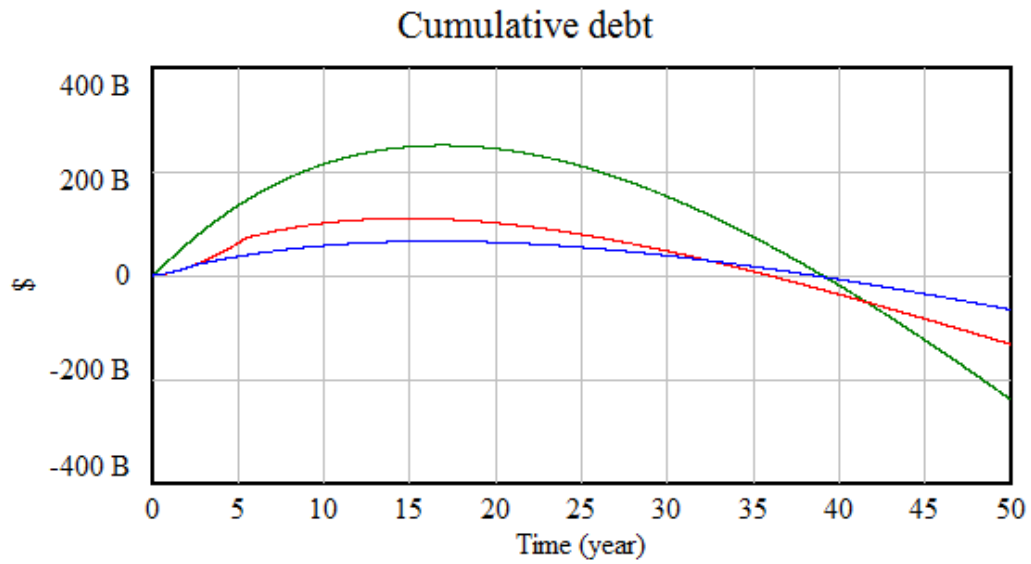
In terms of expanding the model from just state owned buildings, it could be used as a platform for creating a System Dynamics model to look at the effects of retrofitting specific types of buildings such skyscrapers or other privately owned buildings. Additionally adding a tax rebate plan for privately owned companies would allow this model to be used for exploring potential ways to expand this model to not only apply to state owned buildings.

Finally adding a sector to this model to show the effects of these policy changes on the labor force will benefit the user of this model to see the various ways money is saved from implementing one policy; One of these benefits being with the additional profit that the government gains through revenue from jobs versus the loss of providing unemployment.

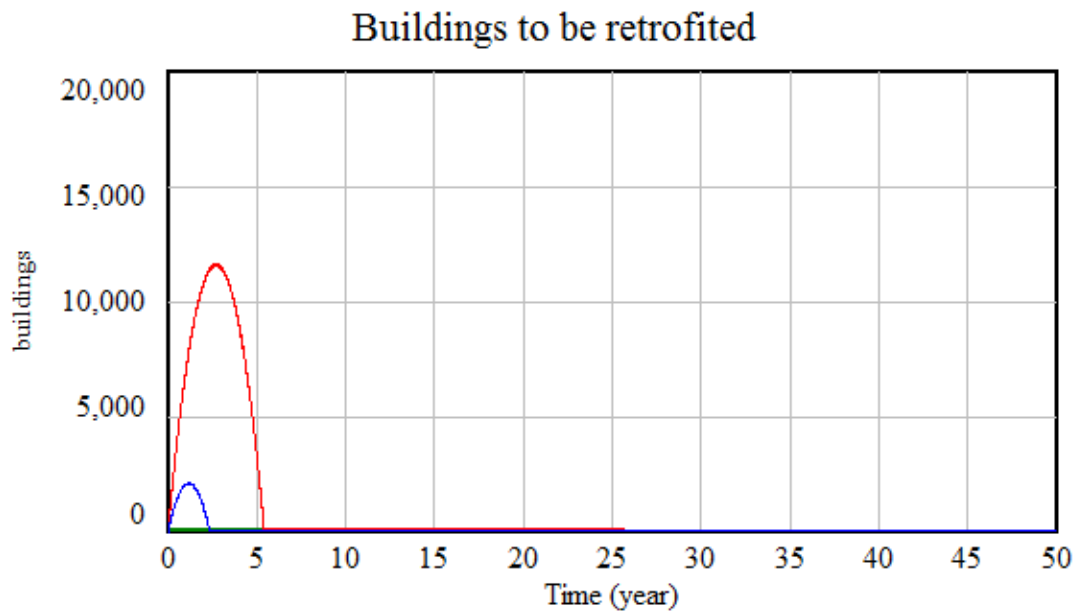
Appendix

Appendix A-Results

Auditor Productivity



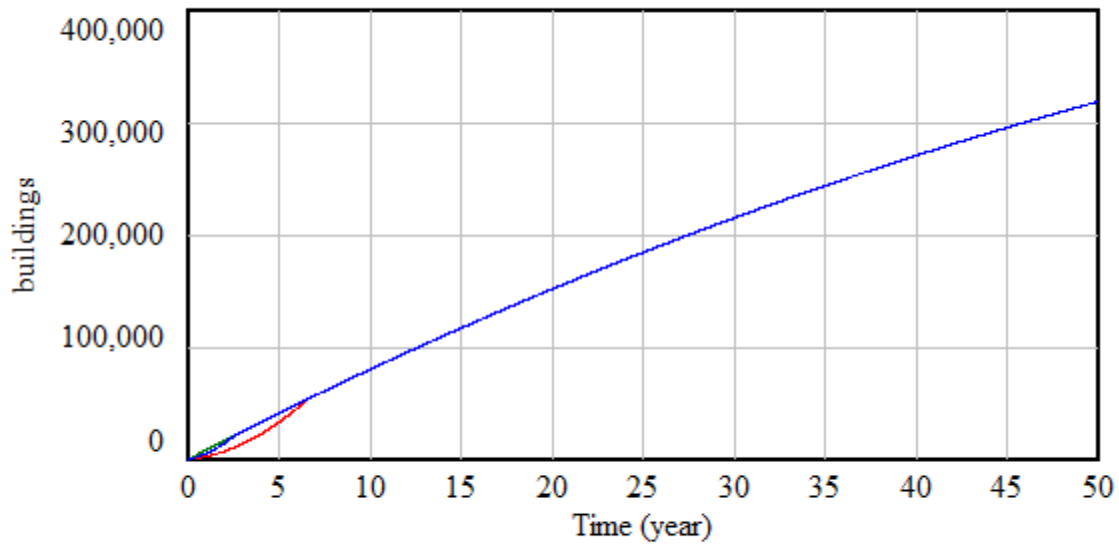
Cumulative debt : Low Auditor Productivity —————
Cumulative debt : High Auditor Productivity —————
Cumulative debt : base —————



Buildings to be retrofited : Low Auditor Productivity —————
Buildings to be retrofited : High Auditor Productivity —————
Buildings to be retrofited : base —————

