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CAMPUS ASSESSMENT OF BUILDING HEATING ENERGY CONSUMPTION - INFORMING THE CLIMATE ACTION PLAN

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ABSTRACT

We present a methodology to assess the technical feasibility of building thermal energy reduction strategies from an architecturally diverse building stock that is not metered. While carbon emissions forecasting efforts are typically the domain of planning and policy, the process detailed here can inform institutional decision-making relative to investments in renewable energy, infrastructure, and offsets to further reduce carbon footprint. As a case study, we estimated the Smith College campus building thermal energy losses, an analysis which informed our Sustainability and Climate Action Plan [1]. Due to building specific physical constraints and planned renovations, different thermal envelope improvement scenarios were then considered to estimate the heating energy reduction potential of these envelope improvements. The current total heating energy consumption from 79 of our campus buildings was found to be 57,000 MMBTU/yr. Across the three building categories with minimal existing insulation and poor sealing conditions, the nominal annual thermal energy loss per square foot ranged from 27,000-37,000 BTU/ft^2. Should envelope improvements be made targeting a 5 year simple payback, this annual thermal energy loss would be reduced by 40% to 34,000 MMBTU/yr. More extensive and less cost effective envelope improvements suggest further energy reductions approaching 30,000 MMBTU/yr (between 13,000-23,000 BTU/ft^2/yr depending upon the building type).

1 Introduction

Through the American College and University Presidents' Climate Commitment, colleges and universities across the country have pledged to take specific action to reduced their carbon footprint. Signatories are required to develop an institutional action plan detailing their targets, actions and timeline for achieving carbon neutrality. An institutional plan for achieving carbon neutrality must be adopted within two years of signing the commitment. Among other requirements, this plan must set interim targets for goals and specific actions that will lead to climate neutrality. In addition to campus efforts, municipalities and other institutions across the nation are pledging to reduce their carbon footprint through state run initiatives. These carbon emissions are produced in a variety of ways including transportation, production and procurement of goods, disposal of waste, landscape management, and building energy consumption.

As progress toward completing the Smith College Sustainability and Climate Action Management Plan, a greenhouse gas inventory was completed. This inventory indicated that the greatest source of carbon emissions results from the boilers, water heaters and co-gen steam used to heat buildings and provide domestic hot water, as shown in Figure 1. This inventory provides a single data point indicating the current total carbon emissions resulting from building space heating across the campus. Understanding the heating loads for individual structures requires either metered data for these individual structures or a methodology for estimating these heating loads. Because building energy consumption is a significant carbon producing activity, several tools have been developed to use energy data in estimating ex-

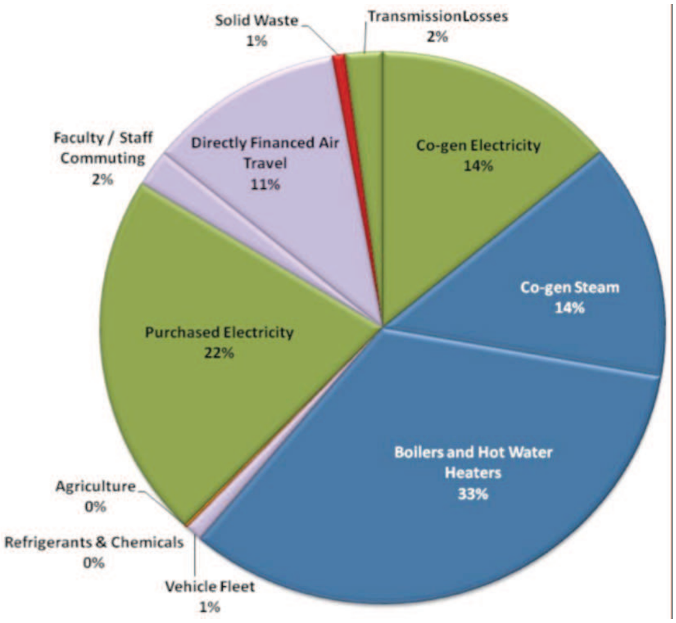

Figure 1. Smith College eCO_2 emissions by source in 2009. [1]

isting building energy loss. However, many institutions do not collect energy data for individual structures. In these situations, the ability to assess energy losses is nontrivial.

In estimating building heating energy consumption, some campuses have elected to hire technical consultants to perform energy audits across the campus or on particular structures that are known to be significant consumers. These consultations can involve baseline energy estimates for HVAC, lighting, utility systems and building envelopes, conducted through either modeling or an analysis of metered data. Campuses can opt to receive a variety of outputs ranging from design submittals to commissioning and performance verification. For campuses that choose consultants to inform their climate action plans, buildings that consume the most significant total energy are specifically targeted [2–4]. Categorically, the loads in these buildings include lighting, electrical (plug) loads, heating, cooling, refrigeration, etc. Oberlin College, for example, contracted with consultants to perform energy audits on 10 of their largest energy consuming buildings that comprised roughly 1/3 of their total building footprint [2]. Their reduction strategies then focused on improvements made to this subset of buildings.

