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MUTUAL EFFECT OF BUILDING SECTIONS ON ENERGY RETROFIT PLANNING

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Abstract: Understanding the interaction between building sections and its impact on the energy performance of individual sections and the entire building can help improve decision-making for retrofit planning. To extend the understanding of the complex relationship of building sections, this study focuses on the interaction of different sections of a multifamily residential building with several housing units. A sample condominium with multiple individually owned housing units (thus, call for independent decision making for retrofit planning) has been modeled for the purpose of energy performance evaluation. The energy performance of housing units under different retrofit scenarios with various perspectives has been assessed; One is the greedy scenario, which focuses on the improvement of just one unit and the other is a non-greedy approach in which other units and the energy conservation in the entire building will be considered in the plan. This research aims to demonstrate the effect of collective decision-making and to assess the effect of solely made decisions on the energy performance of the whole building. The findings show that the mutual impact of building sections can benefit adjacent units even though they are not directly participating in the retrofit plan, and this implied interaction may lead to a more realistic insight into the energy consumption of buildings. The findings also demonstrate that if owners choose the proper non-greedy scenario, they can improve the benefit for other units and the entire building. The result of this study can be helpful to form a cost-effective retrofit plan for designers.

Keywords: Building interaction, Energy efficiency, Simulation, Retrofitting plan

1 Introduction

Energy conservation in buildings, which account for more than 40% of the nations' total energy consumption (BED-Book 2011), has received considerable attention in various research efforts. It is evident that physical properties of the buildings as well as weather profile are among the critical factors in energy consumption. In majority of the energy conservation efforts, these properties are used for quantification of energy consumption and evaluation of performance at building level and potential strategies for energy efficiency improvement are explored. Therefore, in the conventional approaches, an isolated building is studied and the retrofitting plan will be decided based on the building features as a whole. In recent years, a variety of simulation methods and software applications have been developed that can provide a wide range of information such as HVAC systems and equipment, zone loads, building envelope, lighting, and solar infiltration (Crawley et al. 2008). With these developments in simulation tools and methodologies, researchers have been able to study various strategies to explore optimization of energy efficiency in buildings through alteration of envelope features, HVAC attributes or architectural modifications (Ascione et al. 2010; Olofsson, Andersson, and Sjögren 2009).

Benefiting from simulation strategies, at a different scale (i.e., building network level), it has been shown that due to close spatial relationship of buildings a non-negligible difference could be observed between energy consumption of single-building view and network view (Pisello et al. 2012), which was defined as Inter-Building Effect. (Laura Pisello et al. 2012) evaluated the performance of buildings in terms of their indoor operative temperature dynamics and verified the effect of urban morphology on indoor thermal behaviors. Therefore, in order to assess a more realistic insight of energy consumption, studies (Laura Pisello et al. 2012; Pisello et al. 2012; Xu, Taylor, and Pisello 2014) have evaluated the performance of the buildings in a network. Accordingly, achieving the full potential of energy saving and a more accurate prediction of a building's performance calls for examining all variable features of the target building. These features include envelope attributes, HVAC attributes, urban texture, weather profile and behavior of neighbor buildings.

Considering the aforementioned scales of single building and buildings network, we have investigated the effect of a smaller scale, namely the mutual effect of sections in one building. This perspective addresses a gap in research by investigating (1) how different sections of one building can interact with each other and affect the energy consumption, and (2) whether it is important to consider differences in physical characteristics at building section scale. Therefore, in this study, the interaction of building sections will be explored by changing the physical characteristics of the building sections with real-world implications of retrofit planning. The main implication of the findings is for the condominium buildings where each housing unit has the authority of performing separate retrofitting plan. By considering these interactions, a slight change in the plan can benefit other units and the whole building. Making decision based on the collective benefit can also be an alternative for single buildings retrofit planning based on the findings of this study.

