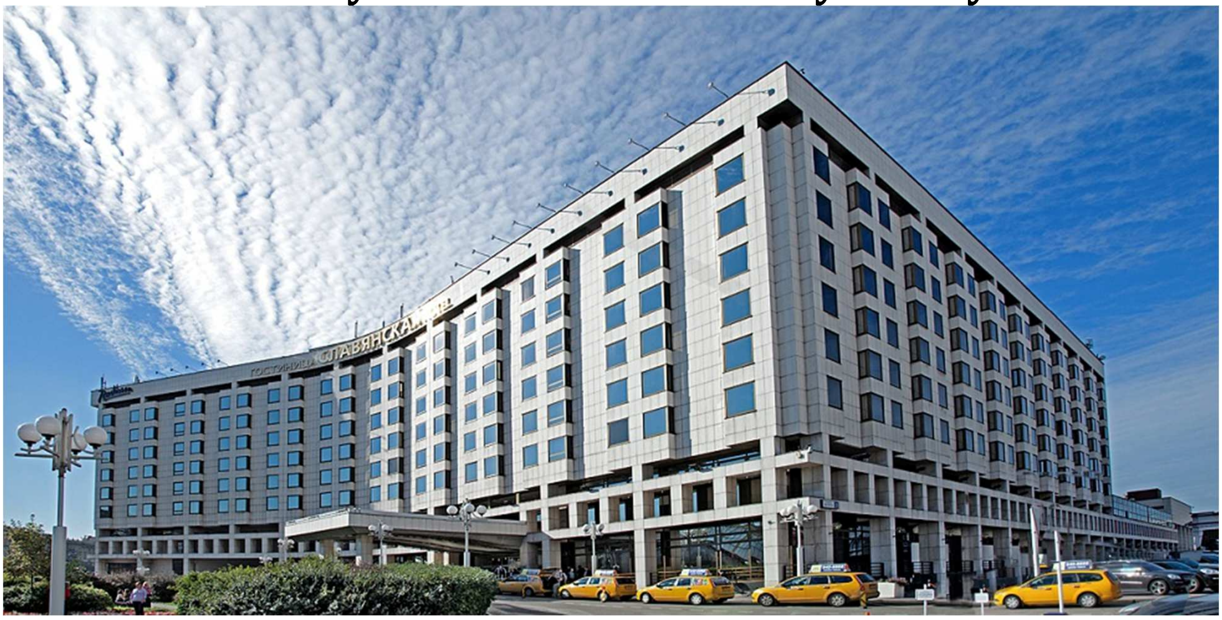
Short-term advancements and long-term visions for sustainability at the Radisson-Slavyanskaya Hotel



by
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An Interactive Qualifying Project
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degree of Bachelor of Science
by

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Abstract

The global hotel industry has become increasingly aware of its environmental impact. This report examines the practices of the Radisson-Slavyanskaya Hotel in Moscow, Russia with respect to environmental sustainability. Energy audit data, guest input, discussions with hotel management, renovation challenges, and financial calculations led us to three specific short-term recommendations and multiple long-term suggestions aimed at reducing the energy use of the hotel. The technical and financial feasibility of potential upgrades was gauged in order to provide the most practical solutions for the hotel. We focused on the central AC system, window films, and room occupancy sensors, each of which result in significant water, electricity, and steam savings for the Radisson-Slavyanskaya Hotel.

Acknowledgements

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- Alexander Drozdov, Technical Director, Radisson-Slavyanskaya Hotel

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Executive Summary

Introduction

Our project focuses on sustainable development and improvement of technical systems at the Radisson-Slavyanskaya Hotel in Moscow, with the goal of improving the hotel's environmental sustainability while at the same time reducing energy usage. Currently the hotel uses an excessive amount of energy due to various inefficient systems installed at the hotel including windows, lighting, and air-conditioning. Although the energy use of the hotel is not extremely excessive, due to the age of the building, structural aspects of the building such as windows and walls use outdated technologies, the modern equivalent of which are vastly more energy efficient.

Upgrades to the Radisson-Slavyanskaya's installed systems have been minimal, with large equipment such as laundry machines and chillers being over ten years old. Similarly, the lighting in the hotel has slowly been changed over to mostly fluorescent lights, however, overarching limitations resulting from aging electrical transformers have prevented the further upgrade of lights to the LED type. For sustainable improvements to be truly effective, we must consider the three aspects of sustainability alluded to here: economics, the environment, and social responsibility, all of which were taken into consideration when proposing our interventions for Radisson-Slavyanskaya.

Goals and Objectives

The final aim of our project was to establish a set of both short-term and long-term upgrades and programs for the Radisson-Slavyanskaya Hotel that would have the greatest possible increase of environmental sustainability, while at the same time adhering to managerial requests, renovation limitations, and financial practicality. Through background and initial on-site research, we highlighted key areas of focus for our project. We determined four objectives to meet our project goals:

1. Identify upgrades to Radisson-Slavyanskaya sustainability
2. Analyze potential solutions for sustainable impact
3. Analyze potential solutions for economic impact
4. Develop a long-term plan for the Radisson-Slavyanskaya

Objective 1
In order to successfully complete the objectives listed above, we met with hotel management including the general and technical directors. From these discussions learned of their positions on changing hotel policies and systems. An extensive energy audit conducted in 2012 of the Radisson-Slavyanskaya Hotel was the starting point for our energy use analysis. To supplement this data, a walkthrough of the hotel highlighted areas of focus for our potential equipment upgrades. Historical energy use data in the audit on electricity, water, and steam consumption served to display any seasonal trends and major users of energy.

The purpose of this information collection was to narrow down our list of possible upgrades into a manageable group of optimal changes. We used the data from the audit to find areas that were the biggest users of energy. Not only was energy use considered, but its relative importance to the hotel's function and customer satisfaction was a factor as well. We gained insight into several technical areas related to the project such as the central air-conditioning system, low-E window films, and motion detecting sensor systems for lights.

Objective 2
In order to address the environmental impact of our potential solutions, we compared the energy usage of the current system installed at the hotel with the new systems. The three main sources of energy for the hotel, electricity, water, and steam were considered in all cases. Systems that individually consumed the most energy were focused on, due to the larger significance such an upgrade would have on the overall energy profile.

Objective 3
Suitable cost of equipment is crucial to the practicality of a proposed solution. Using the pricing and specification information we obtained, we calculated the energy savings and potential profitability of implementing these upgrades at the Radisson-Slavyanskaya. Calculation of payback periods allowed us to determine what positive or negative impacts the operation and maintenance costs of the product would have on the savings discovered through a reduction in energy use. To count for the progress of technology in the hotel industry, we evaluated the payback period and return on investment of each of the proposed solutions. The result of the financial calculations determined the economic feasibility of each upgrade.

Objective 4
Based on our background research and understanding of hotel systems, we developed a set of potential solutions that could possibly be implemented in the Radisson-Slavyanskaya's future. This plan consists of two parts: technical upgrades and program recommendations. The proposed technical upgrades range across a wide variety of systems such as lighting, piping, and HVAC. The program recommendations are focused on raising awareness for sustainable development and on improving the hotel's image as a sustainable member of its community. These solutions were designed to not only reduce resource usage like the short term solutions, but to improve the hotel's sustainability in a more holistic fashion.

Findings

Through our research, we have determined that there are three main technological improvements that could be made at the Radisson-Slavyanskaya for maximum impact on environmental sustainability in the short-term. These upgrades focus on the HVAC and lighting systems of the hotel, as categorically these are the two biggest consumers of electricity in the hotel. Specifically, we suggest that the hotel install low-E window films for better insulation, upgrade the A/C chillers to more efficient models, and retrofit lighting controls in parts of the hotel to be controlled with occupancy sensors.

Window films
We found that installing light-filtering window films on window interiors can be implemented within the limitations of the Radisson-Slavyanskaya hotel, and will decrease environmental impact and boost energy savings. The ease of installing such films, coupled with their insulation properties, will serve to ultimately decrease the hotel's cost of operations and ensure this retrofit will pay for itself over time.

We performed a cost analysis to determine the feasibility of this project in the short term. Using the total cost of purchasing and installing the window films as well as the calculated annual energy savings, we concluded that this investment would pay back in 8.11 years.

Central air conditioning system
We have determined that significant strides could be made in reducing resource use at the Radisson-Slavyanskaya Hotel by upgrading the chillers and cooling towers of the air conditioning system. Specifically, we recommend installation of magnetic bearing centrifugal chillers together with closed-circuit hybrid water cooling towers as replacements for the current systems in place at the hotel. This new technology would decrease energy and water use by the hotel's air conditioning system, while employing the most environmentally-friendly cooling agents and byproducts.

Through financial calculations it was determined that given the high initial purchase price, upgrading the cooling towers would not result in enough energy savings to be financially feasible. However, updating the current chiller with the newer models is a viable short term solution, with the payback period concluded to be 8.27 years.