For institutions that did not detail their plan for energy reductions by leveraging outside consultants, published recommendations were used to guide their planning either by referencing current building energy code standards or recommendations established for LEED new and existing construction [5–7]. These institutions recommended various standard building envelope retrofit techniques to be adopted, such as insulation and sealing, but provided no indication of the estimated energy reduction associated with implementing these strategies.

Our work provides an extension to the methods detailed in these climate action plans. While it is useful to hire consultants to examine strategies for unique and consumptive structures, they often represent less than half of the total campus heating energy consumption. The rationale for establishing a methodology for estimating campus wide building heating energy consumption was thus three fold. First, we aimed to estimate the current heating energy needs of the relatively uniform structures, such as academic and residential buildings, that are none the less responsible for a significant fraction of the total campus heating energy needs. Second, with this method, various retrofits to specific buildings were considered based on existing conditions in the building as well as planned maintenance. Finally, we developed a suite of models used by our Facility Management Department (and of use to other campuses) for capital planning.

While steam and electricity meters are being installed on select campus buildings, there is currently no reliable data on individual building energy consumption. Due to the lack of metering, building characteristics are required and an energy simulation tool must be used to quantify building performance. As a means of estimating building energy consumption when no metered data exists, or to reduce the capital investment required for extensive energy audits, energy simulation tools have been used to predict current energy requirements as well as the potential energy reductions due to specific building retrofits [8]. While not yet being used for developing college or university Climate Action plans, extensive simulation tools, such as [9], are available for providing detailed estimates of building and/or campus energy consumption as well as for forecasting energy savings through retrofit analysis. To minimize the required effort in modeling an extensive number of buildings, here we propose a methodology to approximate the total campus heating energy consumption through simulation of a subset of buildings that are carefully selected to represent the diversity in the building stock on campus. For detailed and targeted retrofit planning, it is recommended that more detailed models then be generated to represent individual structures.

Our methodology analyzes institutional heating loads in order to quantify energy reductions from proposed retrofits on individual buildings. We then use our campus as a case study for the retrofit analysis we conducted to inform our climate action plan. The findings from this study were integrated into the Energy and Buildings section of the Plan [1] and are discussed in more detail here. First, we introduce the modeling software used, the method used to categorize the performance of individual buildings, along with a sensitivity analysis to examine the influence of building properties on heating energy consumption in Section 2. The current total heating loads for the buildings of interest are then estimated and a retrofit assessment is presented in Section 3. It is critical to note that our use of the terms heating load and heating energy consumption are analogous in that both include

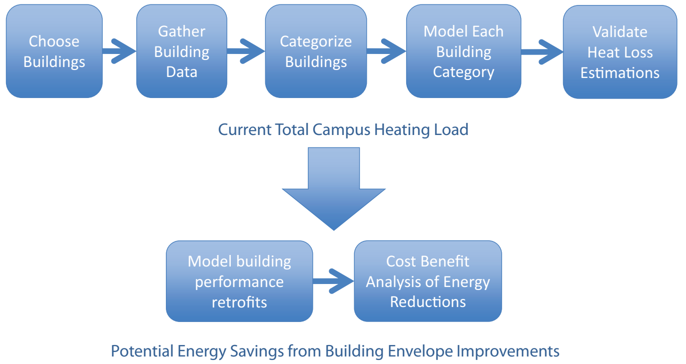

Figure 2. The general methodology used to estimate total campus building heating energy consumption.

the energy end use associated with the heating system and transportation losses.

2 Building Categorization

The process of categorizing the individual buildings in preparation of modeling total campus building heat energy consumption involved the selection of the buildings that were to be evaluated, the identification of the building parameters that most significantly influenced building heat loss, the classification of the buildings based on architectural type and heat transfer parameters, followed by the acquisition of detailed data for buildings that were used to represent each building category. This process is shown in Figure 2. We note, that while presented in such a fashion, this method is not actually linear. Building data are required for establishing the models that are used to perform a sensitivity analysis that motivates the categories chosen for more detailed modeling and evaluation.

2.1 Building Selection

In this study, we were most interested in the structures that other climate action plans had discluded from detailed energy audits (such as residential and academic buildings) that together resulted in a significant portion of the total campus heating energy consumption (load). We focused on buildings with relatively similar heating end use equipment (the least complicated HVAC systems). Thus, in framing the task of estimating the campus heating loads, we first set out to determine the level of complexity of the HVAC systems for each building. Buildings which have HVAC systems that use heating circulation beyond basic floor radiators on either one pipe or two pipe steam, were discluded from this study. Each of these unique buildings have sufficiently complicated heating systems to warrant an energy audit. Buildings that have little to no heating energy loads were not analyzed. There were 79 buildings considered here with a total building footprint 1,648,000 ft^2 representing 54% of the built space on campus.