The rest of the paper is organized as follows: Section 2 describes current studies on the improvement of energy performance plans and proceeds with defining the objective of this study. Section 3 summarizes the simulation process and description of multiple scenarios for simulation. In section 4, analysis and results will be presented. Section 5 presents a discussion on the results. Finally, in section 6, the implication of findings will be discussed, and the limitations and future research potential will be outlined.

2 Background and Research Objective

A principle concern in operation of the built environment is to improve energy consumption of buildings compared to their current state. The research efforts could be grouped in two categories of human-centered and building-centered. In the former, studies investigated the relationship between occupant behavior and energy performance of buildings. This category could be further characterized by features such as occupancy schedule (Santin 2011; Steemers and Yun 2009; Balaji et al. 2013), thermal comfort preferences (Jazizadeh and Becerik-Gerber 2012; Jazizadeh, Ghahramani, et al. 2014), multi-agent interactions between humans and devices (Klein et al. 2011), and feedback systems for occupant behavior modification (Jazizadeh et al. 2013; Jazizadeh, Becerik-Gerber, et al. 2014). For the efforts in the building-centered category, studies have extensively explored the energy consumption associated with a building as a single entity (Jaffe and Stavins 1994; Bichiou and Krarti 2011). This is the first step to set the target level of energy and improve the energy efficiency of the building. To this end, many researchers focused on evaluation of the energy consumption of buildings by characterizing the envelope features(Tuhus-Dubrow and Krarti 2010), indoor thermal behavior(Laura Pisello et al. 2012), HVAC equipment and morphology of buildings(Bichiou and Krarti 2011; Ratti, Baker, and Steemers 2005). In a third sub-category of studies, in addition to aforementioned characteristics, researchers defined a new concept that is due to mutual influence of buildings in close spatial relationship and explain the complex interaction of buildings within an urban network of buildings (Pisello et al. 2012). It has been shown that this Inter-Building Effect (IBE) which can be the result of mutual shading and mutual reflecting (Pisello et al. 2014) can be a non-negligible amount of energy depending on the climatological context (Jiang et al. 2015). They assessed up to 42% inaccuracies caused by considering building as a single unit rather than a network of buildings in the energy performance prediction based on the climatological and seasonal level.

For comprehensive exploration of potential energy saving in buildings, all the aforementioned parameters should be taken into account. In this study, we argue that a fourth sub-category of considerations should also be taken into account. This category focuses on the effects that variable physical characteristics of different sections in a building could bring about. This is especially important in multifamily condominium buildings with independent authority for each unit, in which decision-making is usually carried out based on the units benefits. This research is built upon the previous research(Laura Pisello et al. 2012) concerning the mutual effect of buildings when they are in a network. The objective is to study the mutual impact of different spaces in one building on energy performance and look for the interaction of different sections at single-building level.

Existence of the interaction is mainly due to the effect of a component operation on the microclimate around it and its consequential effect on the energy performance of the other components. In contrary to focusing on individual decisions for retrofitting plan, collective decision-making can be applied in order to conserve the energy consumption to a higher potential level. By implementing various retrofitting plan and simulation analysis, the objective is to evaluate the potential of a retrofit plan that avoids a greedy energy saving strategy (i.e., just for one unit) and benefit adjacent units and more importantly the whole building (i.e., non-greedy strategy). The non-greedy strategy could also be interpreted as an eco-friendly one, which gives higher weight to environmental concerns by improving the whole building energy. Discovering the extent of how much energy performance can be improved could help the decision makers from different aspects including: (1) better insight for retrofitting decisions, and (2) identifying a plan, which could optimize the energy consumption of a building compared to price.

3 Methodology

Simulation studies were used as the main approach in evaluation of interaction of building sections. This process primarily assesses the mutual impact of building sections by evaluating the effect of different scenarios on the energy consumption of whole building. The aim is to see if there is a direct relationship between the building sections with spatial relationship and the energy consumption behavior of them. We have hypothesized that due to the mutual impact of building sections group retrofitting can be more beneficial for the whole building and units with almost the same effort of retrofitting.