Room occupancy sensors
Lighting accounts for 20% of the energy use in the Radisson-Slavyanskaya Hotel. In the year 2011, over nine million rubles were spent on lighting alone in the hotel. We determined that installing occupancy sensors in certain areas of the hotel will help decrease lighting costs by preventing lights being left on when rooms are not in use. Such upgrades are feasible and easy to install in the short term but also have extended long-term value for the hotel.

In order to determine if installing these sensors is financially possible in the short term, we performed a cost analysis. Using the total cost of purchasing the occupancy sensors as well as the calculated annual energy savings, we concluded that this investment would pay back in 8.47 years.

Conclusions and Recommendations

In order to reduce resource usage and to lower energy spending, we recommend that the Radisson-Slavyanskaya hotel implement the following short-term technological changes:

1. Revamping the hotel windows by *retrofitting with low-E window film*
2. Decrease energy usage by *upgrading the air conditioning chiller units* to magnetic bearing centrifugal models

3. *Installing room occupancy controls* when possible

In our research to develop a short-term plan of technological upgrades for the Radisson-Slavyanskaya Hotel, we also explored a number of options, which were beyond the scope of our project but ultimately could help the hotel move toward sustainability. For long-term, holistic improvement of the hotel' sustainability, we recommend that the hotel make the following technological changes upon the occurrence of large scale renovations:

1. Replacing old windows with energy efficient low-E windows
2. Replacing the centralized HVAC system with variable refrigerant flow units for individual rooms
3. Installing recyclable, PVC-free piping in the hotel
4. Replacing all fluorescent and incandescent bulbs with energy efficient LED bulbs
5. Implementing a grey water reclamation system

We also recommend that the Radisson-Slavyanskaya hotel consider the following programs in their hotel to encourage sustainable practices and to improve their image as a sustainable member of the community.

1. Provide sustainability training for employees
2. Provide educational materials about the hotel's sustainable efforts to guests
3. To practice sustainable sourcing when purchasing goods and materials

Authorship Page

The background sections regarding sustainable development globally and in Russia, occupancy sensors, window films and the systems present in the Radisson-Slavyanskaya Hotel were written by Elizabeth Martino. The background sections regarding guest surveys and air conditioning systems were written by Jonas Ciemny. The background regarding the management interviews was written by Keaton Smith. The background was edited by Keaton Smith.

Methodology objectives 1 and 3 were written by Jonas Ciemny. Objective 2 was written by Keaton Smith. Objective 4 was written by Elizabeth Martino. The methodology was edited by Elizabeth Martino.

The results and findings regarding technical aspects of the air conditioning system were written by Jonas Ciemny. The financial analysis of the air conditioning upgrades was written by Georgy Mazin. The results and findings regarding the technical aspects of the window films and occupancy sensors were written by Elizabeth Martino. The financial analysis of the window films was written by Anna Smurgyina. The financial analysis of the motion detection lighting controls was written by Alexander Shanstev. The results and findings section was edited by Keaton Smith.

The recommendations for the air conditioning system and long term programs were written by Jonas Ciemny. The recommendations for occupancy sensors, window films and long term technical upgrades was written by Elizabeth Martino. This section was edited by Keaton Smith.

We believe that the authorship of this report was equally distributed among all team members.

Table of Contents

Table of Figures

1. Introduction

With saving natural resources and reducing energy usage becoming hot topics in today's incredibly industrialized world, a previously "more is better" culture is developing into a new mature outlook on human impact on the environment. Efforts made today to increase efficiency and reduce waste means less burden on society tomorrow. Recently there has been increased attention given to reducing human environmental impact and ensuring present actions do not negatively impact future intentions (Jones, 2014). In particular, sustainability is becoming a growing area of interest in the hotel industry. There has been evidence that sustainable development, in addition to its clear environmental impact, simultaneously improves the satisfaction of guests and employees at the hotel, while at the same time fulfilling an inherent social contract between businesses and their surrounding communities (Bohdanowicz et al., 2011).

This project addressed sustainable development of the Radisson-Slavyanskaya Hotel in Moscow, Russia. We aimed to provide the managerial staff of the hotel with a set of long term and short term recommendations for technical and non-technical improvements that could be made in the hotel. The project explored how to measure the sustainable practices at the Radisson-Slavyanskaya and how to extend these practices to further improve the hotel's sustainability. We considered such factors as the hotel's environmental impact, its social responsibility in the community, effects on the hotel's finances, and the importance of sustainable improvements for both guests and employees.

The background section evaluates the current state of the global hospitality industry as well as in the Radisson-Slavyanskaya Hotel. It addresses the most current obstacles and goals of the key players in the business. Through a series of interviews and surveys, we also examined the priorities of the management and guests of the hotel regarding environmental sustainability. By understanding and clearly defining the current issues with respect to sustainability of the hotel industry, innovative improvements to policies and physical systems of the hotel can be explored.

The methodology chapter details a series of comparative analyses that were executed by a multidisciplinary team consisting of both engineering students and financial students. In the results and findings chapter, we used these analyses to measure the economic and environmental benefits of potential short term improvements that could be made in the hotel, as well as determining whether or not these suggestions catered to the immediate needs of the hotel management. In the conclusions section we outline the benefits and limitations of our proposed short term technological improvements as well as outlining a set of potential long term changes that could be made to improve the hotel's sustainability.

By evaluating and measuring current practices and then outlining new sustainability initiatives to be implemented in the Radisson-Slavyanskaya Hotel in both the short and long term, this project aims to have a positive impact on the hotel's sustainability, economic development, and ties with the surrounding community.

2. Background

Here we begin by detailing the underlying theme of our project: improving sustainability, encompassing economic, environmental, and social equity. More specifically we discuss the need and motivation for sustainable future development in all three of these areas as related to the Radisson-Slavyanskaya Hotel in Moscow, Russia. We examine previous work in the hotel industry in such development, with an eye toward creating a plan encompassing both short- and long-term advancements for the Radisson-Slavyanskaya. Furthermore, we consider the current state of affairs at the Radisson-Slavyanskaya, from technological and structural information on the building to attitudes and receptivity toward the concept of sustainable development as a whole. With this in mind, we finally examine in detail the needs of the Radisson-Slavyanskaya moving forward, especially in specific short-term technological upgrades but also in creation of a long-term plan centered on sustainability.

2.1 Sustainability and the tourism industry

The accepted definition of sustainable development is development that "meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987, p. 43). The concept of sustainability accounts for three areas that are affected by development: societal, economic and ecological. The societal element of sustainability endeavors to protect basic human rights within the industry by providing equal opportunities and maintaining the integrity of cultural heritage. The economic aspect of sustainability focuses on protecting the efficiency of all fiscal activities and ensuring the monetary success of the future industry. The ecological aspect of sustainable development, and the emerging focus of the tourism industry, is based on maintaining the natural state of the environment by reducing the use of energy and water and limiting pollution and production of non-biodegradable waste (Mihalic, 2012).

Historically, the tourism industry has been recognized as a "green" industry; since it lacked production of any physical consumer products, the industry was thought to have no adverse environmental effects. Over the last two decades, however, the massive ecological impact of global tourism has become increasingly evident to hoteliers, legislators, and especially hotel guests ("Hotels hop aboard environmental bandwagon", 1994). The growth of the tourism industry (34% in eight years) and the volume of consumers it draws make it one of the largest contributors to the degradation of the global environment (Tirados, 2011). The industry's yearly energy consumption is comparable to that of the entire nation of Japan and its yearly physical waste is on the same scale as the waste production of France (Muhi et al., 2013). The contribution of the industry to global environmental destruction includes carbon dioxide emissions, large volumes of food waste, gratuitous energy and water usage, and bulk purchase and waste of non-recyclable materials. Hotels alone use the most energy and resources out of all sectors of tourism. In Europe, for example, hotels use 39 terawatt-hours (TWh) of energy annually, contributing to a potential 13.6 megatons of carbon dioxide emissions (Bohdanowicz, 2005).

The shift in perception of tourism's effects on the environment is causing an increase in "green" policies among hotel owners and managers. Some may debate the "green wash" of hotel policies is less of an attempt to decrease the environmental effects of the hotel and more of play on the "green consumerism" movement. The idea is that by publicizing the efforts to improve sustainability, even if they are ineffective and do little to actually offset the destruction of the environment, consumers will gravitate toward the hotel with minimal effort on behalf of the hotel itself. This school of thought stems from the past tendencies of managers and owners to focus primarily on the societal and economic sides of sustainable development; in some ways, many are skeptical about the true motivation behind the sudden increase in environmental policy in the tourism industry (Jones, 2014).

Such skepticism is corroborated by a study of Swedish and Polish Hotels done in 2006, which surveyed 255 Swedish hotel managers and 124 Polish hotel managers and asked them to rank, on a seven point Likert scale, what incentives would convince them to improve policies with respect to environmental responsibility. The responses to this survey (Figure 1) demonstrate that demand from customers for environmental improvement and reduction of operating costs are generally the strongest incentives for management to implement changes in their operating procedures (Bohdanowicz, 2006).