2.2 Modeling Building Performance

Modeling the building energy consumption for space heating requires the knowledge of building information for each structure which includes the building footprint (surface area on which the building stands), total area of occupied and unoccupied spaces, number of floors, shape, substructure, superstructure, exterior walls, roof, windows, exterior doors, interior partitions, interior doors, flooring, ceilings, heating source (such as oil, natural gas or steam), heating distribution mechanism (such as air ducts or water pipes), and heating end devices (such as standing radiators, radiative floorboards, or registers).

These data were collected by viewing archived records and maintenance databases, conducting staff interviews, or a site inspection. For our analysis, building details were obtained from the Facilities Management Department. Archives archived records included a combination of a master spreadsheet, architectural drawings and/or construction plans. While inconsistent in quality, additional documentation existed due to planned renovations and retrofits where the extent of documentation was dependent on the purpose of the retrofit. To supplement these records where gaps in data existed, personal interviews were conducted with facility management staff. Of greatest utility, and of critical importance, these interviews resulted in a comprehensive listing of the wall and attic insulation level for each building on a discrete great/good/none scale as well as the type of insulation employed if it existed. With the construction details, we could then estimate wall and attic thermal resistance values based on the construction material as well as the type and thickness of any existing insulation.

Several building energy simulation tools have been developed by private companies and public institutions and are well summarized in [10]. In selecting the method used to model building heating energy consumption, we desired an existing program that could be leveraged by Facilities Management for future strategic planning. Additionally, we desired an energy simulation tool that could be easily employed by other campuses to reproduce our methodology for a different campus building stock. For these reasons, we elected to use the Department of Energy EQuest building energy simulation tool which adds a graphical user interface to the DOE-2 energy simulation modeling software. It is important to note that several versions of the EQuest software have been approved by the California Energy Commission Title 24 as a non-residential Alternative Calculation Method (ACM).

The EQuest software estimates the energy requirements for both electricity and space heating. Of interest in this work is the building energy consumption estimates for space heating, given as a model output, an example of which can be seen in Figure 3. The internal databases were used for weather data as well

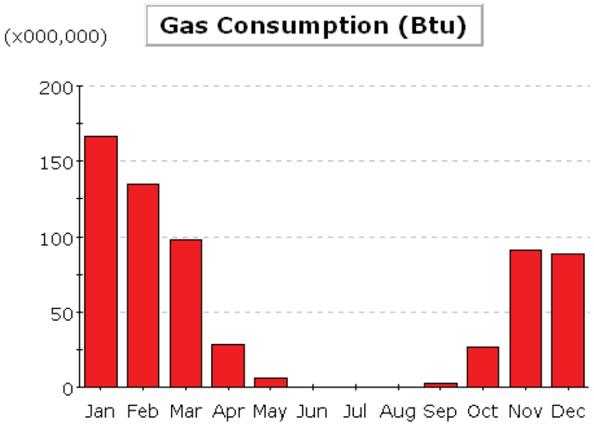

Figure 3. EQuest simulation output showing annual energy consumption for space heating taken at the nominal conditions for the wood-frame building category described in Section 2.3.

as material construction specifications. For our needs, the data from these libraries influenced the calculations of material thermal resistance as well as the ambient temperature, wind speed, and solar gain throughout the year.

2.3 Parameter Sensitivity Analysis

Of significance to this work, campus buildings were categorized according to their building parameters. In establishing these categories, first the influence of the buildings parameters on the building heating load must be determined. Of greatest desire is the minimal number of building categories that adequately estimate the total campus heating load and provide sufficient resolution to conduct a retrofit analysis to estimate the feasible energy reductions. As expected, there exist several combinations of building parameters for which each distinct set of parameters could represent a single building category. For these reasons, we conducted a parameter sensitivity analysis. Should a parameter have a relatively small influence on the heating load, it was not considered as a parameter for which a specific building category should be distinguished.

The conductive heat loss from the building relates to the thermal resistance of the exterior surface materials of the walls, attics, windows, and even doors, such that $\frac{kA}{\Delta x} = \frac{1}{R}$ where R is the overall thermal resistance (R-value). Therefore the conductive heat losses are a function of building parameters that relate to material thermal resistance ($Q_{conduction} = f(R - value)$). The convective heat transport through the wall is driven by the air infiltration rate (air leakage), such that the heat transfer coefficient is a nonlinear function of the infiltration rate ($\bar{h} = \alpha_1 \dot{m}_{air}^{\alpha_2}$). The convective heat loss from the exterior wall surface to the ambient depend on the exterior wall surface conditions, which influence free or forced convection, as well as the temperature gradient. Assuming moderately low exterior wind speeds, one would expect free convection from the building exterior surface, however, this is not a controllable building parameter. The radiative heat losses are predominantly driven by the building surface emissivity, quantifying the ratio of the radiation emitted by the surface to that by a blackbody. The controllable building parameters which most influence the radiative heat losses are the material surface, finish and color ($Q_{radiation} = f(\varepsilon)$. In establishing the building categories, using this simple perspective, we then chose to focus on wall and attic R-values, the fraction of the building exterior surface area that is comprised of windows, the exterior surface color, and the air infiltration rates.