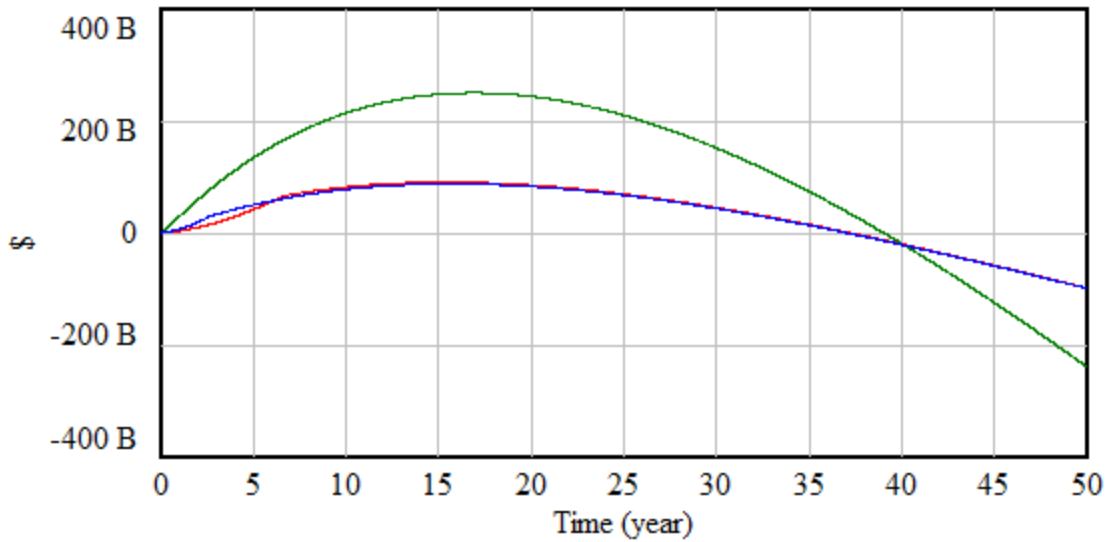
Contractor Productivity

Buildings Retrofit



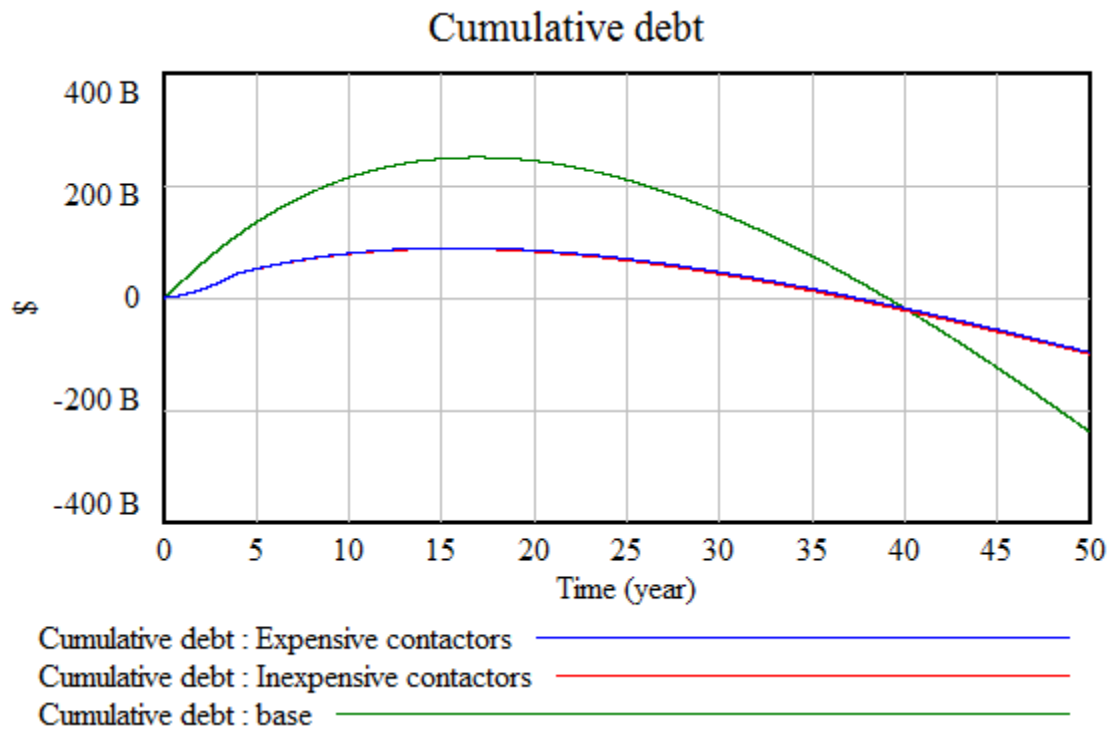
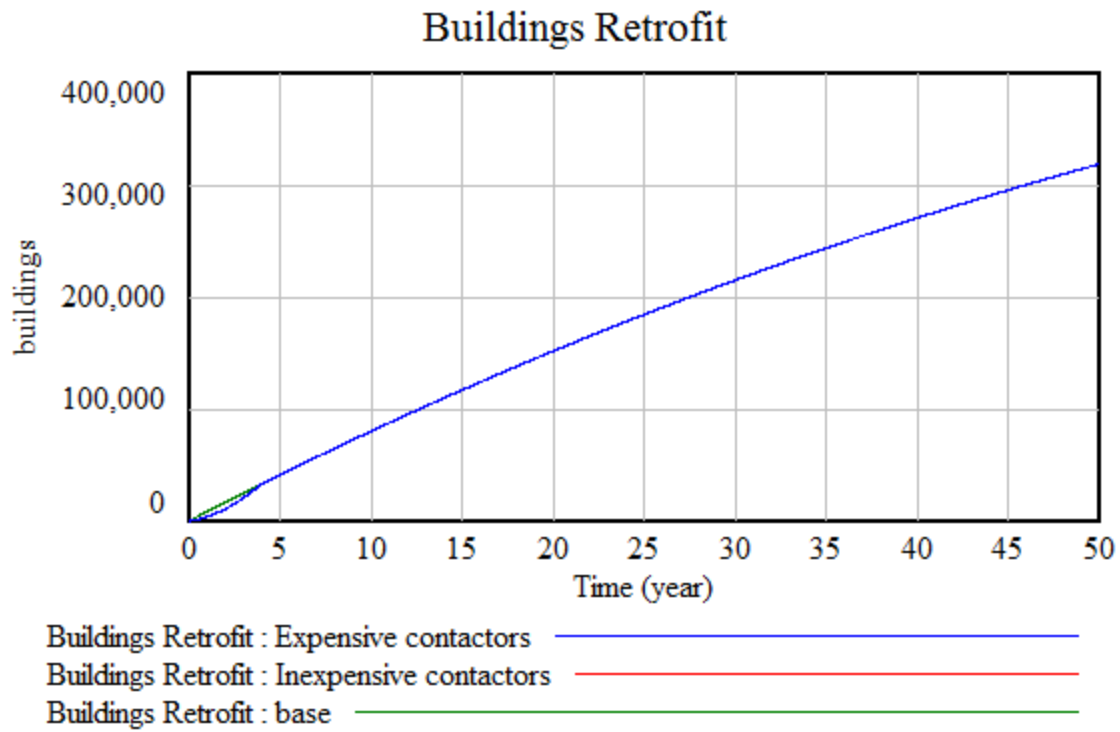
Buildings Retrofit : High Contractor Productivity —————
Buildings Retrofit : Low Contractor Productivity —————
Buildings Retrofit : base —————

Cumulative debt

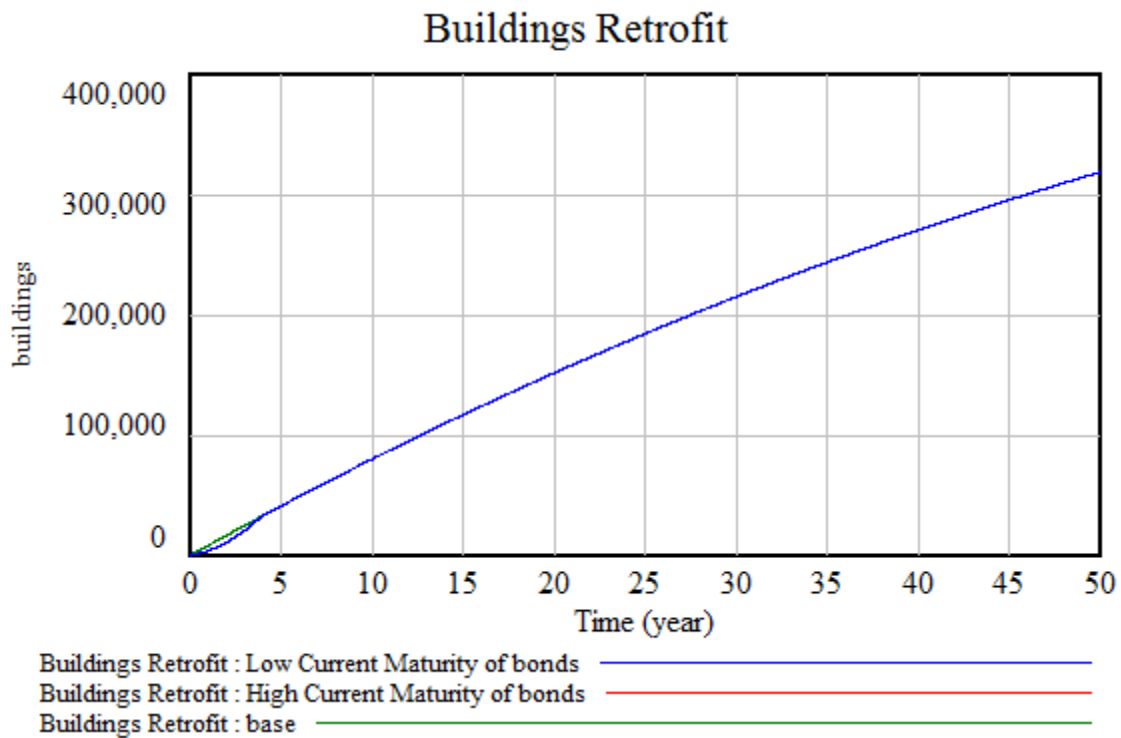
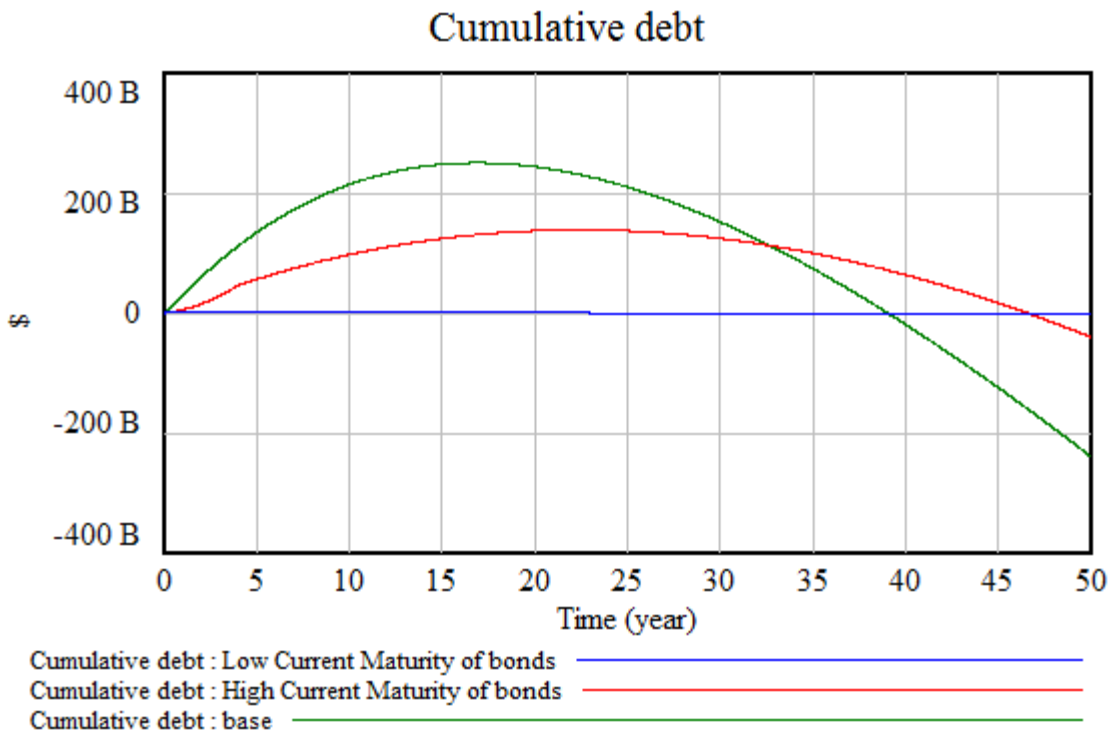


Cumulative debt : High Contractor Productivity —————
Cumulative debt : Low Contractor Productivity —————
Cumulative debt : base —————