3.1 Simulation Process

To explore the potential interaction of building sections, a test case using computational simulation tool, EnergyPlus has been developed. The main reason for choosing EnergyPlus is the capability of software to integrate the building envelope, HVAC system, water and renewable energy into the simulation and how it can be coupled with other interfaces to provide the visual aspect of simulation (Crawley et al. 2001). For the purpose of this study, the Openstudio platform which can be used as a plug-in of SketchUp has been chosen as the main tool of simulation. The analysis has been conducted based on a realistic physical condominium building in Gunnison, Colorado as one of the coldest cities of U.S. The main reason for choosing a cold city for the simulation is not only the large amount of heating load in thermal zones but also, significant changes expected to see in the loads after physical changes (i.e., retrofitting). A 2-floor building with six housing units at each floor was modeled and the middle unit of front row of first floor was considered as the control unit. Figure 1 shows the layout of the model.

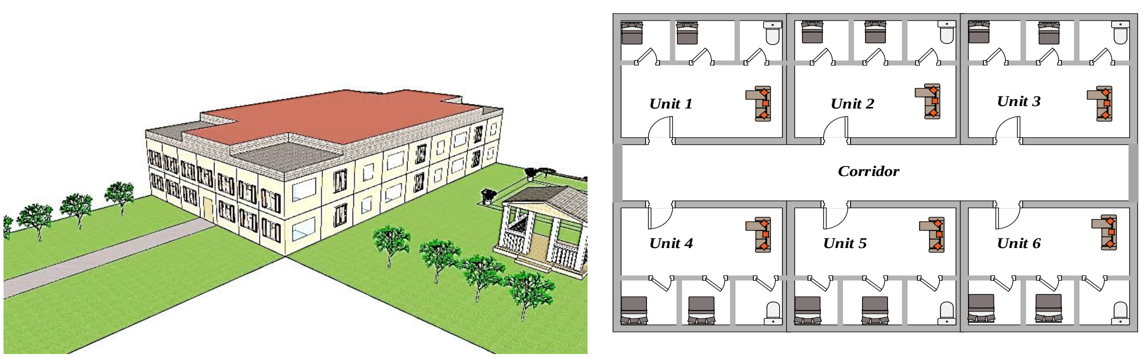


Figure 1: Model of multi-family residential condo

For the baseline and comparison purposes, two sets of construction materials with their heat transfer coefficient has been defined in **Error! Not a valid bookmark self-reference.**. The first set which is named the baseline belongs to the normal case where no retrofitting and modification is applied to the units. The second set of construction material are the materials used for the walls that will be retrofitted. To evaluate the performance of the building under retrofitting scenarios, the heating load of each thermal zone in the winter was selected as the metrics. That is mainly due to the type of retrofitting scenarios implemented on the model in which the insulation and improving the indoor thermal performance is the main focus.

Table 1: Architectural description

Description	Item	U value (W/ (m^2. K)
Baseline	External wall	1.487
	Partition	2.551
Retrofitted	External wall	0.502
	Partition	2.358

3.2 Procedure of Evaluating the Interaction of Building Sections

Three different retrofitting scenarios were developed and implemented to assess the effect of section interaction on energy consumption of building. The considered retrofitting scenarios focused on insulation of the walls as one of the most effective factors in improving the energy performance of a building. The insulation of the wall and change in the material and texture can decrease the thermal conductivity and thus heating load. The interaction of sections can be observed after implementing the retrofitting plans from different in energy saved.