In order to examine the influence of these building parameters on annual heating loads, we constructed a model of one of the Smith College wood frame buildings (Haven House). Weather data were taken from a neighboring community in Amherst, MA. This building was built by the College in 1899, and has a 5300 ft^2 footprint, a total gross occupied area of 21,768 ft^2 on four floors, a predominantly rectangular shape oriented with the greatest length east-west, wood frame, a flat slate roof (modeled as roof shingles due to the material limitations in EQuest), a wall with no insulation and 2x4 wood framing (16 inches on center), an attic with no insulation, a 12 inch concrete slab on grade (earth contact) with no interior finish, wood flooring (2 inch plywood underlayment), and single pane glass windows with 30% net wall surface area coverage. From conducting blower door tests on two load bearing masonry residential buildings (Lawrence and Morris House) that are nearly identical in age, construction, layout, and function, we found that the the air infiltration rates are approximately 0.08 cfm/ft^2 of building exterior surface area (0.97 cfm$_{50}$/ft^2). The infiltration rates resulting from these blower door tests were used as our nominal conditions (for those buildings that had not been sealed), as opposed to the EQuest default value of 0.03 cfm/ft^2. There are no overhangs, blinds, or skylights. The minimum HVAC design air flow was chosen to be 0.50 cfm/ft^2.

The activity areas are 60% residential bedroom space, 15% residential living space, 15% corridors, 5% bathrooms, and 5% kitchen and food preparation space. These structures are considered to be occupied from Aug 24-Dec 19, Jan 7-Mar 22, and March 30-May 10. Two occupancy profiles are then used to model the Non-HVAC end uses. The end uses considered were interior lighting and plug loads. When unoccupied, all of these end uses were set to operate throughout the day at 5% of the installed rate of consumption. When occupied, these end uses vary from 5-90% of the installed capacity throughout the day. The installed capacities are shown in Table 1. End uses not modeled included process loads, motors, air compressors, interior task lighting, exterior lighting, domestic hot water, kitchen preparation and refrigeration. It is important to note that many of the residential buildings considered do have kitchen spaces, but they are no longer being utilized to their original capacity, thus they

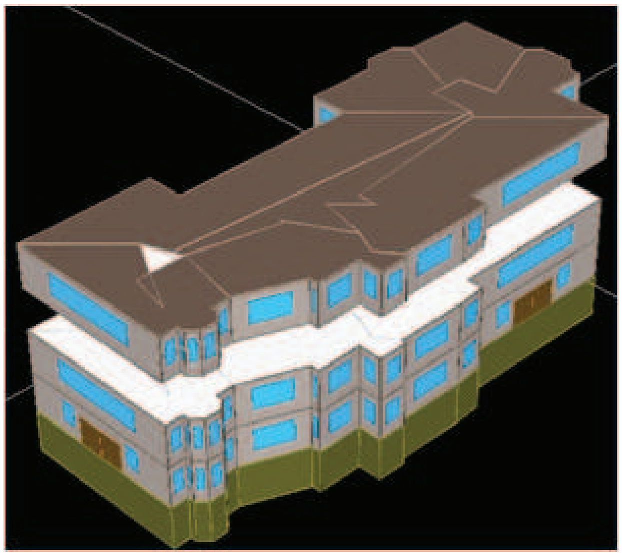

Figure 4. EQuest model constructed for sensitivity analysis used to guide building categorization. This model serves as an estimation of the heating loads for the wood frame building category.

have not been considered as having an appreciable sensible heat contribution.

When the building is being heated, the indoor core temperature is kept to 70°F while occupied and 64°F while unoccupied. To model the one pipe steam system with floor radiators, a natural draft steam boiler combusting natural gas was used with an 80% boiler efficiency. The resulting annual heating load at these nominal conditions was estimated to be 759 MMBTU (34,900 BTU/ft^2).

Table 1. End use installed consumption (W/ft^2).

	Interior Lighting	Plug
Residential	0.5	0.3
Corridor	0.57	0
Kitchen	1.19	1
Restrooms	0.77	0.1

The sensitivity of the annual building heating load as a function of the air infiltration rate is shown in Figure 5. We considered infiltration rates ranging from the nominal conditions we found with blower door testing to that requiring mechanical ventilation. Of critical importance, we were interested in determining whether the relationship between the heating load and the infiltration rate was nonlinear, also indicating the need for a target air exchange rate for maximal payback. Clearly, over the range of infiltration rates considered, there is a relatively linear relationship between the infiltration rate and the annual heating load. As expected, the heating requirements decrease as the air infiltration rate decreases and reducing the infiltration rate can result in significant energy savings, 26%, as is well established in literature. Of critical importance to us, is whether or not this parameter should be included in building categorization. For parameters which result in a reduction in the heating load of greater than 10%, we recommend that it be considered. For our particular campus, very few buildings have been properly sealed, therefore sealing was not a parameter which influenced our categorization.