Contractor Wage

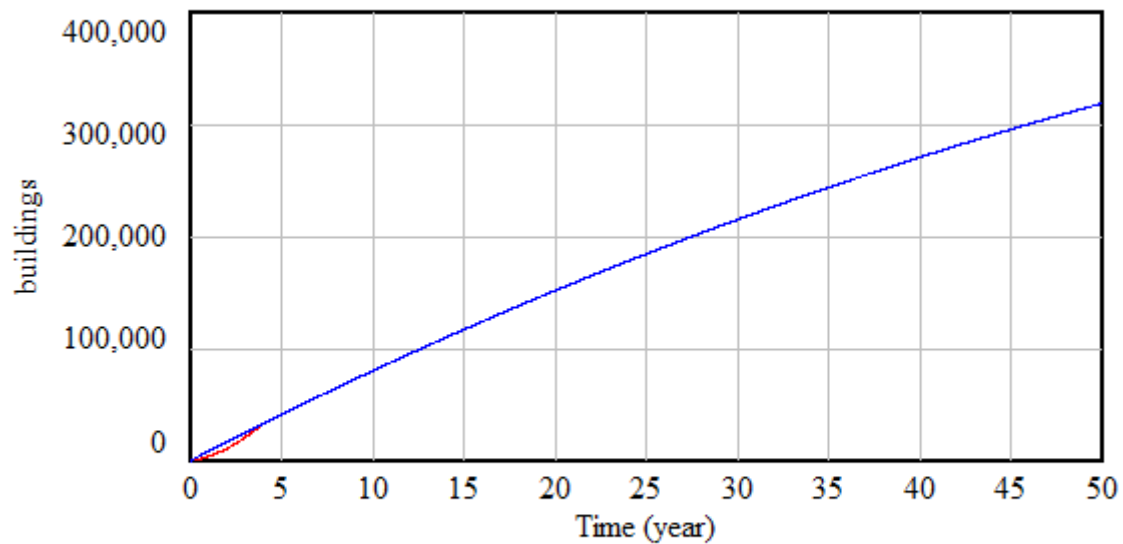


Current Maturity of Bond



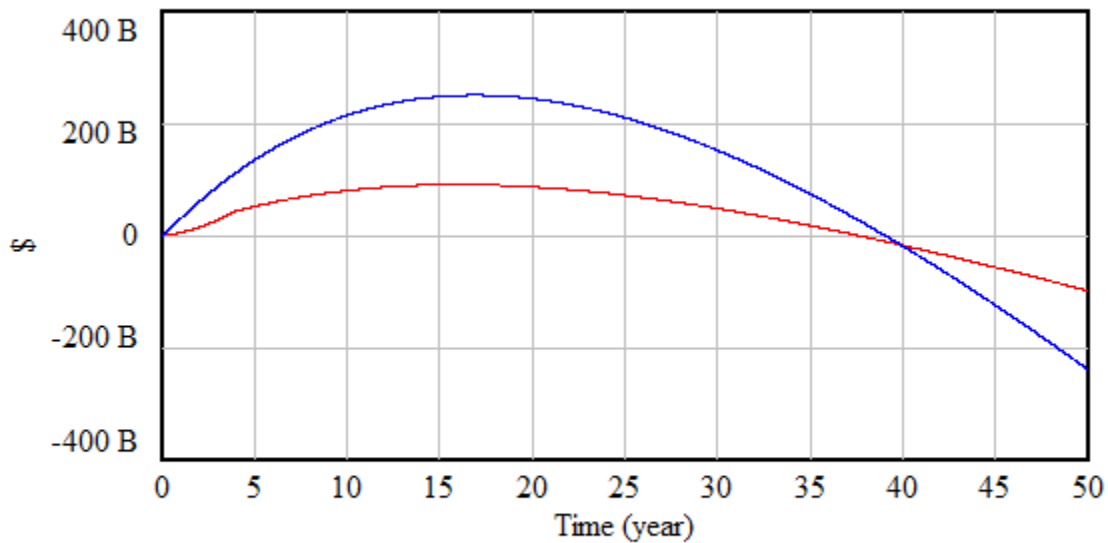
Initial Auditors

Buildings Retrofit



Buildings Retrofit : Low Initial Auditors —————
Buildings Retrofit : High Initial Auditors —————
Buildings Retrofit : base —————

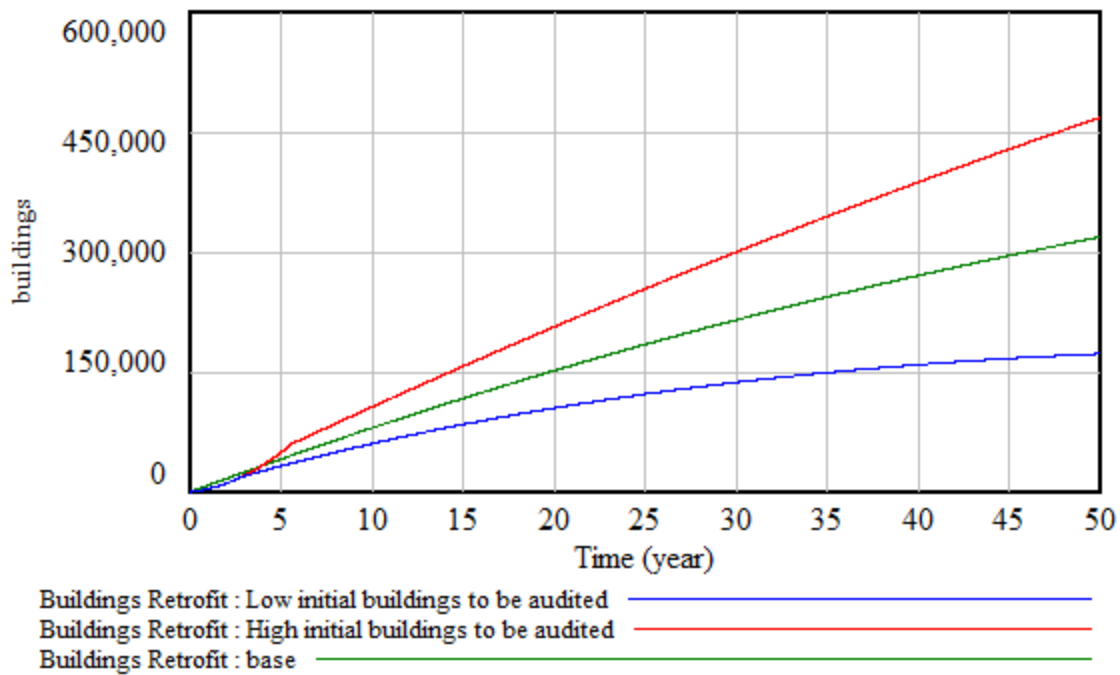
Cumulative debt



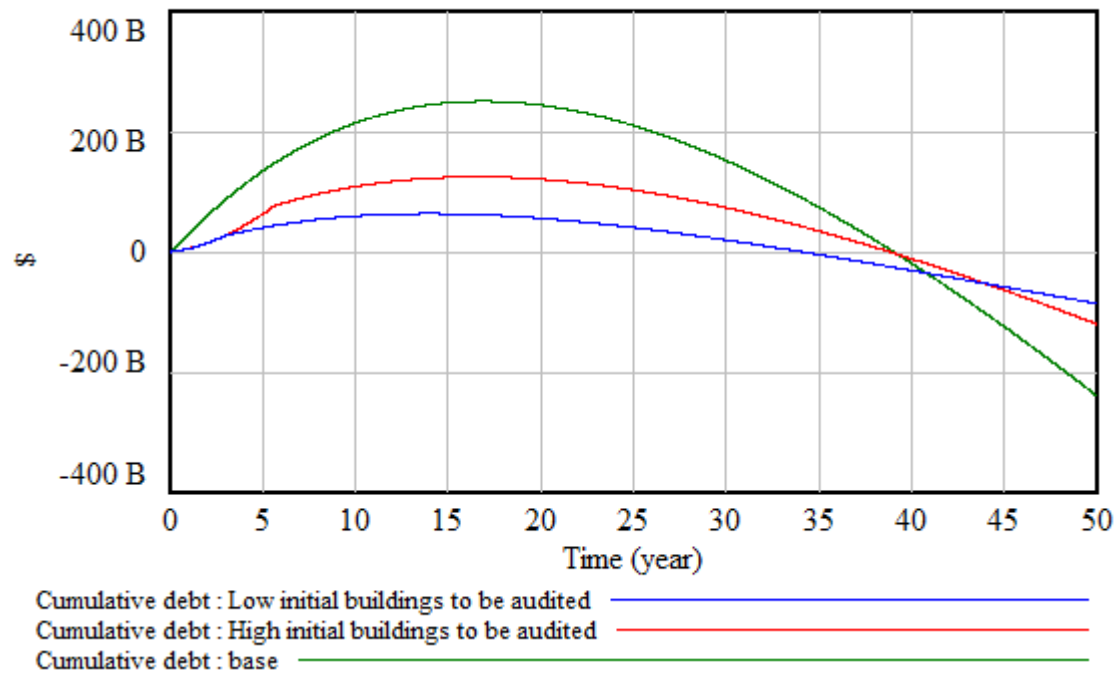
Cumulative debt : Low Initial Auditors —————
Cumulative debt : High Initial Auditors —————
Cumulative debt : base —————