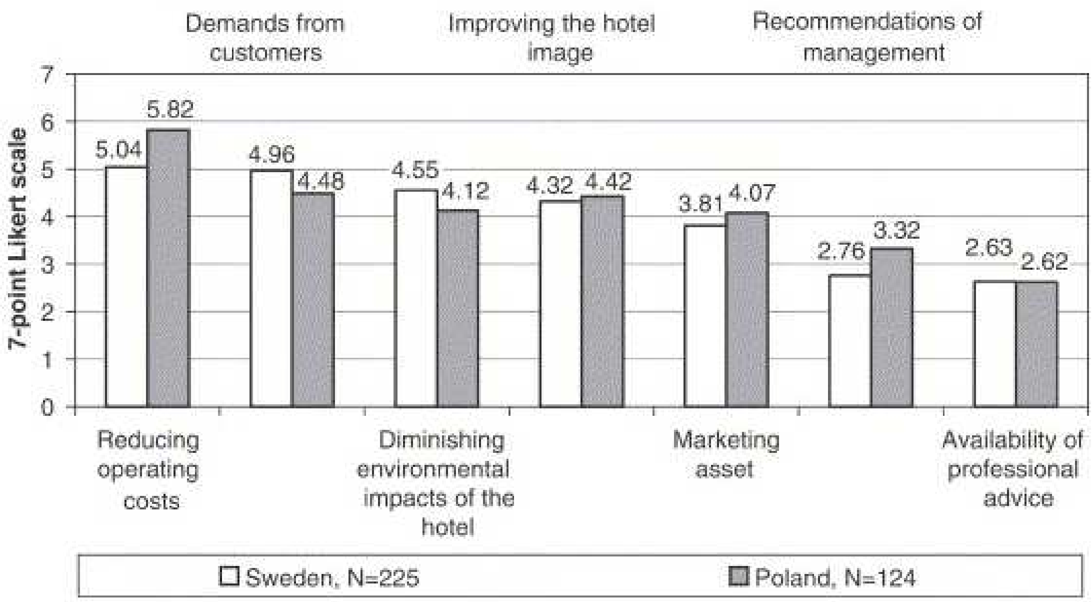


Figure 1: Managers' responses to incentives for improving environmental sustainability

Whatever the motivation behind the change may be, the hotel industry is moving toward a more holistic outlook on development. According to Dief, contrary to speculations that hotel management is unwilling or unable to reverse the detrimental effects of hotel practices; current trends in management policies show a transition from strictly societal and economic sustainability to truly complete sustainable development in the hotel industry (Dief, 2010). This shift in focus to include environmentalism in developmental consideration means that sustainable and equitable changes are becoming less of an ideal and more of a reality. For this reason, we decided to explore multifaceted, sustainable developments in this project, rather than approaching the problem from a strictly economic or social viewpoint.

2.2 Reducing use of resources at the Radisson-Slavyanskaya Hotel

The Radisson-Slavyanskaya is an example of this phenomenon described by Dief; it is showing interest in cutting down on energy and resource consumption. Truly sustainable thinking, though, is a big shift in mindset, and can seem intimidating at first; we observed that managerial staff members of the Radisson-Slavyanskaya were most receptive to and comfortable with small initial steps rather than a complete overhaul of hotel systems. They expressed greatest interest in technological upgrades which could be implemented in the short-term, primarily focused on reducing the hotel's use of resources and ultimately providing noticeable financial benefit for the hotel in addition to positively impacting the environment. The managers of the hotel further desired a more detailed long-term plan of potential changes, which could be implemented in the event of the success of the short-term advancements and the opportunity for more in-depth evaluation.

We believe much of the management's hesitation stems from the fact that sustainability and corporate social responsibility as concepts are relatively new in Russia. The lack of a foundation devoted to environmentalism makes it difficult for anything but short-term changes to seem realistic at the present time. However, our research into the Radisson-Slavyanskaya customer base and their interest in sustainability lends credence to the idea of a long-term plan as proposed. Our research into both current Russian infrastructure and the guests of the Radisson-Slavyanskaya Hotel is detailed here.

2.2.1 Sustainable development in Russia

The Russian economy, heavily reliant on natural resources, presents difficulty for the Radisson-Slavyanskaya as it attempts to improve sustainability through CSR. Even though the hotel industry in Russia isn't directly affected by this dependency, the development of unsustainable trends in Russia will prevent hotel companies from making large scale sustainable changes. Recycling programs, for example, are virtually non-existent in Moscow, meaning that if the hotel were to attempt to create a local recycling program there would be no support from the city (personal communication, Anna Smurginya, September 16, 2014). Without the support of a sustainable infrastructure, changes that have positive impact on the community are daunting for the hotel to implement ("Sustainable Development in Russia", 2013).

The future of the Russian economy may create external pressures for Russian companies to shift their policies to be in compliance with sustainable ideals. Studies of international economics indicate that in the next twenty years, the global economy will see large initiatives to decrease extraction of natural resources. The United Nations is developing new ways to measure economic growth and success that take into account the three pillars of sustainability. Using the previous methods of determining growth, Russia saw an 8%

rate of increase in gross domestic product (GDP) in the year 2006. However, after taking into account the depletion on natural resources, the Russian economy actually shrunk by the rate of 13.6% ("Sustainable Development in Russia", 2013).

Despite the current unsustainable trends being demonstrated by Russian government officials, the existing legislation is already designed toward protection of the natural environment. The problem arises from lack of enforcement of such laws. The new way of measuring a nation's economic success will create incentive for the Russian government to increase enforcement of environmental laws in order to remain a major player in the future global market ("Sustainable Development in Russia", 2013). In the next few decades, the pressure from the government to stay competitive globally may create a new motivating force for managers to consider sustainability.

2.2.2 Radisson-Slavyanskaya guest attitudes toward sustainability

Another important consideration in improving sustainability is that with every change, the comfort and satisfaction of hotel guests must be preserved. Being one of the top business hotels in the city of Moscow, understanding the attitude toward sustainability among the international business community will help the Radisson-Slavyanskaya improve its image as a sustainable hotel. In order to determine the importance that customers and long-term contract holders place on sustainable practices, the survey in Appendix C was given to guests of the hotel. The surveys were anonymous, self-administered questionnaires that were placed in the guests' rooms and were taken at the guests' convenience. The questions are either discrete response (yes or no) or interval response questions on a one to five Likert scale. The responses were structured as to make the survey quick to complete, with the goal of increasing guest participation (Bhattacherjee, 2012). The data collected from the surveys serves the purpose of addressing the following questions:

- What is the role that environmentally sustainable practices play in customers and companies choosing their hotel?
- Does the attitude toward sustainability differ between those traveling internationally and those travelling within Russia?
- Does the availability of information regarding sustainable practices impact the decision making process of the hotel guests?

In order to maximize participation from guests, the questionnaire included a version in both Russian and English. A candy was placed with the questionnaire by hotel cleaning staff to further increase guest interest in the questionnaire. Four hundred copies of the questionnaire were printed and distributed throughout the hotel over the time span of one week (Tuesday to Tuesday). Of the copies distributed, sixty-nine questionnaires were filled out.

Our surveys showed that the guests of the Radisson-Slavyanskaya do care about sustainability, both in general and in choosing a hotel; there was over a 75% positive response rate in both categories. 79% of patrons also expressed interest in knowing what their hotels did for sustainability. Furthermore, a significant 34% of customers asserted that they were on business trips for which their sending companies encouraged stay at a sustainable hotel. The results of this questionnaire also give us a glimpse into the international opinion on sustainability, as 79% of guests said they were not from Russia. For more detailed results and analysis of the survey, see Appendix D.

The questionnaire we administered does have some limitations, beginning with its relatively small sample size of sixty-nine hotel patrons. Hotel guests may also have been affected by social desirability bias, which may lead them to select answers which put them in the best light—in this case, that they know and care about sustainability (Bhattacherjee, 2012). Even in light of these limitations, our survey does show that guests believe sustainability to be good, even if they may not actively support it. This piece of information lends credence to our assertions that future sustainable developments of the Radisson-Slavyanskaya could positively affect its appeal to guests in the international business community.

2.3 Sustainable practices in the hotel industry

To get an idea of what solutions might be effective at reducing resource consumption of the Radisson-Slavyanskaya, we researched ways in which other hotels have pushed for environmentalism in a sustainable fashion. Here we present this information, divided between abstract changes in priority and concrete upgrades to technology.

2.3.1 Sustainable technological upgrades

One successful initiative for sustainable development in the tourism industry has been the Think Planet initiative. The Rezidor Group, parent company to Radisson Hotels, launched Think Planet as part of the 2013 Responsible Business Program. Think Planet is based on four pillars, two of which are technologically focused (Figure 2). These pillars lay out a road map of the environmental initiatives to be taken by the Rezidor Group during 2013 ("2013 Responsible Business Report", 2013).