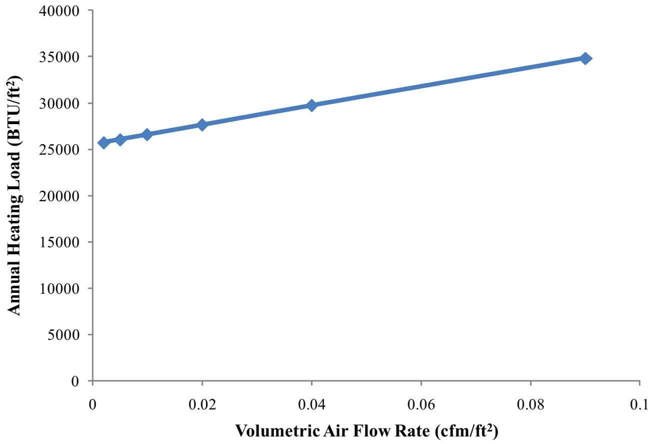

Figure 5. Sensitivity of annual heating load on the volumetric air flow rate from the building (air infiltration rate).

The sensitivity of the annual heating loads to the overall thermal resistance of the exterior walls or attic is shown in Figure 6. Here we have estimated R-values using material thermal conductivities and thicknesses with layer by layer construction. As expected, there is a reduction in the heating energy consumption due to added attic insulation, resulting in a 3% reduction in the annual heating load. For attic overall thermal resistance of up to an R-value of 20, the most significant fractional decrease in annual heating load is observed. Further insulation does not appreciably reduce the annual heating load. However, it is important to note that this degree of insulation does assume that the insulation is uniformly packed and is well sealed at the edges. The overall thermal resistance of the exterior walls has a significant influence on the annual heating loads (up to 12%), however is often far more constrained in the type of insulation and application due to the building architecture. It is important to note that in most wood frame or mason veneer buildings of this age the wall cavity available for insulation does not permit R-values greater than 12. Therefore, adding further insulation would require building internal wall partitions or building outside the building exterior at a considerable economic cost.

In considering the heating energy consumption due to con-

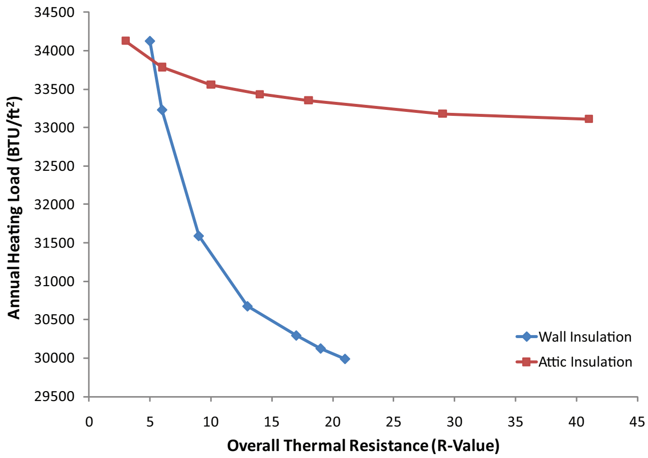

Figure 6. Influence of the overall thermal resistance of attics and exterior walls on the annual building energy consumption for space heating.

duction, it is important to note that the conductive heat transfer is a linear function of thermal conductivity and is not sensitive to the location over which the insulation is applied. That said, the walls have a larger exterior surface area than the attic. Due to this larger surface area, insulating the walls will decrease the total annual heating load more appreciably than insulating the attic. The cost to insulate, and structural modifications required, will be considered in the retrofit analysis. In deciding whether the extent of the existing insulation should be considered in categorizing buildings, we considered the potential reduction in annual heating loads, shown in Figure 6, the variability in existing levels of insulation for all of the buildings, as well as the potential payback period. Due to the rapid payback and ease with which the retrofit can be performed, we opted to include attic insulation as a building parameter worthy of categorizing despite its relatively small contribution to the overall reduction in annual heating loads.

Changing the net floor to ceiling fractional (single pane glass) window surface area by 10% greater than or less than the nominal value of 30% has a 3% influence on the annual heating load. Due to the large variability in window placement and size across the building stock, the relatively small contribution this parameter has on overall building heating requirements, this building parameter was not considered in the building categorization.

In considering the exterior surface color of the building, we found that the surface color did not significantly influence the annual heating loads (2.6%) over the range from an absorbency of 0.4-0.9. This range spanned the external color range of the Smith College buildings. As a result, neither the building color or the surface type were considered as building parameters warranting their own building category.