Initial Buildings to Be Audited

Buildings Retrofit

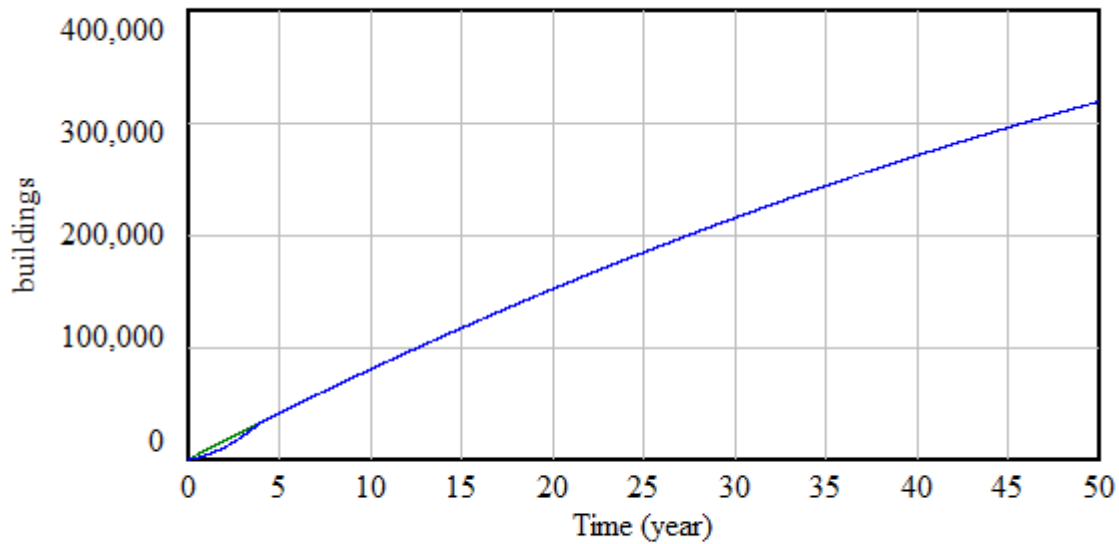


Cumulative debt



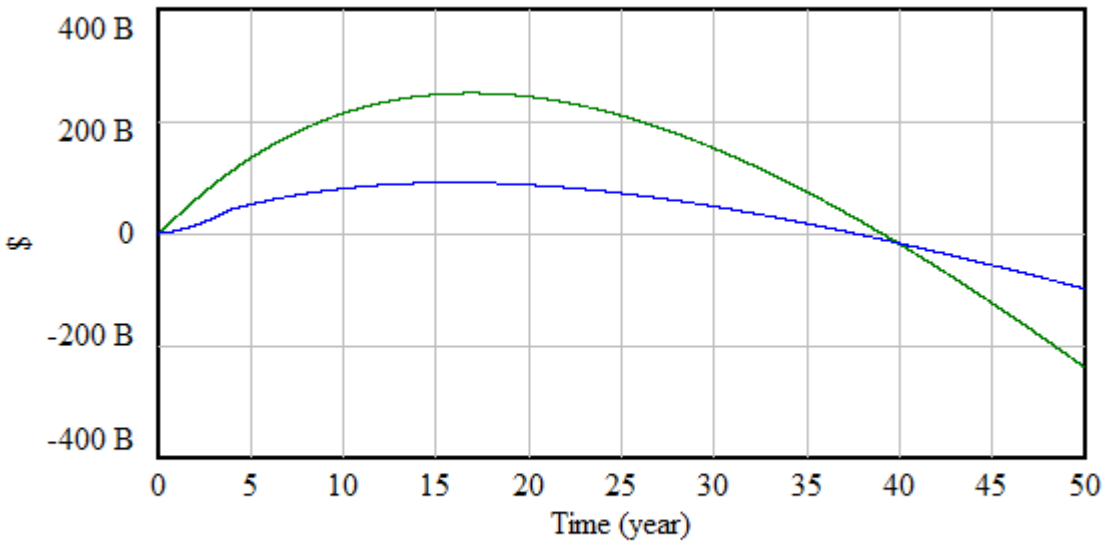
Initial Cash

Buildings Retrofit



Buildings Retrofit : Low Initial Cash —————
Buildings Retrofit : High Initial Cash —————
Buildings Retrofit : base —————

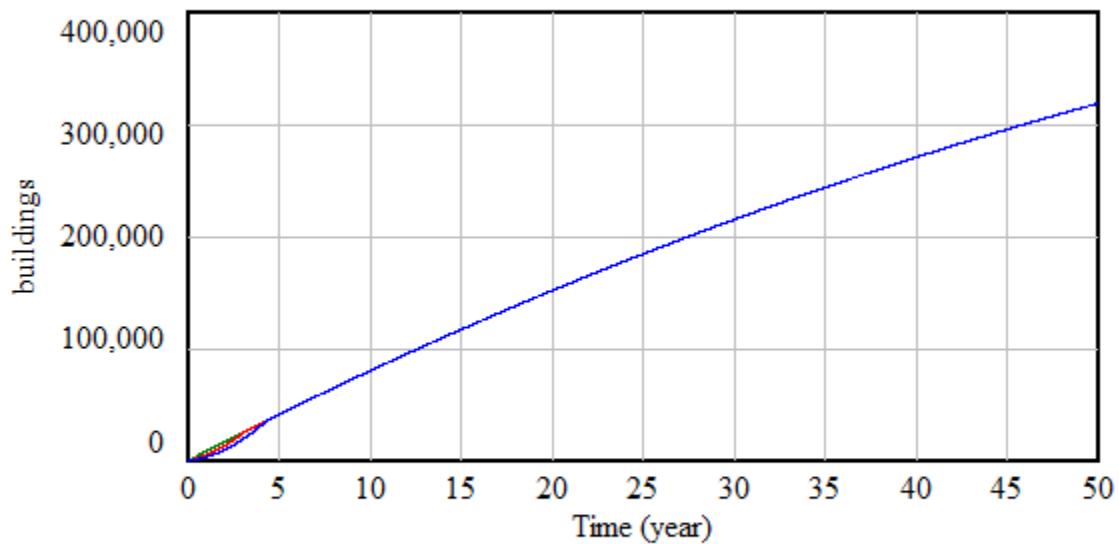
Cumulative debt



Cumulative debt : Low Initial Cash —————
Cumulative debt : High Initial Cash —————
Cumulative debt : base —————

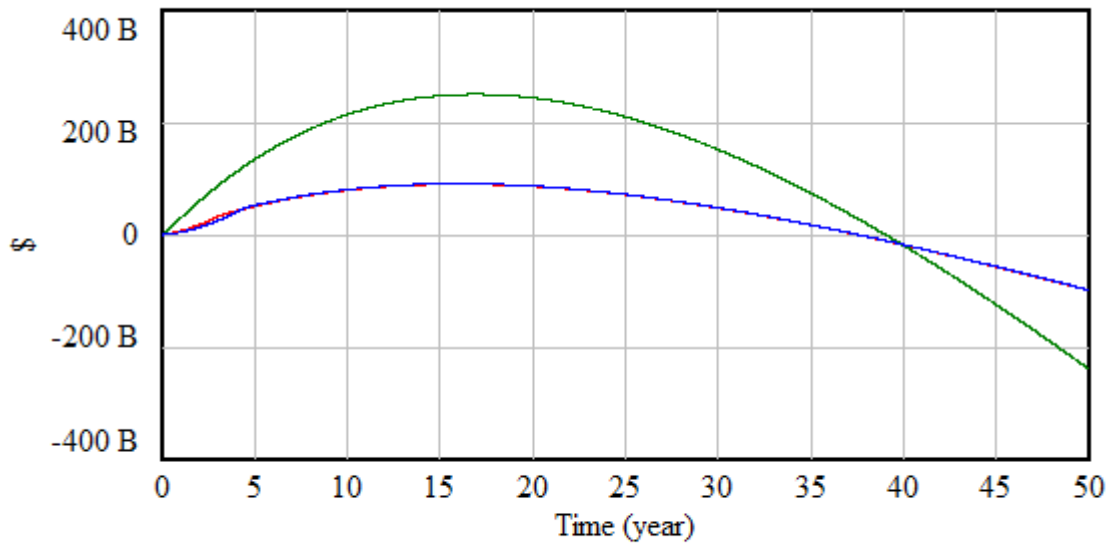
Initial Contractors

Buildings Retrofit



Buildings Retrofit : Low initial contractor —————
Buildings Retrofit : High initial contractor —————
Buildings Retrofit : base —————

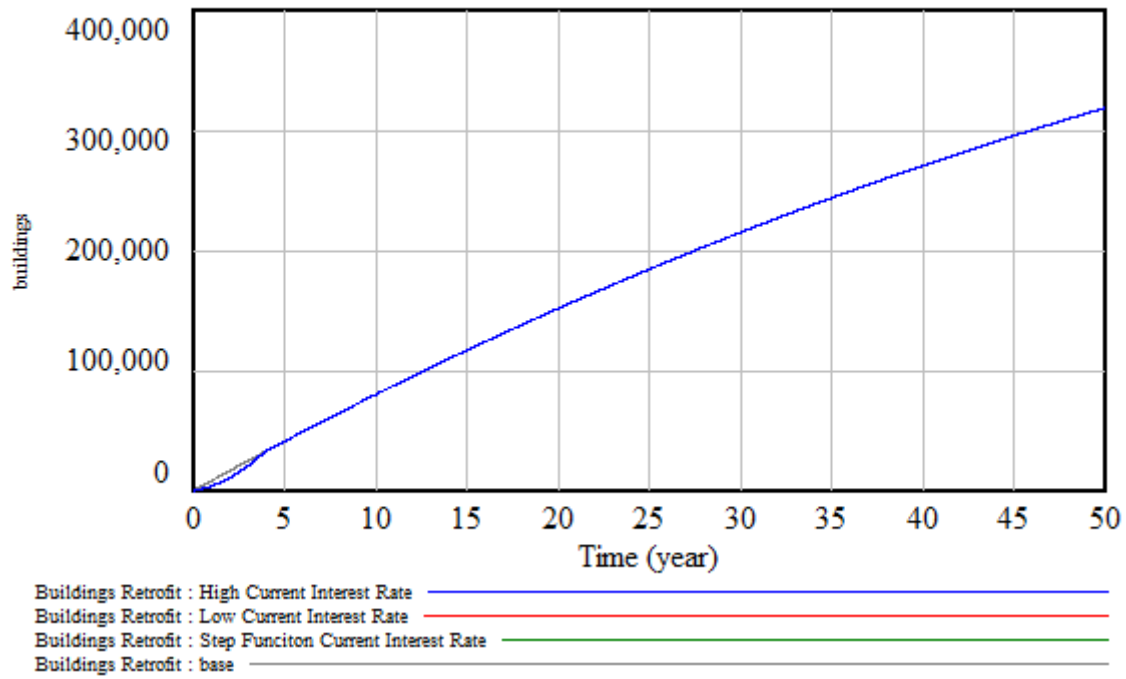
Cumulative debt



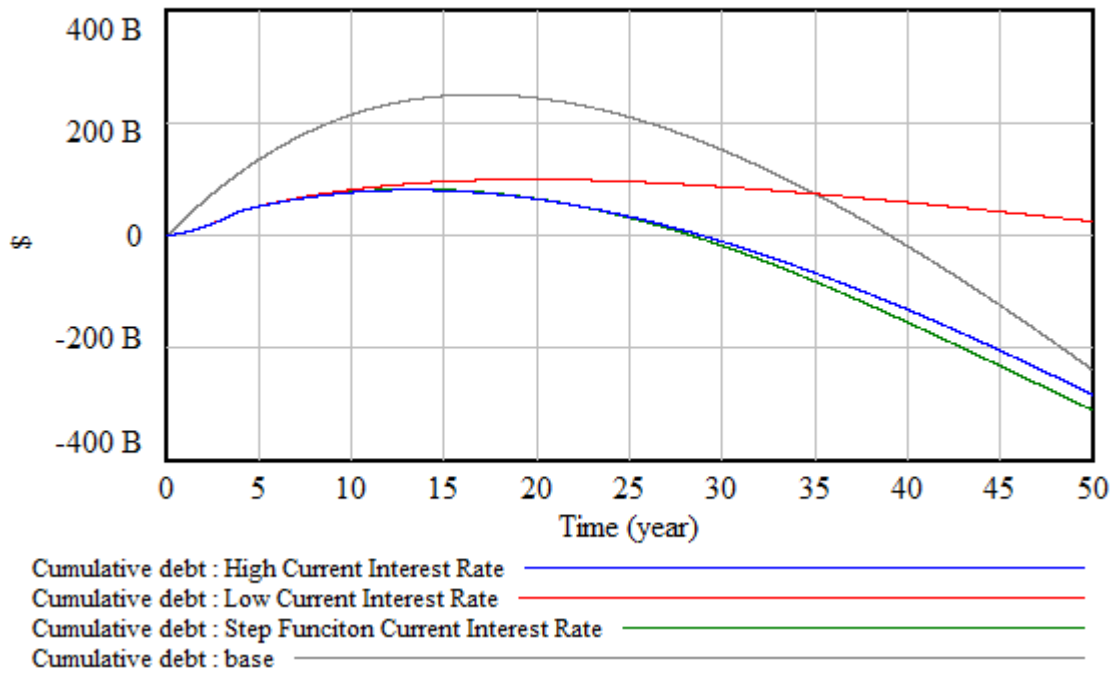
Cumulative debt : Low initial contractor —————
Cumulative debt : High initial contractor —————
Cumulative debt : base —————