Think Planet investments: Testing innovative energy saving technologies such as wireless guest-room controls.
LED lighting retrofit: A group-wide decision to fit Philips LEDs and take advantage of the supplier's technical guidance.

Figure 2: Think Planet technological pillars

As part of Think Planet, the Rezidor group has identified categories of environmental impact in the global hotel industry. Various improvements were then put in place in different Radisson hotels to reduce impact in one or more of these categories. For example, to reduce energy usage as part of Think Planet, the Radisson Blu in Media City, Dubai replaced 5,200 lights with LED bulbs in 2013. This retrofit saved the hotel 70% in yearly bulb replacement costs and reduced energy consumption by 4% annually ("2013 Responsible Business Report", 2013).

The Radisson Blu in Cardiff, Wales implemented similar technological upgrades, though for heating, ventilation, and air conditioning (HVAC) rather than lighting. The GEM Intelligent Room Control system, manufactured by SaveMoneyCutCarbon, was installed in rooms of the Cardiff Radisson Blu to reduce use of HVAC systems when guests are not in a room. This upgrade generated savings from 30% to 45% in HVAC energy costs, while being fully automatic and virtually undetectable by guests. The system is expected to reach a return on investment fourteen months from installation (Savmoneycutcarbon.com, 2013). The purpose and positive impacts of these technological changes are evident below (Figure 3 and Figure 4), showing a trend of decreasing energy use throughout all Rezidor hotels.

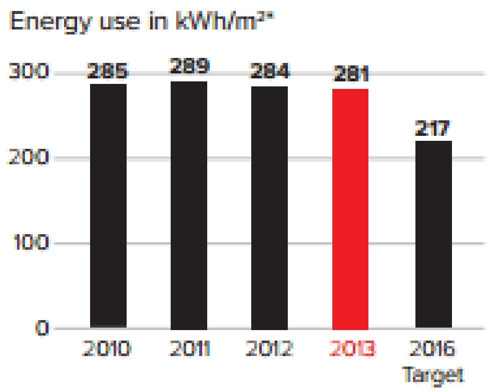


Figure 3: Rezidor Hotel annual energy use

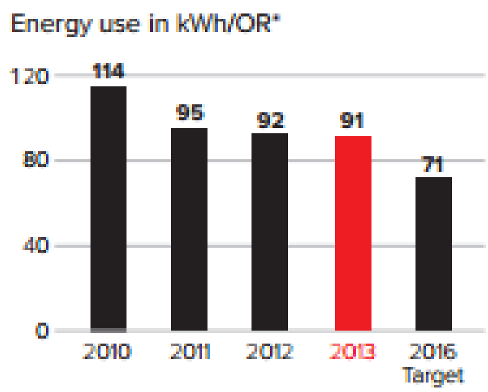


Figure 4: Rezidor Hotel annual energy use per room

The Rezidor group has also placed a priority on water savings, having installed water-saving toilets installed in 71% of its hotels and water-saving faucet aerators in 79% of its hotels. The Radisson Blu hotel in Dubai also employs bottle-free water dispensers in an effort to cut down on plastic bottle waste (Figure 5). Like their energy use, the Rezidor Group's water use has been on the decline, partly due to these measures (Figure 6) ("2013 Responsible Business Report", 2013).

Figure 5: Bottleless water dispenser (for bottle filling)

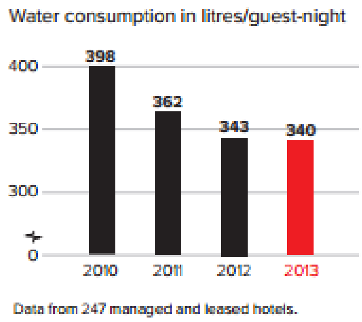


Figure 6: Rezidor Hotel water use reduction

Apart from the Rezidor group, other hotels are also looking at green technologies, specifically from the ground up in new development. Studies have shown that the crucial element in energy-friendly buildings around the world is their initial design. Architecturally, people are developing more ways to use natural materials in building designs and to provide ways for the buildings to expand and operate without producing unnecessary waste and pollution. The most successful energy efficient hotels in the U.S. provide amenities for electric cars and are developing energy management systems (timed lighting, low flow toilets, and energy efficient air conditioning, for example) (Southan, 2010).

This research on technological advances in the tourism industry was helpful for us in determining what changes would be best to implement at the Radisson-Slavyanskaya. We were able to gain insight into what was proven to be of greatest benefit, and take this information into account especially in our short-term plan of action for the Radisson-Slavyanskaya Hotel.

2.3.2 Shifts in sustainable mindset

With sustainability in mind, many hotels have set a precedent in sustainable development and improvement for the industry as a whole. Practices are being established and refined which lead to improvements in all areas of sustainability. These enhancements go beyond the technologically-oriented upgrades discussed above and into changes in policy and attitude.

As part of the Think Planet initiative, the Rezidor Group has implemented some such changes throughout many of its hotels. The other two Think Planet pillars are more policy-oriented as opposed to technologically-based (Figure 2), and serve as the basis for the Rezidor Group's changes in policy (Figure 7).

Think Planet Habits: Employee awareness: in operations through back-of-house posters, training videos and the special promotions such as a quiz.
Think Planet tools: Easy to implement energy saving tools which provide a quick return on investment.

Figure 7: Think Planet pillars on policy change

For instance, "green housekeeping" policies have been implemented in a large number of Rezidor Group hotels to promote water savings. The Radisson Blu Ulysse Resort and Thalasso reuses "grey water", or wastewater collected from guest rooms, to irrigate all of the gardens on the property. The Radisson Blu Hotel in Beijing also reuses grey water in toilets and in the onsite gardens. In the year 2013, the two hotels combined saved the volume of over 13,500 m^3 (equivalent to approximately 13 Olympic swimming pools) in fresh water ("2013 Responsible Business Report", 2013).

As another example, Scandic Hotels underwent a complete turnabout after being close to collapse by putting a large focus on sustainability. A new CEO saw that the current trend was for hotels to wait for customers to come to them, similar to the product industry. The best way to increase customer base was to simply put more focus on the customer. Implementing decentralized management helped, but the second factor was environmental responsibility. It was critical to educate employees on sustainable development to make the communication between management and employees as seamless as possible. Such employee education was ultimately for the benefit of the customer, since now customer service associates (as opposed to management) were making more and more guest-related decisions on a daily basis, better enabling the needs of the customers to be accounted for (Goodman, 2000).

Scandic Hotels also implemented an upgraded information technology system which would allow hotel managers to distribute information to and compare with competing hotels regarding performance. This best-in-class (BINC) system included eight factors: finances; brand image; employee-customer interaction; work done toward partnerships; energy efficiency; water use; and an index that benchmarks environmental performance in several less common areas. This final benchmark includes waste disposal, equipment, types of lighting used, use of a temperature monitoring system, as well as food and beverage. By partnering with suppliers and working requesting special products that were not currently available, Scandic Hotels was able to further reduce their negative impact on the environment (Goodman, 2000).

Another successful program, implemented largely in Europe, was Hilton's *we care!* initiative. The plan aimed to encourage employees to make changes in their lives both at work and at home with environmentalism in mind, and was executed using a combination of training workshops for staff members, rewards for top-performing hotels, and periodic performance measurements and goals. The *we care!* program resulted in significant benefits for Hilton, saving millions of dollars by reduction in energy and water usage and preventing nearly 30,000 metric tons of CO2 emissions, and was generally positively received by involved employees for being effective, easy to carry out, and raising environmental awareness. And from the program, the hotel gained valuable knowledge about ways to make similar programs effective--including the need for open-mindedness, good planning, employee support, meaningful measurement of progress, partnership with like-minded suppliers, and cooperation with experienced outside organizations. The success of the *we care!* program centered around its commitment to not only reduction of usage and emissions but also changing Hilton's employees' attitudes toward environmentalism (Bohdanowicz, 2011).

By researching long-term changes in policy in addition to short-term technological advances, we have gained insight into directions in which the Radisson-Slavyanskaya might consider moving. These successful programs are useful for us in establishing a long-term plan focused on sustainability for the Radisson-Slavyanskaya Hotel, in addition to the technological upgrades which are more feasible to be implemented under the immediate scope of this project.

2.4 Presentation of the state of affairs at the Radisson-Slavyanskaya

Once we determined successful actions of other hotels, with an eye toward both immediate and far-reaching changes, we looked further into the reality at the Radisson-Slavyanskaya Hotel. This research helped us determine specific suggestions we could make to Radisson-Slavyanskaya management in order to cut the hotel's resource use in a sustainable fashion. Below is that information, which we gained either in a walkthrough we performed personally to generally assess the hotel's systems or from a third-party energy audit of the hotel to which we were given access.