2.4 Final Building Categories

Following the sensitivity analysis, eleven building categories were defined based on the level of attic and wall insulation as well as the construction type. With construction details for each of the 79 buildings, three categories of buildings based on construction material were identified. The three categories were Load Bearing Masonry Buildings, Masonry Veneer Buildings, and Wood Frame Buildings. These three construction types included most of the buildings of interest. Some buildings were hybrids of the above categories; for example those having partial wood and partial masonry structures due to additions since original building construction. These buildings were assigned a category based on the material that covered the majority of the exterior surface area. Wall details of each of these construction types were developed and specific thermal resistance values were calculated for each of these categories, as shown in Table 2.

Table 2. Calculated thermal resistance values (R-values) for each building category.

Building Type	**Wall R**	**Attic R**	**Category**
Masonry Veneer	4.5	3.0	1
Masonry Veneer	4.5	13.6	2
Masonry Veneer	4.5	44.5	3
Wood Frame	3.2	3.0	4
Wood Frame	3.2	13.6	5
Wood Frame	3.2	44.5	6
Wood Frame	12.2	13.6	7
Wood Frame	12.2	44.5	8
Load Bearing Masonry	5.5	3.0	9
Load Bearing Masonry	5.5	13.6	10
Load Bearing Masonry	5.5	44.5	11

The possible extent of insulation in the buildings included the degree of insulation in the walls and the roof. Walls without additional blown or rigid insulation were given a category as well as those walls which were satisfactorily insulated. Attics with R-values that were significant (near R-45), had some insulation (near R-14), or no insulation (near R-3) in the roof cavity were categorized. If a building was determined to be in an unknown category, it was assumed to have no insulation in the roof/attic or walls. Additionally, if a construction type did not have any buildings classified within the category, then that category was discluded from our analysis.

For example, due to the construction of load bearing masonry, the only possible way to improve the thermal resistance of the walls would be to build out from the current walls (expanding the exterior) or into the living space (reducing occupancy area). Thus adding insulation to the walls of the buildings would require significant alteration to the building resulting in a significantly longer payback period. There is no precedence for the college to build in or out on any currently standing buildings on campus solely for better wall insulation. Therefore, there were three classifications of insulation determined for the load bearing masonry associated with attic conditions, as can be see in Table 2.

The wood frame buildings had four degrees of insulation. Due to the ease of blowing insulation into the wall cavities as well as into the attic/roof cavities, there was a broader range of insulation quality observed across campus. Wood frame buildings with insulated walls were considered to be fully insulated with the entire interior wall cavity filled (resulting in an overall R-value of 12.2). For attics that were inaccessible, if the wall cavities were insulated it was assumed that the attics were also insulated.

3 Building Heating Loads

Given the building categories previously established, specific buildings were selected to represent each building category and then modeled in EQuest. Knowing the number of buildings in each category, the total campus annual heating energy consumption (of the 79 buildings considered) was then estimated. Because there was no meter data to validate our energy estimates we compared our estimates to those provided by facility management for the total campus fuel use. The technical and economic feasibility of various retrofits was then considered to assess the energy reduction potential of various thermal envelope improvements. Once the possible investment in thermal envelope improvements was determined, payback periods of scheduled retrofits were estimated.

3.1 Current Heating Loads

The three different building constructions (load bearing masonry, masonry veneer, and wood frame) were modeled following the same process as described in conducting the sensitivity analysis. Generally, the performance of each building was of a similar magnitude when normalized by the building square footage, as shown in Figure 7. As expected, the annual heating loads were lower for categories that contained buildings with insulation. The load bearing masonry buildings have higher heating loads than the wood frame and masonry veneer. Generally, the load bearing masonry buildings have a larger footprint. The annual heating energy consumption ranges from 27,400 BTU/ft^2 to 37,200 BTU/ft^2 across all building categories.

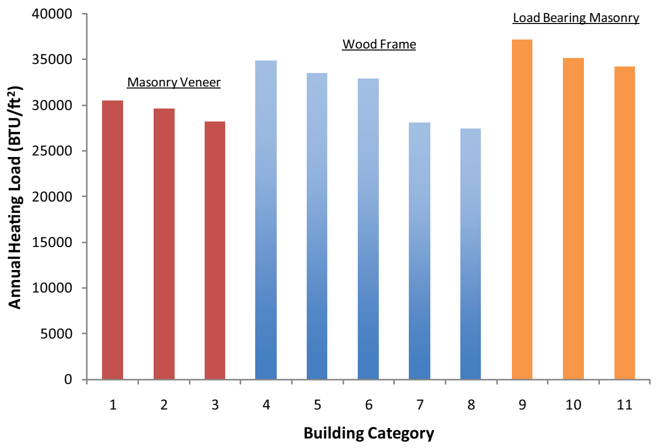

Figure 7. Annual heating energy consumption for each building category.