Interest Rate

Buildings Retrofit

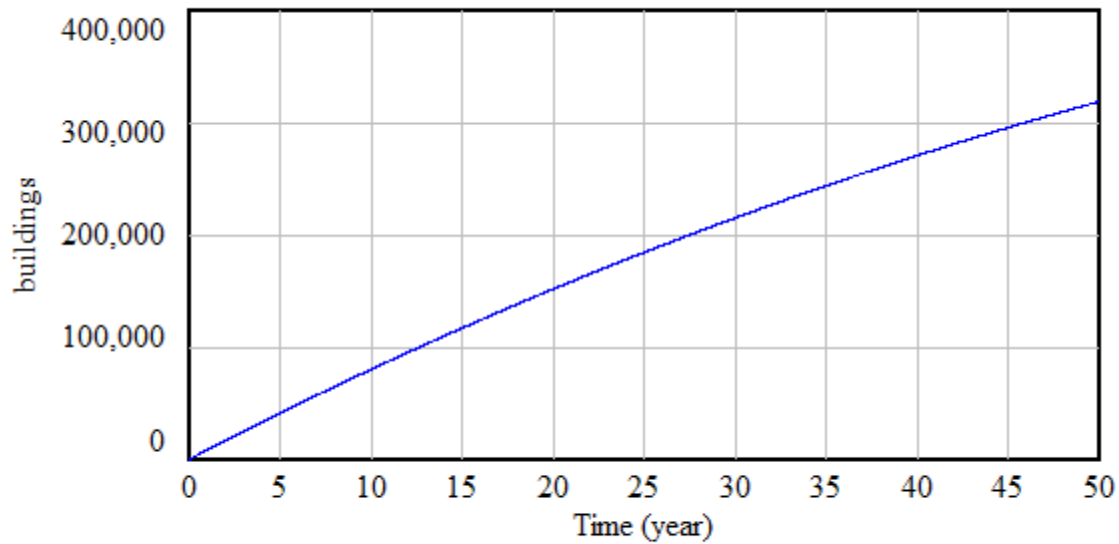


Cumulative debt



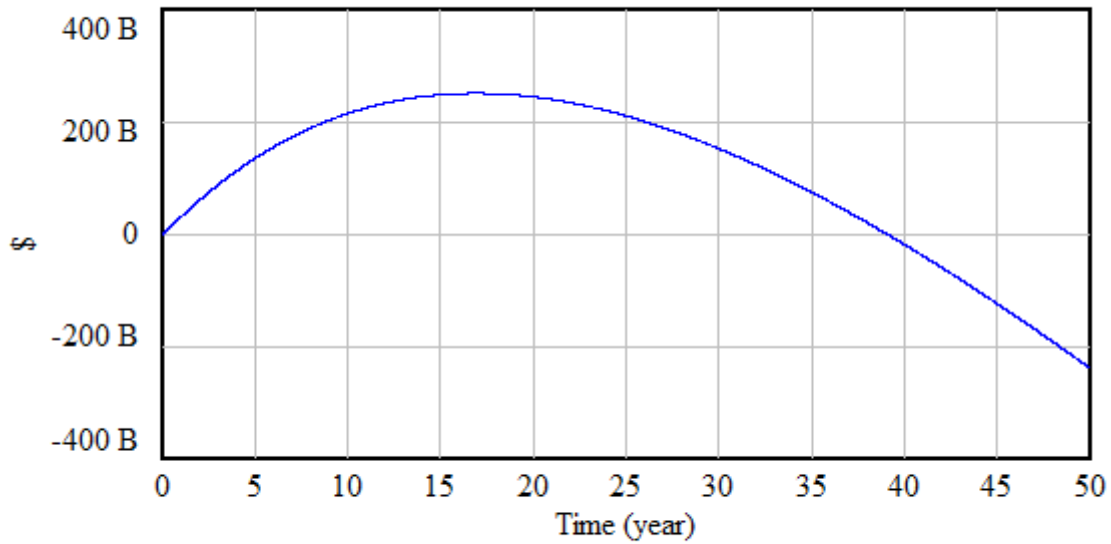
New Auditors

Buildings Retrofit



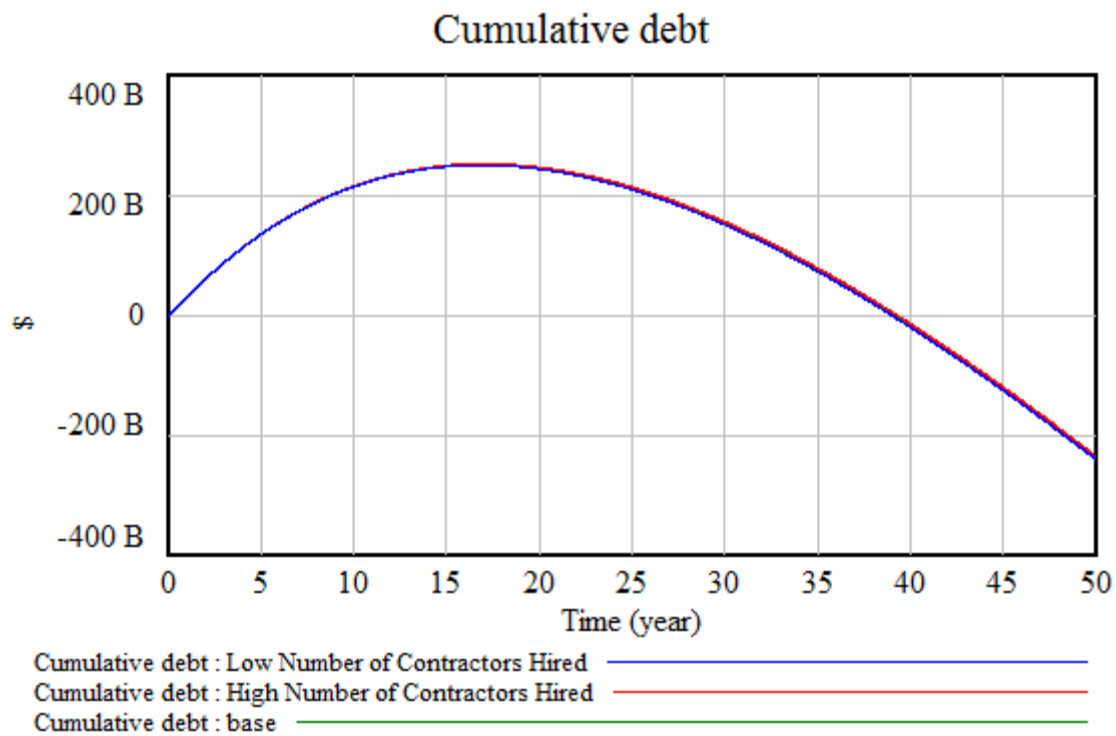
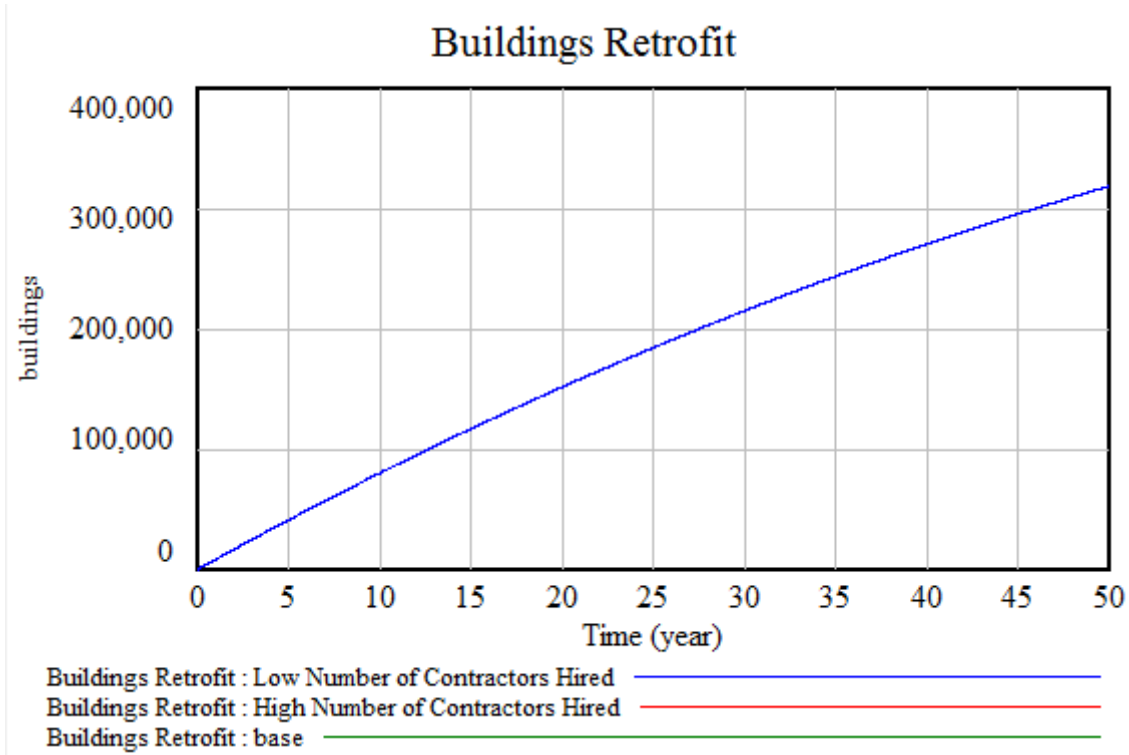
Buildings Retrofit : Low New Auditors —————
Buildings Retrofit : High Rate of New Audiots —————
Buildings Retrofit : base —————