2.4.1 General overview of hotel systems

The Radisson-Slavyanskaya Hotel was built in 1990 and has eight floors and a floor area of 12,060 square meters. There are 1,210 windows and 6,031 square meters of glass in the hotel. Most of the windows are double-glazed and tinted but are not protected by any sort of light-filtering film. Due to the age of the windows, we can assume that the glass is annealed rather than tempered. The frames are in decent shape but the rubber gasket that holds the glass in place is degraded in some places.

The hotel uses no natural gas, oil, or other supplemental fuel sources; all of the electricity and water is supplied by the city of Moscow. Hot steam is supplied by the city at 150 degrees centigrade and is the hotel's source of heat for domestic hot water (DHW). The heating and air conditioning systems are centralized, so instead of each guest room having separate thermostat controls, the whole building is set to one uniform temperature. This means that 210,000 cubic meters of air space are being heated by one system.

There are 427 total guest rooms in the hotel. Each standard room has two hall lights, a wardrobe light, two sets of bathroom light fixtures, three floor lamps and a small desk lamp. There is also an iron, a coffee maker, and a hair dryer in each room. Most, if not all, of the light fixtures use compact fluorescent light bulbs (CFLs). In the bathroom of each room there is one sink, one shower head, and one toilet. All of the toilets in the building are dual flush toilets, while all faucets and showerheads are aerated and filtered.

In the halls of the hotel, the light fixtures use compact fluorescent (CFL) bulbs and are on 24 hours of the day. In the past, the hotel had tried to convert the lights in one wing of the hotel to light emitting diode (LED) bulbs. However, voltage fluctuations in electrical current due to faulty external transformers caused the LED bulbs to burn out, and their usage was discontinued.

The laundry facilities in the Radisson-Slavyanskaya have six washing machines and six dryers, all industrial-sized. Including bed linens, curtains, rags, and laundry from the fitness center and restaurants, the hotel processes on average approximately 55,500 kilograms of laundry per month.

The information in this section helped us get a general idea of areas which might need improvement in the Radisson-Slavyanskaya, along with a sense of ways in which potential solutions could fit within the existing framework of the hotel. This information on hotel systems and structure was used as we proceeded with research into specific systems upgrades, especially with our short-term technological suggestions.

2.4.2 Radisson-Slavyanskaya energy usage

The energy audit provided to us by the hotel included energy usage and expenditure from the year 2007 to the year 2011. Over the course of five years, the Radisson-Slavyanskaya Hotel used an average of 12,745,830 kilowatt-hours (kWh) of energy. The average amount spent on energy over this period was 32,110,772 rubles per year making the average cost 2.55 rubles per kWh. While the energy usage has decreased by approximately 1.75 million kWh from 2007 to 2011, the energy spending increased by 21,130,002 rubles. This indicates that the price per kWh increased from 1.686 rubles to 3.658 rubles, which is a hugely significant jump (Appendix F).

The largest user of energy in the Radisson hotel is "Kitchen Appliances with a Heating Element" at 25.3% of the hotel's total yearly energy consumption. The single second largest consumer of energy is "Lighting" at 20.3% of the hotel's total energy consumption. The third largest consumer of energy in the hotel is the air conditioning system. When you combine the energy used by the cooling towers (8.8%) and the chillers (16.4%), the air conditioning system uses 25.4% of the hotels yearly energy (Figure 8).

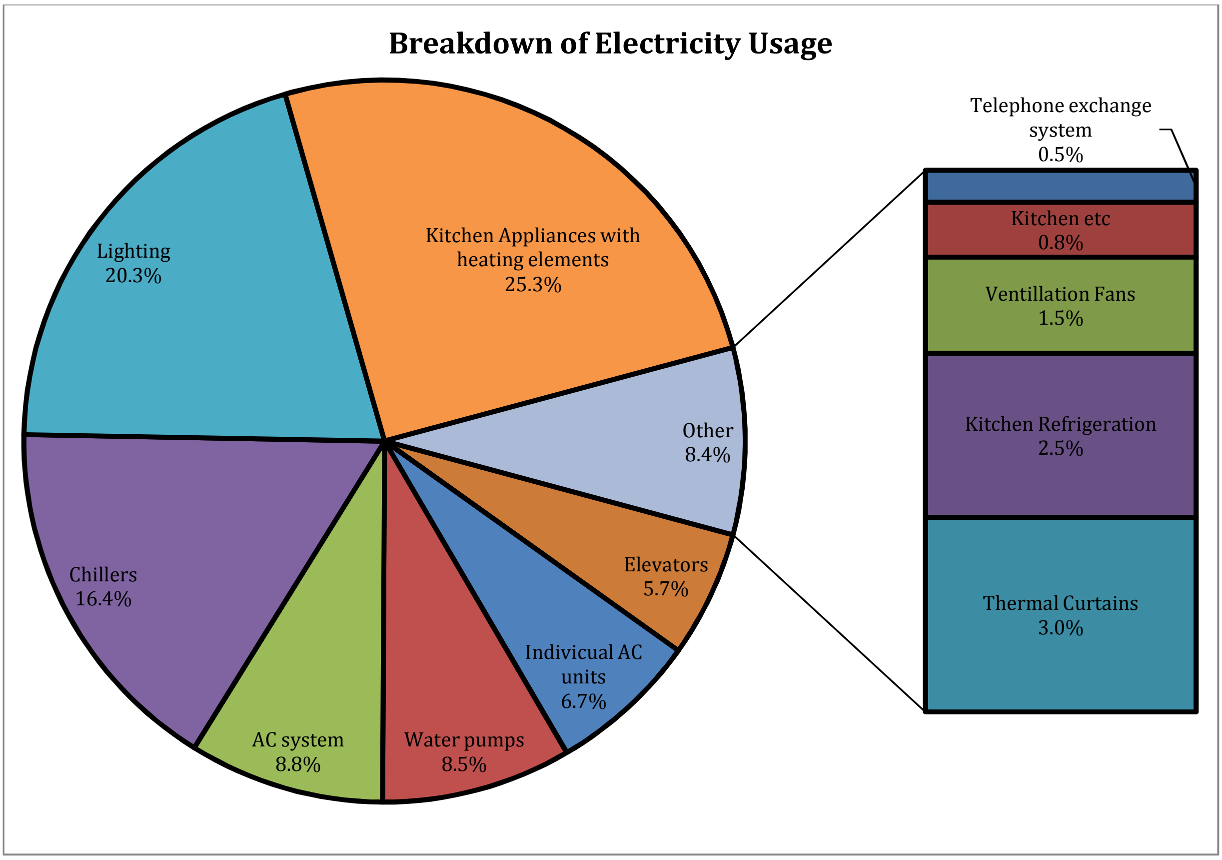


Figure 8: Percentage energy use for major electrically powered systems in the hotel

Since most of the kitchen equipment in the hotel is not owned by the hotel, upgrading that equipment would be impossible. This data indicates that our proposed improvements should instead be focused on the HVAC and the lighting systems. These are two of the largest consumers of energy which implies that the largest reduction of energy usage will result from improvements of those systems.

2.4.3: Radisson-Slavyanskaya water consumption

The audit also provides data on the water usage of the hotel from the year 2007 to 2011. The average yearly water use for this period is 149,794 cubic meters (m^3) of water. The average amount spent on water during this period was 5,565,047 rubles. Over the five years, the average water usage decreased by 16,477 m^3, however the average amount spent on water increased by 3,444,473 rubles. This indicates that the price of water increased from approximately 25 rubles per cubic meter (rub/m^3) to 53 rub/m^3, meaning that reducing water usage could be a significant economic improvement.

Most of the piping throughout the hotel is the original copper piping installed upon construction in 1990. Inspection of the pipes is difficult, however, as they are permanently embedded in the .25m thick concrete walls. Lack of insulation on the piping could be causing massive heat loss and the poor maintenance of the piping itself could be contributing to degradation of water quality. This deterioration has made it impossible for the hotel to implement water-saving technologies.

The data provided by the audit indicates that decreasing water usage will greatly decrease costs for the hotel. However, the old piping and difficulty with accessing this piping, makes any short-term upgrades to systems that use a lot of water very difficult to implement.

2.5 Specific areas for improvement at the Radisson-Slavyanskaya

After gathering information on sustainable efforts of other hotels as well as on the current situation at the Radisson-Slavyanskaya Hotel, we researched technical specifications of some systems at the hotel. This research was aimed at systems which seemed to lend themselves to impactful, short-term improvement. The information we gathered proved helpful in better understanding the nature of the upgrades which we might propose.

2.5.1 Heating, ventilation, and air conditioning systems

Over one-fourth of the electricity consumed at the Radisson-Slavyanskaya goes toward the centralized air conditioning, making this system as a whole the largest user of electricity at the hotel. We therefore focused a large part of our research on this system. This research is detailed here.