Table 2: Characterization of modified elements in retrofitting scenarios

Scenarios	Component	Properties
1	Unit 1- External walls	Super insulated brick/block external wall
2 (Greedy scenario)	Unit 2 - External walls	Super insulated brick/block external wall
	Unit 2- Internal walls	200 mm cast concrete cavity wall with 50 mm air gap
3 (Non-greedy scenario)	Unit 2- External walls	Super insulated brick/block external wall
	Unit 1- External walls	Super insulated brick/block external wall
	Unit 1 and 2- Shared wall	Project Partition

The greedy scenario is defined as the case when the owner only considers the benefit for the target unit itself, and none of the other units was involved in the process of retrofitting. On the other side, non-greedy scenario tries to benefit the whole building and other units as much as possible and to the extent that its own gain would not be affected considerably. In fact, non-greedy scenario tries to incorporate other units in the retrofitting plan while almost the same amount of effort as the greedy scenario has been made. Table 2 represents the detail of retrofit scenario for each case. In the first scenario, the insulation of external walls of unit 1 is improved. Since these walls are not shared with other units, it is expected that unit 1 is the only unit that benefit the energy saving. Scenario 2 and 3 are designed to compare two cases of retrofitting plan. Greedy one which focus on the saving of unit 2 and insulate all the surrounding walls to save energy and non-greedy one that allows unit to be a part of retrofitting plan and share the benefit. In all cases, control units (i.e., unit 1 and 2) were remained the same and their energy performance were monitored in addition to the whole building's performance.

4 Analysis and Result

The simulation results have demonstrated that there is a synergy effect in the building energy consumption, which causes the total energy saving of the building, be more than the amount of energy saved due to retrofitting of only unit 1. "Saved energy" is calculated by subtracting the energy consumed after retrofitting from the energy consumed at the baseline. Comparing the amount of saved energy for the whole building and unit 1, which is shown in Table 3, demonstrate the synergy effect as a result of building sections. As it was mentioned in the scenarios description, it is expected that the whole building saving be about the same amount of unit 2 saving. However, it can be observed the total saved energy is more than the saved energy of unit 1. The performance variation for the heating load is between 14.92-48.42. These findings highlight the existence of interaction between building section and how important the perspective can be in the planning of the retrofitting scenario.

Table 3: Energy saved after implementing retrofitting scenario 1(KWh)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Unit 1												
Heating Load	198	127	94	176	123	36	25	45.38	141	180	133	425
Whole Building												
Heating Load	438	175	138	223	147	47	34	58	174	228	190	487

In Figure 2, the saved energy after implementing retrofit scenario 1 and how the interaction of spaces can make difference in the whole building energy saving are presented. The simulation was running over the year, and the monthly result is shown in the figure.