Cumulative debt



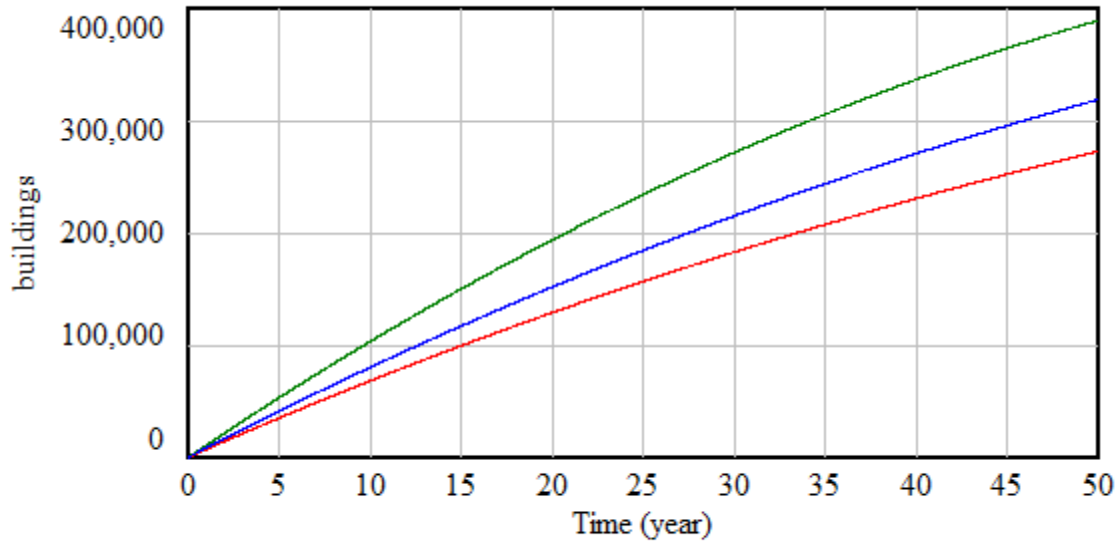
Cumulative debt : Low New Auditors —————
Cumulative debt : High Rate of New Audiots —————
Cumulative debt : base —————

Number of Contractors Hired



People Hours

Buildings Retrofit

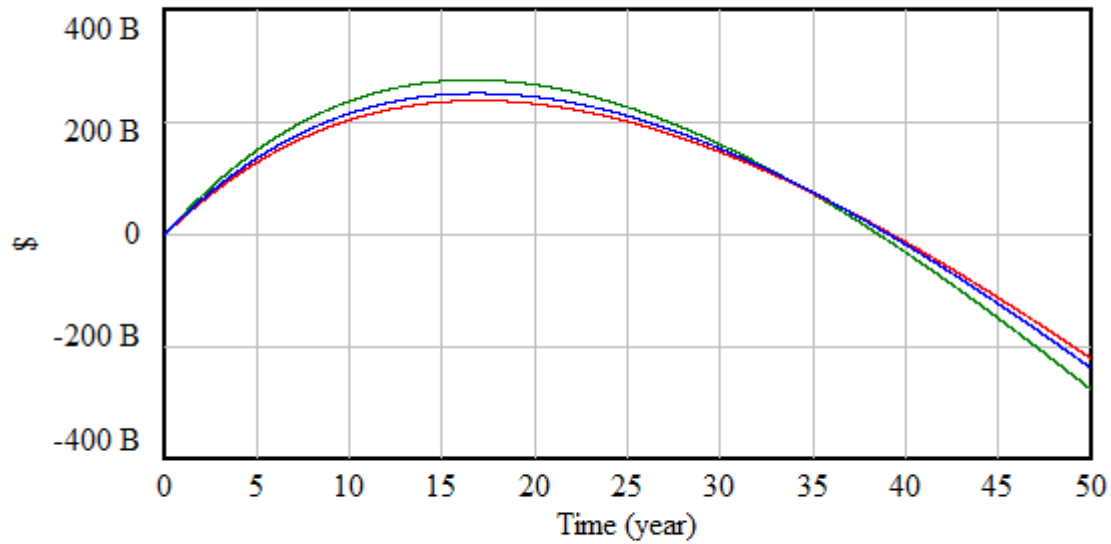


Buildings Retrofit : base —————

Buildings Retrofit : Low people years —————

Buildings Retrofit : high people years —————

Cumulative debt



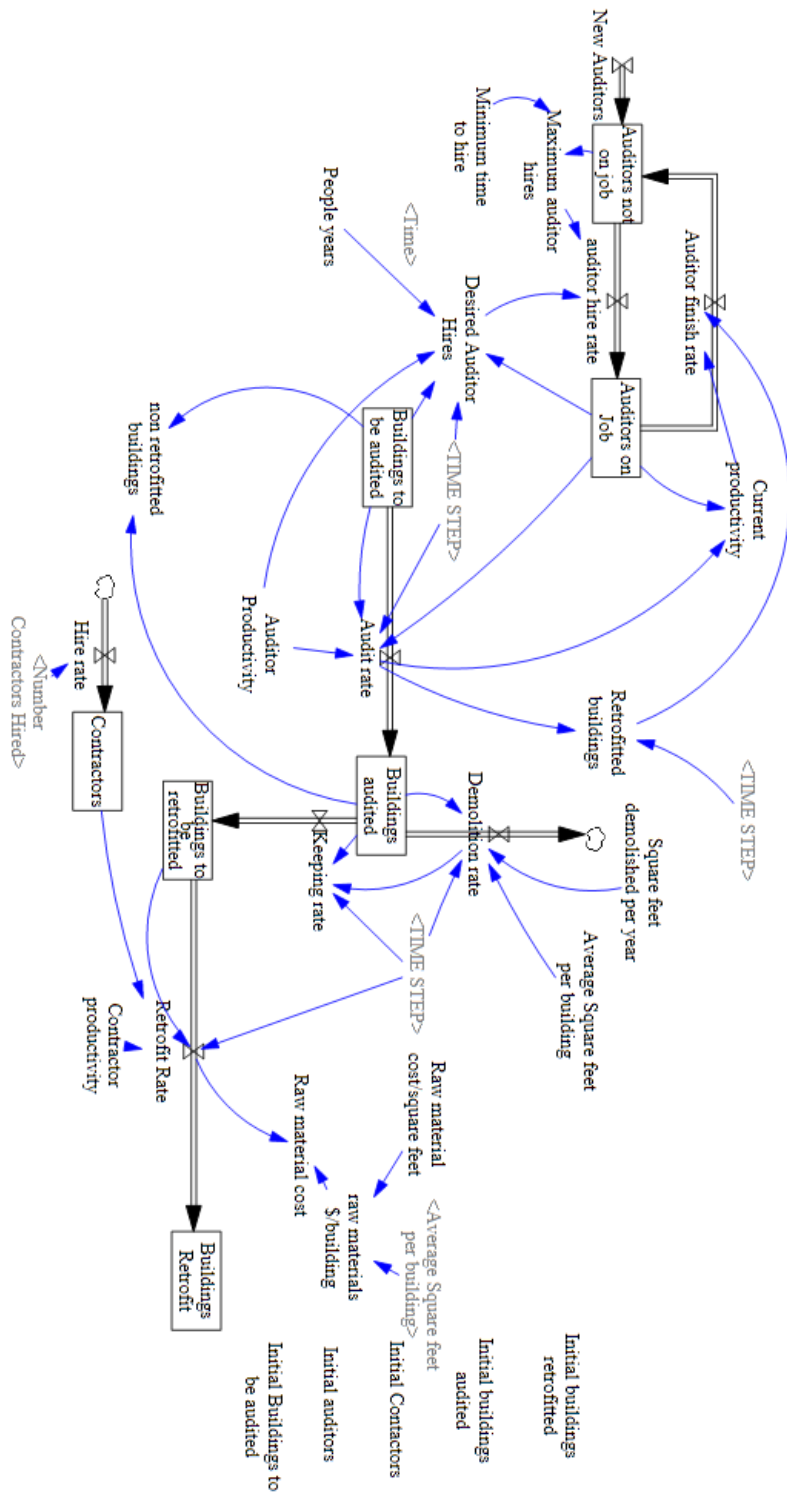
Cumulative debt : base —————

Cumulative debt : Low people years —————

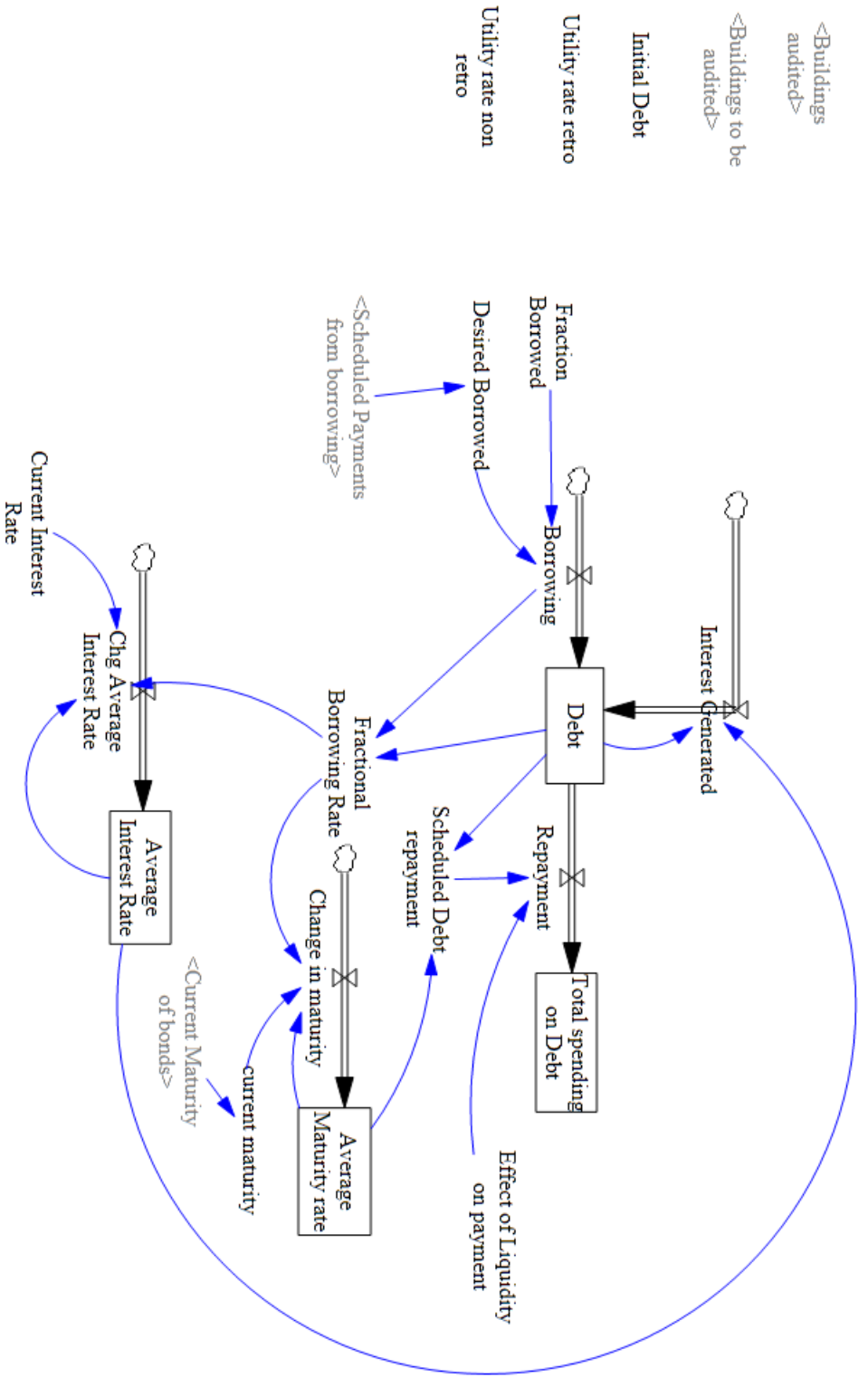
Cumulative debt : high people years —————