Overview of air-conditioning system components

The two components of the air conditioning system we will be focusing on are the chiller and the cooling tower. There are three categories of chillers: electric water-cooled, electric air-cooled, and absorption water-cooled. All three types use a refrigeration cycle consisting of three main components: an evaporator, a condenser, and a compressor (See Glossary for definitions of chiller categories).

Vapor compression refrigeration process

The cold air in a central air conditioning system starts with a chiller, which cools some kind of liquid to be used with an air handling unit (AHU; see Appendix H and Figure 9 below). The chiller unit works by removing heat from this liquid via a vapor compression cycle using a compressor in combination with an evaporator and a condenser (see Glossary for full description of a vapor compression cycle). Figure 10 provides a visual and a more detailed description of the full cooling process in an air conditioning system.

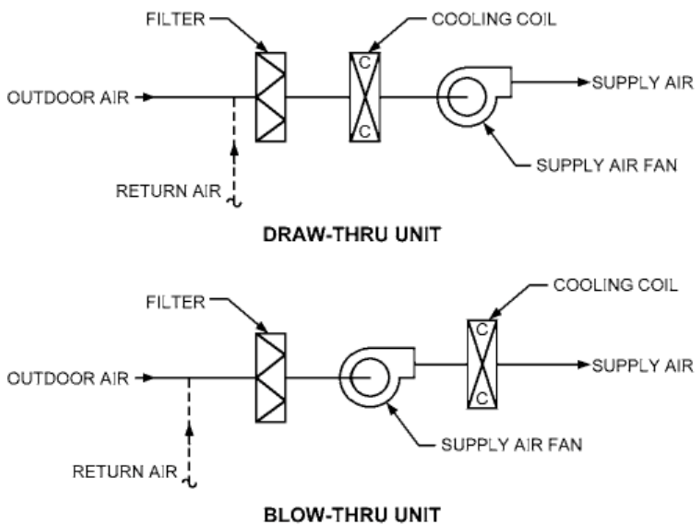


Figure 9: Flow diagram of an AHU. The supply air fan can either be situated before or after the cooling coil depending on physical limitations of the installation site. Return air, or air from inside the building, can be mixed in with outdoor air at the intake to better control the climate inside the building (Owen, 2012).

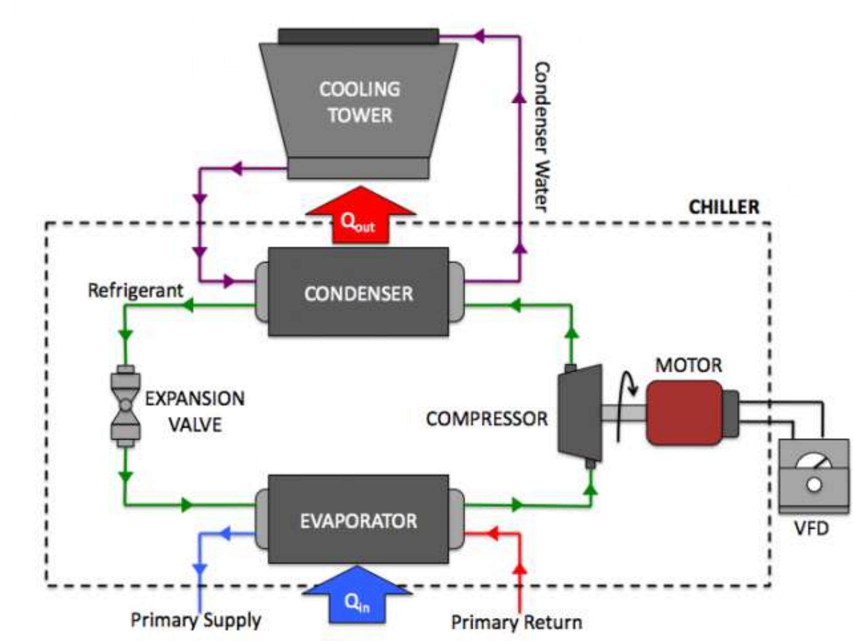


Figure 10: Flow diagram of the three fluid loops in an air-conditioning system. The green arrows are the refrigerant inside of the chiller. The purple arrows are the liquid that absorbs the heat from the refrigerant to be rejected out of the cooling tower. The red and blue arrows are the process fluid that is cooled via the cold refrigerant in the evaporator and then sent to the air handling unit. The VFD, or variable frequency drive, is an optional unit that allows the motor driving the compressor to operate at various speeds (see "Capacity Modulation Using Variable Speed Drives" below for more information on VFDs) (Baglione, 2014).

Refrigerant types

A refrigerant is necessary for the vapor compression refrigeration cycle used in most chillers today. There is a very limited number of elements available for use as refrigerants. The element used must not be toxic, radioactive, solid at room temperature, or have too low of a boiling point. Additionally, some elements are simply too rare to be economically practical for widespread use. This criteria narrows down the available elements to hydrogen, carbon, nitrogen, oxygen, fluorine, chlorine, and bromine. While all of these elements individually are stable and relatively safe, when combined the resulting compounds can be toxic or flammable. For non-commercial uses, flammable refrigerants such as ammonia (NH_3) are suitable. Other compounds such as sulfur dioxide SO_2 have previously been used but are now classified as toxic. Even water (H_2O) can be used as a refrigerant, but its poor efficiency limits its use to absorption chillers ("HFC-134a: An Ideal Refrigerant for Chillers").

The most common types of refrigerants, though, are chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs). CFCs were introduced first in 1928. Because of their good thermodynamic properties, non-toxicity and non-flammability, CFCs became popular in refrigeration equipment. However, in the 1970's evidence of CFCs' impact on the depletion of the ozone layer paved way for research into alternative compounds—largely the result of the Montreal Protocol (see Appendix H).

Compounds with limited or no chlorine do not have this negative impact on the ozone layer. HCFCs containing less chlorine became popular ("HFC-134a: An Ideal Refrigerant for Chillers"). The current answer to ozone depleting refrigerants is HFCs. These new compounds are also more efficient and lower-mass refrigerants than previous CFCs and HCFCs, making new chillers 35-40% smaller and more than 35% more efficient than chillers produced in the 1980's ("HFC-134a: An Ideal Refrigerant for Chillers"). HFC-134a, or R-134a, is becoming the most popular HFC refrigerant choice for chillers produced today.

Cooling tower types

The cooling tower, mentioned above, is the second critical component to a commercial water-cooled air conditioning system. Although it only reduces the temperature of the refrigerant by about ten degrees, that is enough to condense it from a vapor into a liquid. There are two main types of cooling towers: open circuit (direct) and closed circuit (indirect), with hybrids of the two also being feasible. The two cooling towers installed in the hotel are of the open circuit type. Diagrams of each type are below in Figures 11 through 14.

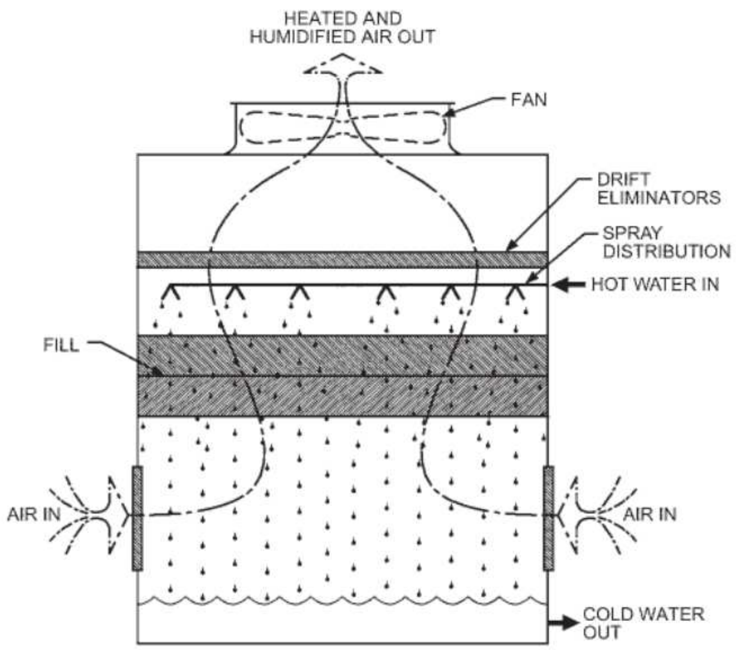


Figure 11: Direct or open loop cooling tower. The liquid to be cooled is sprayed directly over the fill, which exchanges heat with the air being pulled upwards through the unit by the top mounted fan (Owen, 2012).