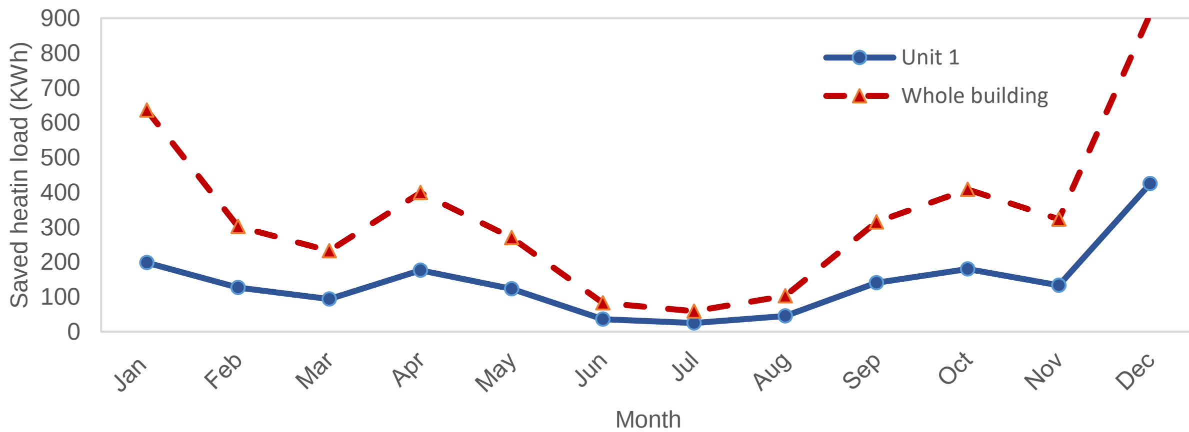


Figure 2: Heating load saved after retrofitting scenario 1

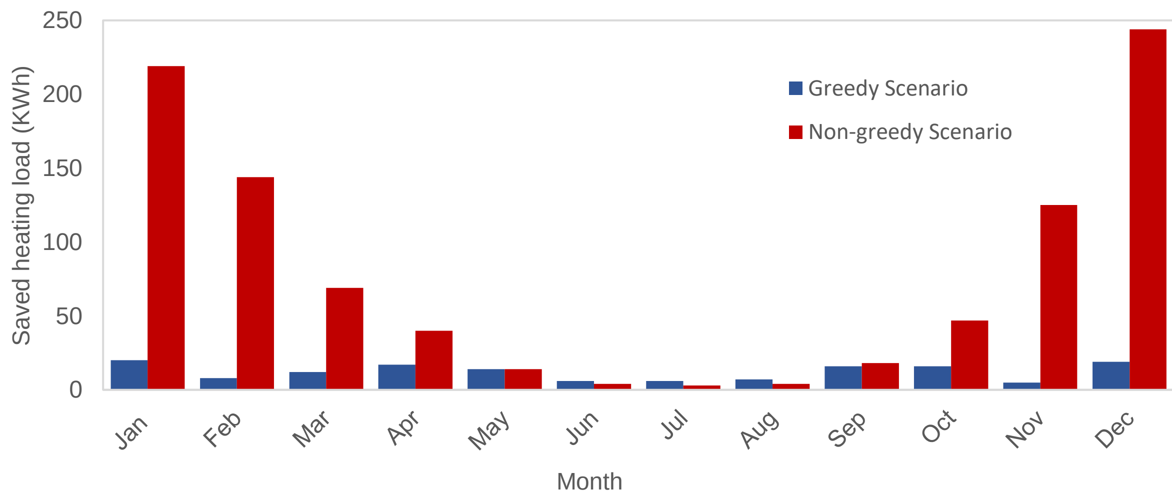
The observation from Figure 2 show that the interaction of spaces in a building may lead to the idea of non-uniform and non-greedy retrofitting scenarios in a way that benefit the whole building and other units more than the greedy retrofitting plans that focus on one unit. For this purpose, a baseline retrofit scenario for control unit 2 was implemented and the insulation of surrounding walls was improved according to the Table 2. Thereafter, another retrofitting plan was performed in which the control unit 2 receive less extent of retrofitting but unit 1 is involved as a part of plan. The later scenario is called non-greedy scenario in this paper.

The data presented in Table 4 demonstrates an interesting result for the energy saving of these two scenarios. Although in the greedy scenario, which is focused on the improvement of the unit 2 performance, unit 1 heating load decreases to some extent, the non-greedy scenario improve the performance of unit 1 and the whole building more significantly.