Appendix B- Model

Building Sector



Financial Sector



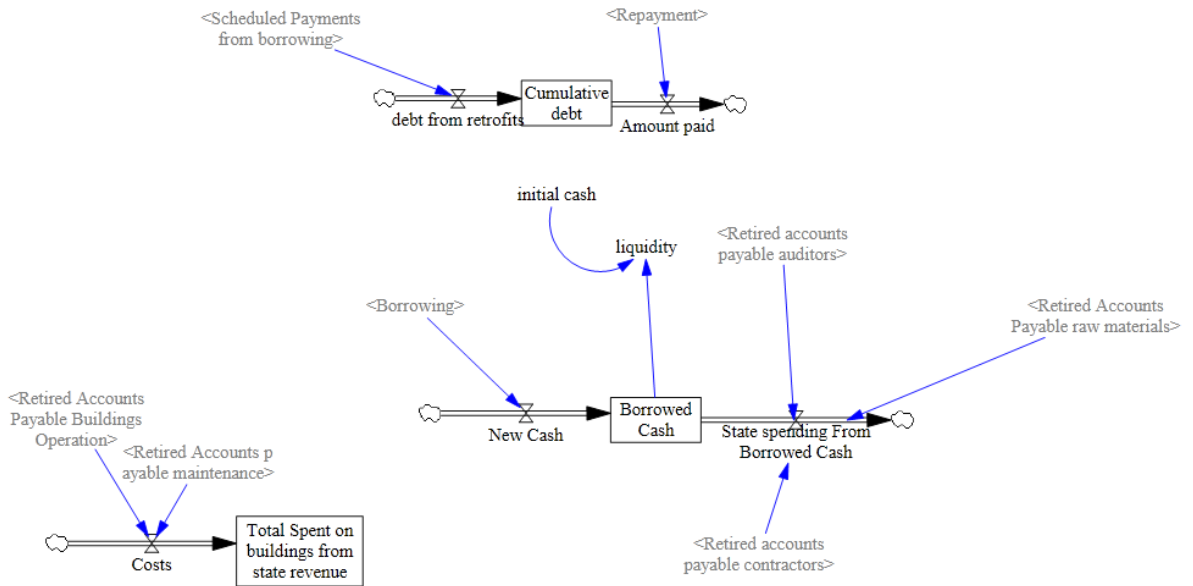
<Buildings audited>
<Buildings to be audited>

Initial Debt

Utility rate retro

Utility rate non retro

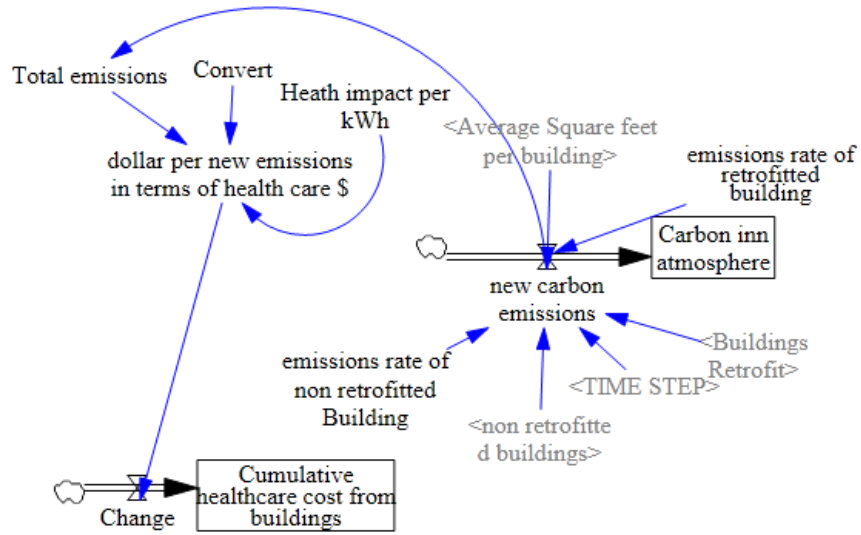
Spending



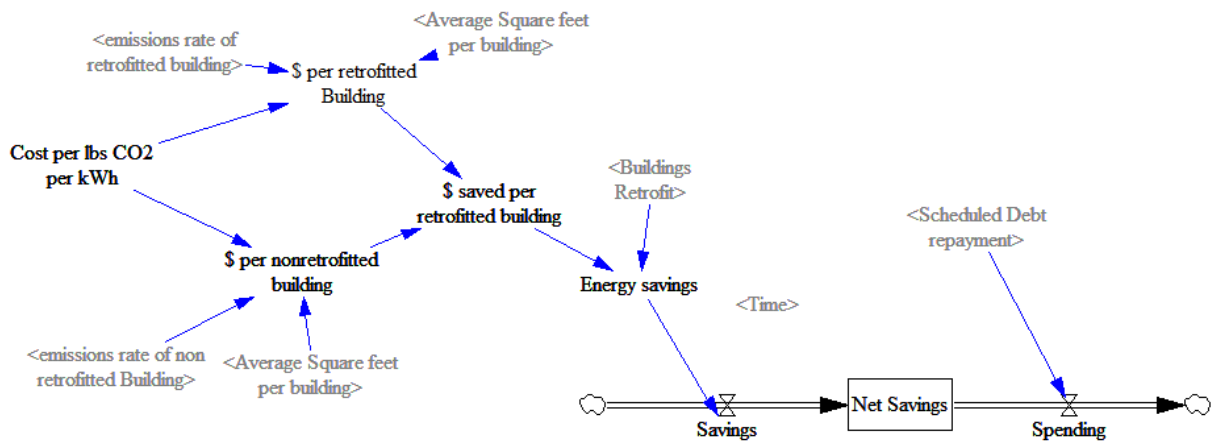
Major Variables

	<scheduled payments from tax revenue>	<Auditor Productivity>
		<Contractor productivity>
Number Contractors Hired		<Contractor's wage>
		<Current Interest Rate>
Current Maturity of bonds		<Current Maturity of bonds>
		<Initial auditors>
	<Contractors>	<Initial Buildings to be audited>
		<Initial Contractors>
		<initial cash>
		<New Auditors>
	<debt from retrofits>	<Number Contractors Hired>
		<People years>
	<Amount paid>	

Carbon Emissions



Savings



Appendix C- Equations

(001) "\$ per non retrofitted building"=
Cost per lbs CO2 per kWh*emissions rate of non retrofitted Building*Average Square
feet per building
Units: \$/buildings/ year

(002) "\$ per retrofitted Building"=
Average Square feet per building*Cost per lbs CO2 per kWh*emissions rate of
retrofitted building
Units: \$/buildings/ year

(003) "\$ saved per retrofitted building"=
"\$ per non retrofitted building"-"\$ per retrofitted Building"
Units: \$/buildings/year

(004) Accounts Payable Auditors= INTEG (
New Accounts Payable Auditors-Retired accounts payable auditors,
0)
Units: \$

(005) Accounts Payable Building maintenance= INTEG (
New Accounts payable maintenance-Retired Accounts payable maintenance,
Initial Accounts Payable Building maintenance)
Units: \$

(006) Accounts Payable Building Operations= INTEG (
New Accounts Payable Building Operations-Retired Accounts Payable Buildings
Operation
,
0)
Units: \$

(007) Accounts payable contractors= INTEG (
New accounts payable Contractors-Retired accounts payable contractors,
0)
Units: \$

(008) Accounts Payable Raw Materials= INTEG (
New Accounts payable Raw Materials-Retired Accounts Payable raw materials
,
0)
Units: \$

(009) Amount paid=
Repayment
Units: \$/year

- (010) Audit rate=
 $\min(\text{Auditors on Job} * \text{Auditor Productivity}, \text{Buildings to be audited} / \text{TIME STEP})$
 Units: buildings/year
- (011) Auditor finish rate=
 $\text{ZIDZ}(\text{Current productivity}, \text{Retrofitted Buildings})$
 Units: auditors/year
- (012) auditor hire rate=
 $\min(\text{Desired Auditor Hires}, \text{Maximum auditor hires})$
 Units: auditors/year
- (013) Auditor Productivity=
 125
 Units: buildings/ auditors/ year
- (014) "Auditor wage Rate- Trained"=
 28000
 Units: \$/auditors
- (015) Auditors not on job= INTEG (
 $\text{Auditor finish rate} + \text{New Auditors} - \text{auditor hire rate},$
 5000)
 Units: auditors
- (016) Auditors on Job= INTEG (
 $\text{auditor hire rate} - \text{Auditor finish rate},$
 100)
 Units: auditors
- (017) Average Interest Rate= INTEG (
 $\text{Chg Average Interest Rate},$
 $\text{Current Interest Rate})$
 Units: Fraction/year
- (018) Average maintenance costs=
 10000
 Units: \$/year
- (019) Average Maturity rate= INTEG (
 $\text{Change in maturity},$
 $\text{current maturity})$
 Units: Fraction/year
- (020) Average operation costs=
 100
 Units: \$/year

- (021) Average Square feet per building=
13300
Units: ft²/buildings
- (022) Borrowed Cash= INTEG (
New Cash-State spending From Borrowed Cash,
initial cash)
Units: \$
- (023) Borrowing=
Desired Borrowed*Fraction Borrowed
Units: \$/year
- (024) Buildings audited= INTEG (
Audit rate-Demolition rate-Keeping rate,
Initial buildings audited)
Units: buildings
- (025) Buildings Retrofit= INTEG (
Retrofit Rate,
Initial buildings retrofitted)
Units: buildings
- (026) Buildings to be audited= INTEG (
-Audit rate,
Initial Buildings to be audited)
Units: buildings
- (027) Buildings to be retrofitted= INTEG (
Keeping rate-Retrofit Rate,
0)
Units: buildings
- (028) Carbon inn atmosphere= INTEG (
new carbon emissions,
100)
Units: lbs CO₂
- (029) Change=
dollar per new emissions in terms of health care \$
Units: \$/year
- (030) Change in maturity=
(current maturity - Average Maturity rate) * Fractional Borrowing Rate
Units: Fraction/(year*year)
- (031) Chg Average Interest Rate=