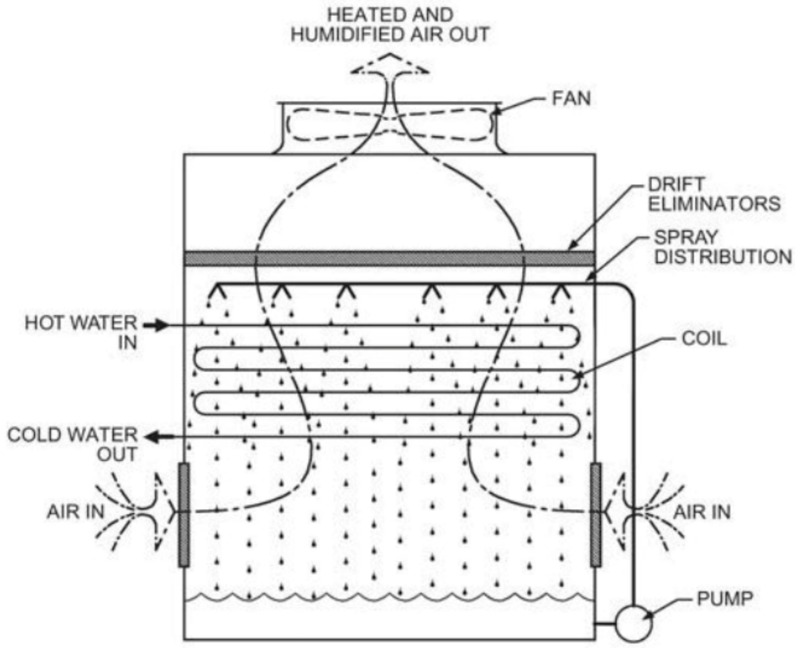


Figure 12: Indirect or closed-loop cooling tower. The liquid to be cooled is sent through a series of tubes inside of the cooling tower. A separate closed loop water source is sprayed over the tubes. The water absorbs heat from the tubes, which then exchanges the heat to the air flowing upwards through the unit (Owen, 2012).

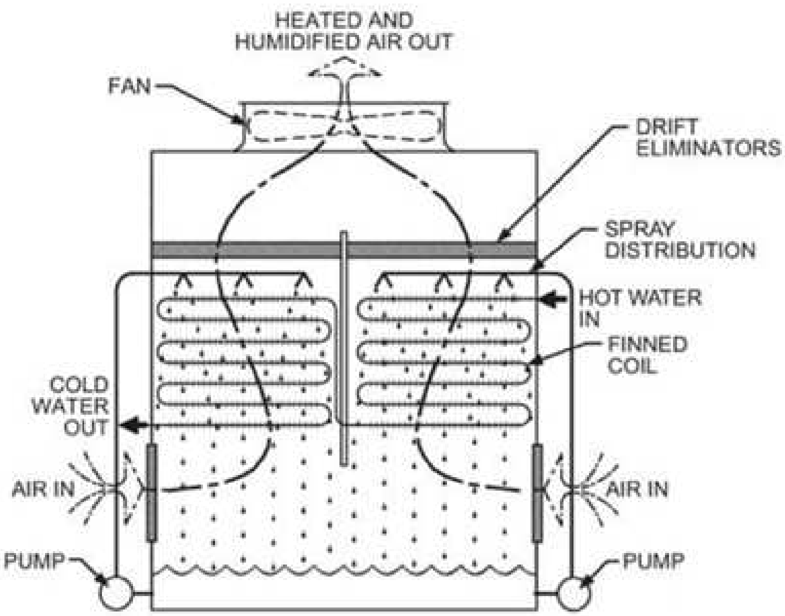


Figure 13: Hybrid cooling tower operating in wet mode. In this mode water is sprayed over all of the finned coils (Owen, 2012).

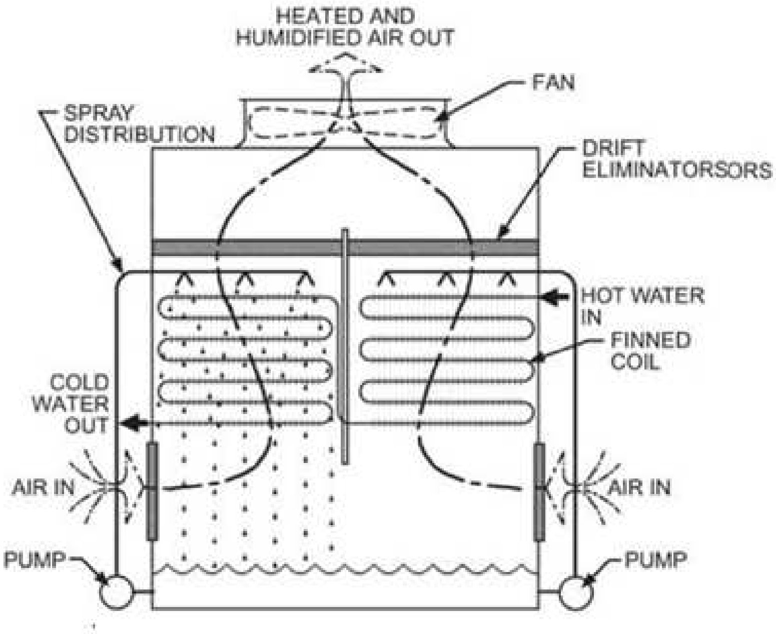


Figure 14: Hybrid cooling tower operating in wet/dry mode. In this mode water is sprayed over half of the finned coils (Owen, 2012).

One benefit to using a closed loop cooling tower system is the ability to use an antifreeze solution in the chiller-to-cooling-tower circuit. Because the liquid in this circuit is not exposed to the environment, no loss of water due to evaporation is possible. The most common type of antifreeze used is ethylene glycol, which, although toxic, has excellent freeze protection. A non-toxic variant, propylene glycol, is also used, but is not as effective at freeze protection and is more expensive. Different concentrations of the ethylene glycol are used depending on the minimum winter temperatures expected. The ethylene glycol solution is often mixed with industrial grade corrosion inhibitors, acid neutralizing buffers, and foam suppressants, all of which delay maintenance of pumps, pipes, and other components in the circuit. These additives further increase the benefit of closed loop cooling towers over open loop cooling towers ("Closed-Loop Cooling Systems 101").

Chiller compressor types

While the compressor type for absorption chillers is relatively straightforward, requiring only a source of heat provided by either hot water or steam, the compressor technology for electric chillers is more varied. The type of compressor can have a significant impact on the efficiency of a chiller. Although there are numerous compressor designs available for chillers, the four types of compressors used most commonly in electric chillers are scroll, reciprocating, screw, and centrifugal (See Glossary for detailed definitions of each type of compressor). The four chillers in the Radisson-Slavyanskaya Hotel all use screw compressors. Diagrams and detailed descriptions of the four main compressor types are below in Figures 15 through 18.

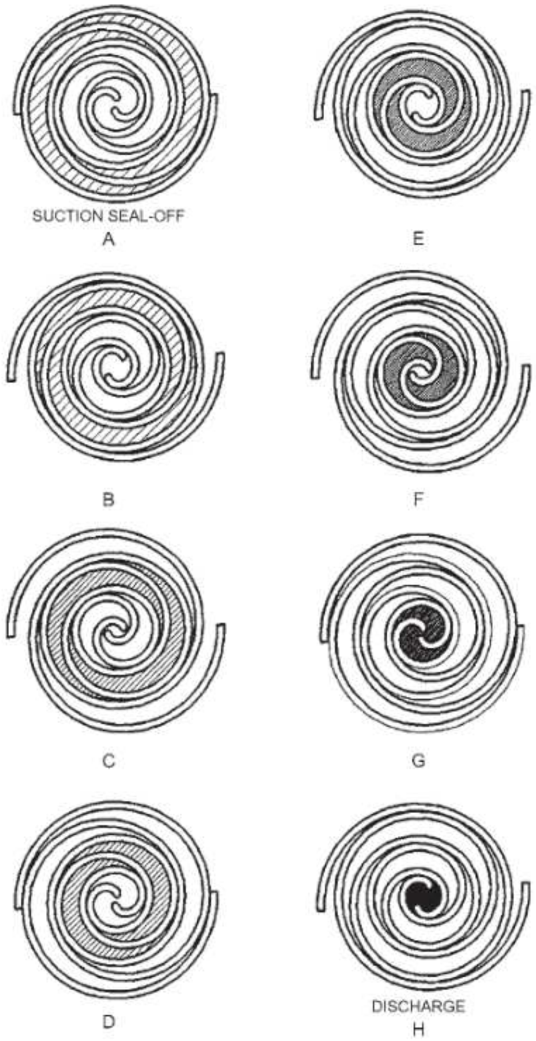


Figure 15: Scroll compressor cycle. A volume of refrigerant is sealed off at Step A. from Step B through Step G the volume of the refrigerant is reduced by the rotation of one of the scrolls. This reduction in volume leads to an increase in pressure. At Step H the high pressure refrigerant is discharged through the center of the scroll (Owen, 2012).