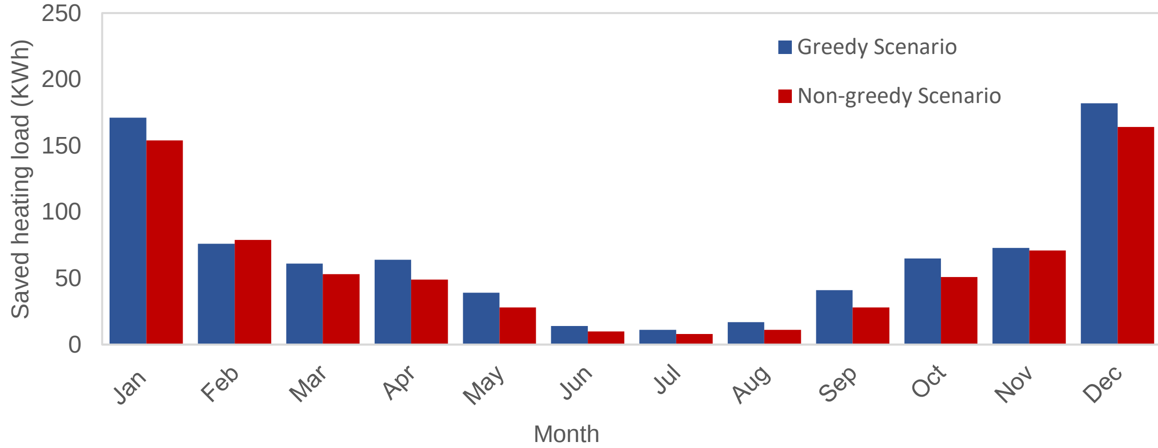
Table 4: Energy saved after implementing retrofitting scenario 2,3 (KWh)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Unit 1												
Greedy	20	8	12	17	14	6	6	7	16	16	5	19
Non-greedy	219	144	69	40	14	4	3	4	18	47	125	244
Unit 2												
Greedy	171	76	61	64	39	14	11	17	41	65	73	182
Non-greedy	154	79	53	49	28	10	8	11	28	51	71	164
Whole Building												
Greedy	246	107	118	144	95	38	30	44	103	146	123	267
Non-greedy	421	249	161	134	71	25	19	28	75	145	241	462

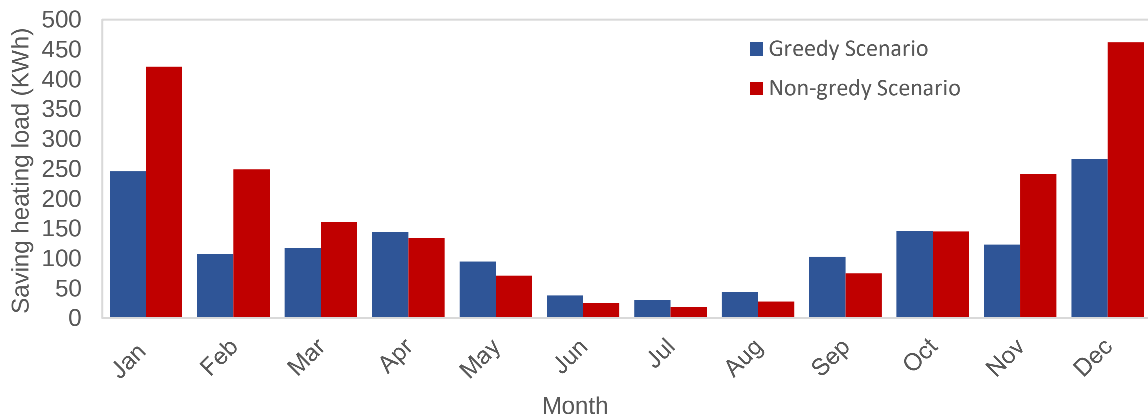
As seen in **Error! Reference source not found.**, after applying the greedy scenario , unit 2 save a considerable amount of energy compared to the slight improvement in unit 1 saving. This is not unexpected since the focus of this scenario is on the unit 2. One should notice that due to retrofitting of internal walls of unit 2, unit 1 is exposed to some degree of improvement which can be the reason of slight saving of unit 1 in scenario 1. However, the non-greedy scenario will improve the amount of saved energy in unit 1 significantly while the decrease in the efficiency of unit 2, compared to the greedy scenario, is negligible in most of the simulation period. It is also shown in **Error! Reference source not found.**-c that the entire building saving improved considerably after implementation of non-greedy scenario. This is important because almost the same effort for the retrofitting has been made (in terms of area and material, which is translated into cost) in both scenarios.