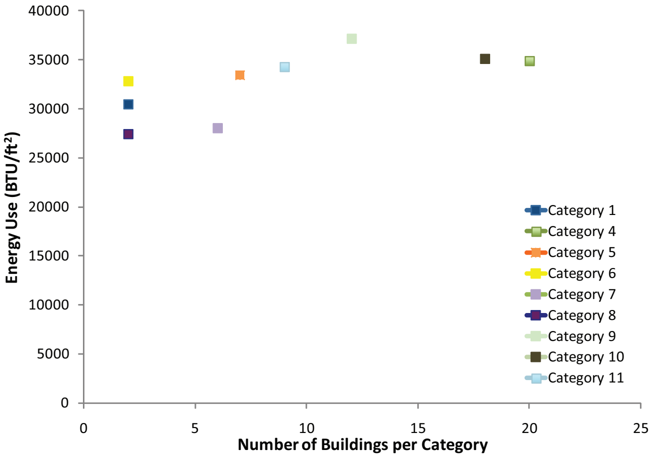

Figure 8. Annual heating energy use as a function of the number of buildings in each category.

The energy use was also mapped to the number of buildings in each category to assess the potential energy reduction of a specific retrofit as seen in Figure 8. The categories with the largest number of buildings are the wood frame with no insulation (category 4) and the load bearing masonry with some attic insulation (category 10). There are very few masonry veneer buildings, thus retrofits possible for this specific construction type are not recommended due to their minimal heating energy reduction when considering campus wide heating energy use.

The total annual heating energy consumption estimate was then compared to the campus fuel energy use. Over the past 10 years, the total campus fuel energy use for space heating and domestic hot water supply result in an energy consumption normalized over the entire campus building footprint of 75,000

BTU/ft^2/yr. While this value is much larger than our range, this average includes buildings on campus that have drastically higher heating loads (larger buildings with complicated architecture and HVAC systems and laboratory spaces) as well as domestic hot water needs. The buildings we are considering in our analysis occupy approximately 54% of the campus footprint. If these energy intensive buildings require approximately two times the normalized heating load of a residential or administrative building, then our estimates are reasonable. While a more direct means of validating our methodology is desired, without meter data, it is not feasible to do so.

Assuming each building performs as estimated by the building modeled for that category, given the number of buildings in that category, the current campus annual heating energy use of the 79 buildings considered was estimated to be 57,000 MMBTU/yr. Note, this total heating load is less than that presented in our Climate Action Plan [1] due to a refinement on the assumption of the building infiltration rates resulting from recently completed blower door testing of select campus buildings.

3.2 Potential Heating Load Reductions

Taking into account the potential retrofits, a feasibility analysis of the buildings was then completed to determine which retrofits could be implemented for specific building types. It was determined that sealing, insulation improvements and window replacements could be implemented in load bearing masonry, masonry veneer, and wood frame buildings in different ways and to varying degrees dependent on the building construction.

Load bearing masonry buildings do not have an internal wall cavity. Therefore, in order to improve wall insulation, internal or external walls would need to be built to create a cavity for holding insulation. Construction of external walls was deemed infeasible due to the College's desire to maintain the existing building aesthetic of 19th century New England architecture. While it would be feasible to build internal walls, it would be very costly. In contrast, the masonry veneer and wood frame buildings have open wall cavities that are easily accessible. Most buildings have easily accessible attics. All masonry veneer and wood frame buildings were assumed to be capable of receiving insulation in both the walls and attics. It was also determined that all building categories could be insulated in the attics due to easy access. Sealing and window replacements were assumed to be feasible for all building categories. Buildings that have recently been completely renovated were not considered as candidates for sealing and window replacements due to prior deferred maintenance on a number of campus buildings.

To analyze the effects of energy reductions, chosen retrofits were modeled for each building category as seen in Figure 10. These retrofits were determined by reducing infiltration rates from the nominal 0.09 cfm/ft^2 to 0.03 cfm/ft^2, adding attic (R-20) and wall (R-12) insulation. Heating energy consumption is significantly decreased with sealing. Less significant energy reductions result due to attic and wall improvements, following sealing improvements. There is no energy reduction for wall insulation in load bearing masonry buildings due to the infeasibility of insulating those walls. Note, this target infiltration rate was set as a performance based standard that is being pursued by Smith College in contract negotiations with energy retrofit contractors.