(Current Interest Rate - Average Interest Rate) * Fractional Borrowing Rate
Units: Fraction/year/year

- (032) Contractor productivity=
6
Units: buildings/(workers*year)
- (033) Contractor's wage=
69870
Units: \$/(year*workers)
- (034) Contractors= INTEG (
Hire rate,
Initial Contactors)
Units: workers
- (035) Convert=
1.297
Units: lbs CO2/kWh
- (036) Cost per lbs CO2 per kWh=
0.14/ 1.299
Units: \$/lbs CO2/ year
- (037) Costs=
Retired Accounts Payable Buildings Operation+Retired Accounts payable maintenance
Units: \$/year
- (038) Cumulative debt= INTEG (
debt from retrofits-Amount paid,
0)
Units: \$
- (039) Cumulative healthcare cost from buildings= INTEG (
Change,
0)
Units: \$
- (040) Current Interest Rate=
0.04
Units: Fraction/year
- (041) current maturity=
Current Maturity of bonds
Units: Fraction/year
- (042) Current Maturity of bonds=
0.08

- Units: Fraction/year
- (043) Current productivity=
 Audit rate*Auditors on Job
 Units: auditors*buildings/year
- (044) Debt= INTEG (
 Borrowing+Interest Generated-Repayment,
 Initial Debt)
 Units: \$
- (045) debt from retrofits=
 Scheduled Payments from borrowing
 Units: \$/year
- (046) Demolition rate=
 min((Buildings audited/TIME STEP),(Square feet demolished per year/Average Square
 feet per building
))
 Units: buildings/year
- (047) Desired Auditor Hires=
 ((Buildings to be audited/Auditor Productivity)/Auditors on Job)*(People years
 /TIME STEP)
 Units: auditors/year
- (048) Desired Borrowed=
 Scheduled Payments from borrowing
 Units: \$/year
- (049) dollar per new emissions in terms of health care \$=
 Heath impact per kWh/Convert*Total emissions
 Units: \$/year
- (050) Effect of Liquidity on Accounts payable auditors = WITH LOOKUP (
 liquidity,
 ((0,0)-(1,1)],(0,0),(0.2,0.1),(0.4,0.3),(0.6,0.7),(0.8,0.9),(1,1))
 Units: Dmnl
- (051) Effect of Liquidity on Accounts Payable Buildings Operation=
 liquidity
 Units: Dmnl
- (052) Effect of Liquidity on accounts payable contractors=
 liquidity
 Units: Dmnl
- (053) Effect of Liquidity on Accounts payable maintenance=

- liquidity
Units: Dmnl
- (054) Effect of Liquidity on Accounts Payable raw materials=
liquidity
Units: Dmnl
- (055) Effect of Liquidity on payment=
1
Units: Dmnl
- (056) emissions rate of non retrofitted Building=
20
Units: lbs CO2/ft2
- (057) emissions rate of retrofitted building=
15
Units: lbs CO2/ft2
- (058) Energy savings=
"\$ saved per retrofitted building"*Buildings Retrofit
Units: \$/year
- (059) FINAL TIME = 50
Units: year
The final time for the simulation.
- (060) Fraction Borrowed=
1
Units: Dmnl
- (061) Fractional Borrowing Rate=
ZIDZ(Borrowing, Debt)
Units: Fraction/year
- (062) Heath impact per kWh=
0.14
Units: \$/kWh
- (063) Hire rate=
Number Contractors Hired
Units: workers/year
- (064) Initial Accounts Payable Building maintenance=
500000
Units: \$
- (065) Initial auditors=

- 1000
Units: auditors
- (066) Initial buildings audited=
0
Units: buildings
- (067) Initial buildings retrofitted=
0
Units: buildings
- (068) Initial Buildings to be audited=
5000
Units: buildings
- (069) initial cash=
100000
Units: \$
- (070) Initial Contactors=
300400
Units: workers
- (071) Initial Debt=
0
Units: \$
- (072) INITIAL TIME = 0
Units: year
The initial time for the simulation.
- (073) Initial Total Accounts Payable Building Maintenance=
0
Units: \$
- (074) Initial Total payments for building operation=
0
Units: \$
- (075) Interest Generated=
Average Interest Rate*Debt
Units: \$/year
- (076) Keeping rate=
 $(\text{Buildings audited} - (\text{Demolition rate} * \text{TIME STEP})) / \text{TIME STEP}$
Units: buildings/year
- (077) liquidity=

- Borrowed Cash/initial cash
Units: Dmnl
- (078) Maximum auditor hires=
Auditors not on job/Minimum time to hire
Units: auditors/year
- (079) Minimum time to hire=
1/12
Units: year
- (080) Net Savings= INTEG (
Savings-Spending,
0)
Units: \$
- (081) New Accounts Payable Auditors=
"Auditor wage Rate- Trained"*Auditors on Job/TIME STEP
Units: \$/year
- (082) New Accounts Payable Building Operations=
Average operation costs
Units: \$/year
- (083) New accounts payable Contractors=
Contractors*Contractor's wage
Units: \$/year
- (084) New Accounts payable maintenance=
Average maintenance costs
Units: \$/year
- (085) New Accounts payable Raw Materials=
Raw material cost
Units: \$/year
- (086) New Auditors=
150
Units: auditors/year
- (087) new carbon emissions=
(Buildings Retrofit*emissions rate of retrofitted building*Average Square feet per
building
+non retrofitted buildings*emissions rate of non retrofitted Building*Average Square feet per
building
)/TIME STEP
Units: lbs CO2/year

- (088) New Cash=
 Borrowing
 Units: \$/year
- (089) non retrofitted buildings=
 Buildings audited+Buildings to be audited
 Units: buildings
- (090) Number Contractors Hired=
 500
 Units: workers/year
- (091) People years=
 3
 Units: auditors/year
- (092) Raw material cost=
 "raw materials \$/building"*Retrofit Rate
 Units: \$/year
- (093) "Raw material cost/square feet"=
 111
 Units: \$/ ft²
- (094) "raw materials \$/building"=
 Average Square feet per building*"Raw material cost/square feet"
 Units: \$/buildings
- (095) Repayment=
 Effect of Liquidity on payment*Scheduled Debt repayment
 Units: \$/year
- (096) Retired accounts payable auditors=
 Effect of Liquidity on Accounts payable auditors*Scheduled Retired accounts payable
 auditors
 Units: \$/year
- (097) Retired Accounts Payable Buildings Operation=
 Effect of Liquidity on Accounts Payable Buildings Operation*Scheduled Retired Accounts
 Payable Buildings Operation
 Units: \$/year
- (098) Retired accounts payable contractors=
 Effect of Liquidity on accounts payable contractors*Scheduled Retired accounts payable
 contractors
 Units: \$/year
- (099) Retired Accounts payable maintenance=

Effect of Liquidity on Accounts payable maintenance*scheduled Retired Accounts payable maintenance
Units: \$/year

(100) Retired Accounts Payable raw materials=
Effect of Liquidity on Accounts Payable raw materials*Scheduled Retired Accounts Payable raw materials
Units: \$/year

(101) Retrofit Rate=
min(Buildings to be retrofitted/TIME STEP,Contractors*Contractor productivity)
Units: buildings/year

(102) Retrofitted Buildings=
Audit rate*TIME STEP
Units: buildings

(103) SAVEPER =
TIME STEP
Units: year [0,?]
The frequency with which output is stored.

(104) Savings=
Energy savings
Units: \$/year

(105) Scheduled Debt repayment=
Debt*Average Maturity rate
Units: \$/year

(106) Scheduled Payments from borrowing=
Scheduled Retired accounts payable auditors+Scheduled Retired accounts payable contractors
+Scheduled Retired Accounts Payable raw materials
Units: \$/year

(107) scheduled payments from tax revenue=
Scheduled Retired Accounts Payable Buildings Operation+Scheduled Debt repayment
+scheduled Retired Accounts payable maintenance
Units: \$/year

(108) Scheduled Retired accounts payable auditors=
Accounts Payable Auditors/time to pay accounts payable auditors
Units: \$/year

(109) Scheduled Retired Accounts Payable Buildings Operation=

- Accounts Payable Building Operations/Time to pay Accounts Payable Buildings
- Operation
Units: \$/year
- (110) Scheduled Retired accounts payable contractors=
Accounts payable contractors/Time to pay accounts payable contractors
Units: \$/year
- (111) scheduled Retired Accounts payable maintenance=
Accounts Payable Building maintenance/Time to pay Accounts payable maintenance
Units: \$/year
- (112) Scheduled Retired Accounts Payable raw materials=
Accounts Payable Raw Materials/time to pay Accounts Payable raw materials
Units: \$/year
- (113) Spending=
Scheduled Debt repayment
Units: \$/year
- (114) Square feet demolished per year=
3.91809e+006
Units: ft²/year
- (115) State spending From Borrowed Cash=
Retired accounts payable auditors+Retired accounts payable contractors+Retired
Accounts Payable raw materials
Units: \$/year
- (116) sum of all the spending=
Accounts Payable Auditors+Accounts Payable Building maintenance+Accounts Payable
Building Operations
+Accounts payable contractors+Accounts Payable Raw Materials
Units: \$
- (117) TIME STEP = 0.0078125
Units: year [0,?]
The time step for the simulation.
- (118) time to pay accounts payable auditors=
1/12
Units: year
- (119) Time to pay Accounts Payable Buildings Operation=
1/12
Units: year
- (120) Time to pay accounts payable contractors=

- 1/12
Units: year
- (121) Time to pay Accounts payable maintenance=
1/12
Units: year
- (122) time to pay Accounts Payable raw materials=
1/12
Units: year
- (123) Total Accounts Payable Building Maintenance= INTEG (
Retired Accounts payable maintenance,
Initial Total Accounts Payable Building Maintenance)
Units: \$
- (124) Total emissions=
new carbon emissions
Units: lbs CO2/year
- (125) Total payments for building operations= INTEG (
Retired Accounts Payable Buildings Operation,
Initial Total payments for building operation)
Units: \$
- (126) Total spending on Debt= INTEG (
Repayment,
0)
Units: \$
- (127) Total Spent on buildings from state revenue= INTEG (
Costs,
0)
Units: \$
- (128) Utility rate non retro=
3000
Units: \$/year
- (129) Utility rate retro=
1000
Units: \$/year

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