(a)



(b)



(C)

Figure 3: Heating load saved after implementing scenario 2 and 3 for a) unit 1, b) unit 2 and c) whole condominium building

To sum it up, a summary of the saving for each scenario is presented in Table 5. As it can be seen, change in the position of the walls to be retrofitted from scenario 2 to 3 can turn the unbalanced initial plan, that benefit one unit more than the others, to a more balanced one that more units participate in the plan and the benefit is shared.

Table 5 - Summary of annual energy saved (KWh) after implementation of scenario 2 & 3

Description	Scenario 2	Scenario 3
Unit 1	146	931
Unit 2	814	706
Building	1461	2031

5 Discussion

Development of strategies for optimization of buildings energy consumption is among the major principals of global energy issues. This is mainly because of the substantial role of buildings in total global energy consumption. On the other hand, it has been shown that the role of decision-makers in conservation of energy in buildings is undeniable. The number of studies focused on the effective parameters on energy consumption in order to reach to the full potential of buildings for energy saving has been increasing. However, there is a gap in examining the crucial role of interaction of building sections. This mutual impact of building sections may be a considerable amount of energy that with proper decisions can help the optimization of energy performance of buildings. Our study confirms that an interaction exists between different building sections and retrofitting of one unit in multi-owner buildings can affect the energy consumption of non-involved stakeholders. We confirmed this hypothesis by comparing the saving of the whole building and the sole unit which was the only retrofitted one.

Using the demonstrated interaction of building sections, we evaluated the effect of this interaction in different retrofitting scenarios and how it can make difference in the saved energy of the individual units and the entire building. We observed that it is possible to achieve a higher level of efficiency for the whole building and individual units by providing the owners the information about the amount of interaction. As it was shown in the scenarios and results, the owner has two options for retrofitting. The first one (scenario 2) mainly focuses on one unit and perform the retrofitting plan on the target unit solely. In the other scenario, owner has the option to benefit the whole building and adjacent unit by doing almost the same effort (that is translated to cost) of retrofitting. By choosing this scenario, the adjacent unit (here unit 1) and the whole building will save significantly more energy compared to the previous case. Although the owner has to overlook some of his/her own benefit, the gain amount of energy saved for the whole building is more considerable than the overlooked benefit. It may seem unfair for the unit 2 owner to undertake the cost of retrofitting and choose the third scenario while having the opportunity to benefit more. However, an eco-friendly thinking and direction is a worthy reasoning for choosing the third scenario.

6 Conclusion and summary

Understanding the interaction of building sections and existence of the synergy effect in the condo buildings can lead to a more efficient retrofitting plan. In this paper, we deomnstrated that an eco-friendly perspective which consider the benefit of more units in the retrofitting plan can lead to more aggregate saving. In the first part, we modeled a two-story cono building with six living units and implemented a simple retrofitting plan on the not-shared walls of the middle unit. After simulating the energy consumption of the building, we found a non-negligble differnce between the whole building saving and the retrofitted unit which can be a proof of the existence of an interaction between different sections of a building . This interaction is the main reason for the observed energy saving of the units that are not involved in the plan. This fact can lead to a change in the perspective of retrofitting plan in multi-owner buildings, where each unit can decide independently for retrofitting. In this paper, the effect of decision-making based on the collective benefit has been assessed by changing the retrofitting plan to one that benefit the entire building and adjacent units in addition to the target unit. We observed that a retrofit plan that was less efficient for the individual unit can be more efficient for the whole building and other units. The findings of this study can be used as a guideline criteria for the decision-makers to achieve a more efficient retrofitting plan.

This work can be expanded by implementing more complex scenarios with different level of insulation and diffeent pattern of retrofitting for the building. . It is necessary to examine these findings in a borader and more complex buildings. Moreover, the cost of each scenario can be a crucial parameter in choosing the scenario. Thus, implementing the cost in the decision-making plan make a more comperhensive feedback for the decision –makers. Further studies are needed to detemine whether these findings could be applied to a block of multiple buildings.

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