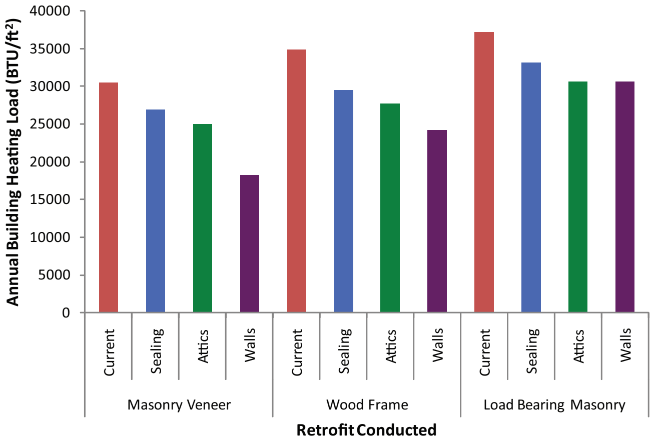

Figure 9. Annual energy reduction potential of chosen retrofits by building type starting from current conditions and sequentially adding retrofits.

To determine the feasible energy reduction potential, we included sealing, insulation improvements for all possible walls and attics, as well as window replacements (upgrading windows to low-e double pane glass) for all building categories. There is a potential to reduce the annual heating loads by 40%, from 57,000 MMBTU/yr to 34000 MMBTU/yr. The masonry veneer and wood frame buildings energy use can be reduced by a more substantial amount due to the feasibility of wall insulation. Due to the long payback period for wall insulation of these load bearing masonry buildings, wall insulation improvements were not determined to be feasible (as previously described) and were not considered in the maximum possible energy reduction potential.

3.3 Strategic Planning

Fast payback periods are attractive when considering energy reduction retrofits in college planning, therefore the cost of these retrofits was extremely important in showing immediate monetary benefits as well as environmental benefits observed in reducing the carbon footprint. While we conducted a cost analysis to aid in the process of strategically planning future renovations, considering renovation and maintenance needs, the details of this analysis are not pertinent to other Colleges, as decisions of outsourcing labor and bulk material purchasing power vary dramatically from campus to campus. Rather, the process by which we conducted this analysis is relevant to other planners undertaking

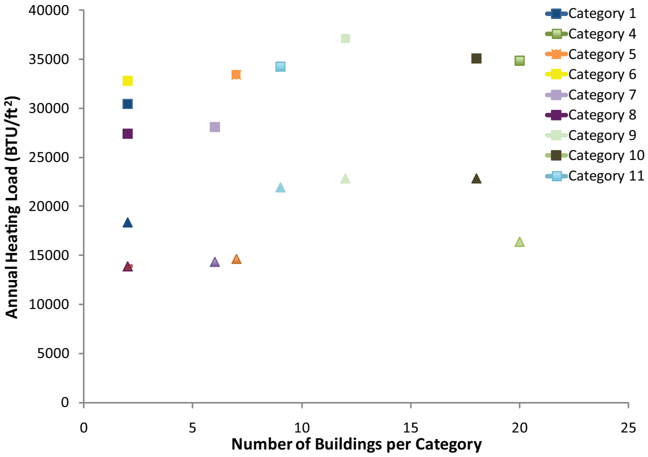

Figure 10. Energy reduction potential for each building category based on all possible retrofits.

such an effort.

The payback periods we calculated ranged between 0.1 years (for sealing) to 30 years (for window replacement) depending upon the type and extent of the retrofit. With retrofit cost details, a sensitivity analysis can be conducted to explore the retrofits with the greatest cost and energy savings uncertainty. Of greatest power, the heating load estimation methodology we present here enables a detailed assessment of the economic savings due to campus investment in other carbon saving activities or even compared to the purchase of carbon offsets.

4 Conclusions and Future Work

A methodology for categorizing buildings and estimating the space heating requirements of those categorical buildings, the campus wide heating loads for unmetered buildings was estimated and analyzed. Load bearing masonry buildings were found to have the greatest space heating requirements, normalized by occupied floor surface area, followed by wood frame and masonry veneer structures. By considering building heating loads, institutions can better quantify their energy use, analyze retrofit feasibility and the potential for energy use reduction as well as the payback periods for retrofit scenarios. The Smith College Department of Sustainability utilized this methodology to analyze their current heating energy needs and considered the potential for heating load reductions. With proposed retrofit plans of a 7-year simple payback period or less, the annual thermal energy losses of the college could be reduced by 40% of the current use, from 57,000 MMBTU/yr to 34,000 MMBTU/yr. With a more aggressive energy reduction plan, energy performance improvements could reduce the use to 30,000 MMBTU/yr, which equates to a range of 13,000-23,000 BTU/ft^2/yr across the building categories.

Well established and accepted standards and guides are available to aid in the process of selecting and conducting a specific building retrofit based on a variety of metrics. Our contribution is in providing a method for approximating the heating energy consumption of buildings across a large and varied building stock without the investment required in simulating each individual structure. This method allows for energy performance to be used, as an additional metric to maintenance needs, for strategic planning. Once buildings are selected as candidates for renovations (based on energy performance and maintenance needs), accepted standards and guidelines can be employed for energy retrofits. At Smith College, select buildings have been recently metered for both steam and electric energy use. With these data, detailed models are being constructed for retrofit planning guided by the method outlined here.

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