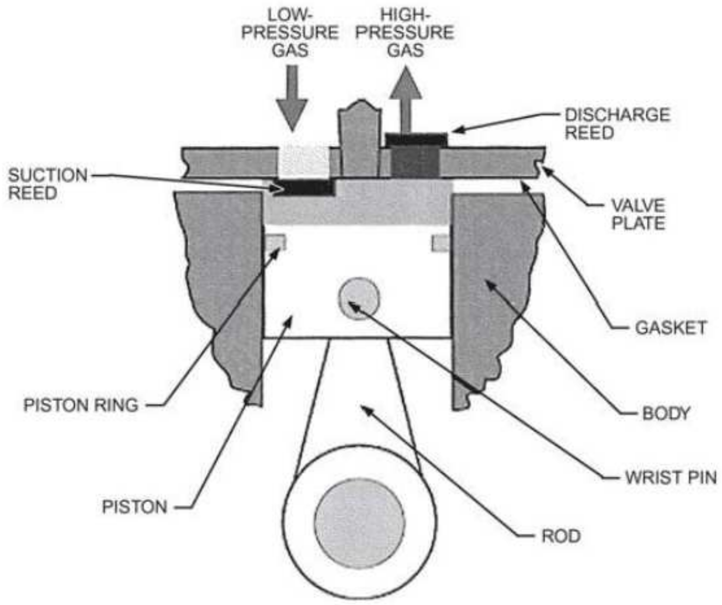


Figure 16: Reciprocating compressor system. Low pressure refrigerant enters the cylinder when the piston is at its most retracted point. The piston then moves toward the valve plate, reducing the volume inside of the cylinder, thereby increasing the pressure of the refrigerant. The high pressure refrigerant is then released through the discharge valve (Owen, 2012)

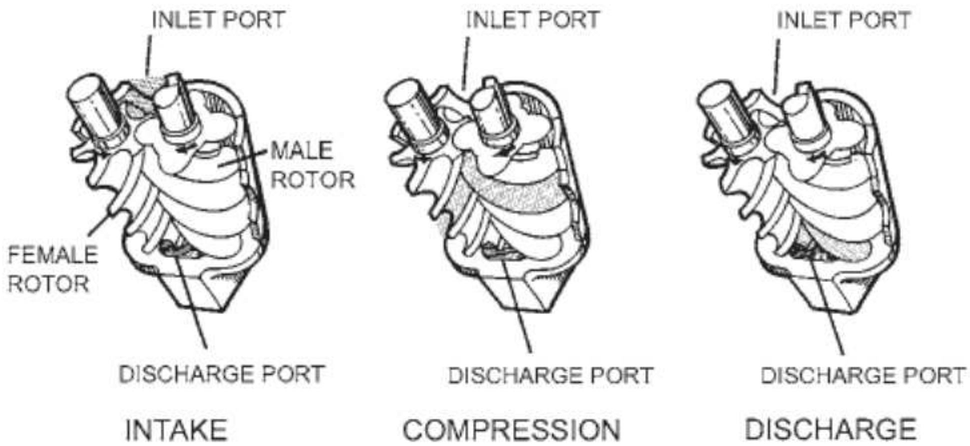


Figure 17: Twin screw compressor cycle. The screws act much like the scrolls of a scroll compressor. Refrigerant enters and is sealed off by the rotating male rotor. The male rotor continues to spin, reducing the volume of the refrigerant until it reaches its maximum pressure at the discharge port where it is released (Owen, 2012).

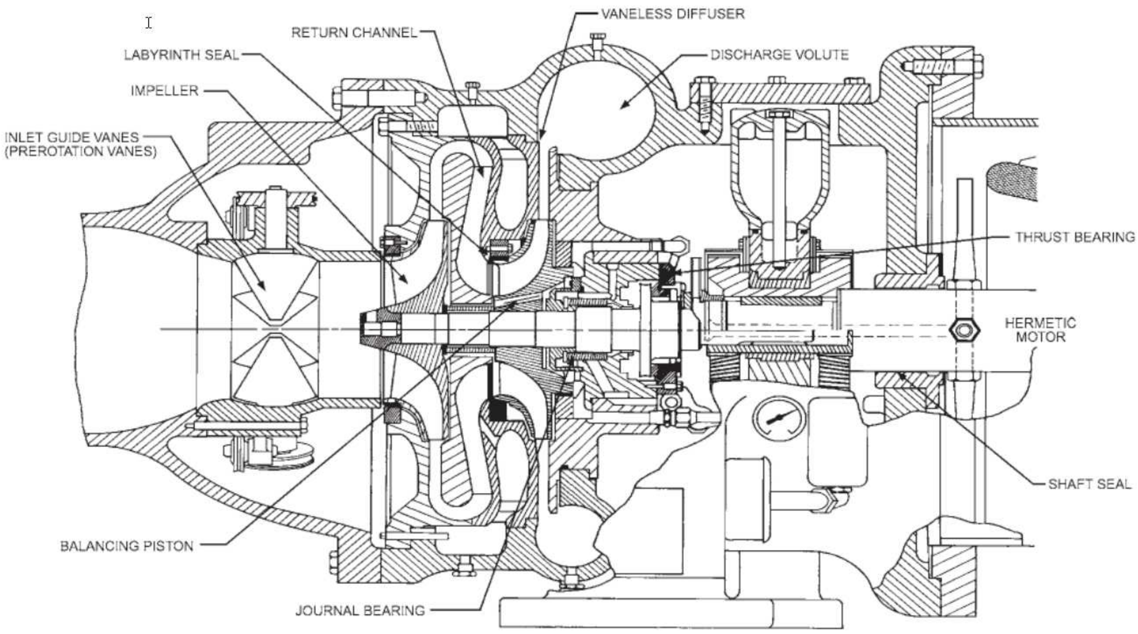


Figure 18: Diagram of a centrifugal compressor. Refrigerant enters at the left side of the unit where it passes through the inlet guide before approaching the impeller. The spinning impeller forces the refrigerant from the center to the edges of the impeller, increasing the pressure forcing the refrigerant through a smaller volume (Owen, 2012)

Chiller capacity modulation using variable speed drives

In order to best meet the cooling needs of a building and to maintain a constant cooling water temperature, chillers need to have the ability to modulate their capacity. The most basic method to control capacity is by having multiple compressor stages per chiller and varying the number of compressor stages in use at a time. Screw and centrifugal chillers have the ability to use inlet valves to restrict the volume of refrigerant, and to bypass hot gas produced by the compressor directly to the evaporator instead of the condenser. Variable speed drives (VFDs) can also be used to modulate capacity by controlling compressor motor speeds in screw and centrifugal chillers. Chillers with VFDs can expect an energy savings of about 25% over traditional single speed chillers ("VFDs for Large Chillers"). The variable speed of the motor allows the chiller to better adapt to varying cooling load of the building.

Chiller capacity rating system

In order to determine the size of chiller required for a specific building, a number of units are used to describe a chiller's cooling ability. The most common chiller capacity rating is kilowatts, or kW for short. Within the United States, the most common unit is the ton, which is equivalent to 3.517 kW. Cooling capacity was compared to the amount of energy required to form one ton of ice over 24 hours. Typically, chillers range in capacity from 20 tons to over 1000 tons. The four chillers in use at the Radisson-Slavyanskaya are rated at 720 kW, or 205 tons each.

Chiller energy efficiency rating system

Due to the relatively large electricity use of a chiller, special attention has to be given to its efficiency. There are two categories for chiller efficiency ratings: when the chiller is running at full load, and when the chiller is running at less than full load. Coefficient of performance (COP), energy efficiency ratio (EER), and kilowatts per ton (kW/ton) are all used to measure a chiller's energy efficiency at full load.

While this may be convenient to compare across multiple systems, it is not a good indicator of real-world performance where full load conditions are rare. Integrated part load value (IPLV) depends on the unloading (operation at steps less than one hundred percent load) ability of the chiller (See Glossary for definitions of the various rating systems).

The key takeaway of the various types of chiller and cooling towers is that depending on the situation, different systems are more appropriate. For example, a small business located in a warm, dry, climate will have different air conditioning needs than a large commercial building situated in a colder temperate climate—such as the Radisson-Slavyanskaya Hotel. For this reason, care should be taken to match up the type of chiller and cooling tower with the requirement of the building. These requirements involve building size, climate, occupancy hours of the building, and energy efficiency requirements. Not all configurations are possible, so in some cases compromises must be made, especially in cases where financial restrictions limit the cost of equipment.

2.5.2 Occupancy sensor lighting controls

A common technical solution to decrease energy usage is to implement motion detection light controls. These sensors will automatically turn lights on or off depending on whether or not motion is detected in the room. The two most common types are occupancy sensors and vacancy sensors. Occupancy sensors turn lights on when motion is detected and turn them off when there is no motion detected. Conversely, vacancy sensors require that the lights be turned on manually, but will turn the lights off automatically when the room is empty.

Occupancy sensors are typically used in bathrooms and wardrobes, as they are not occupied for extended periods of time. Vacancy sensors are better options for guest rooms, as they will not inconvenience the occupant by turning the lights off randomly. Most such sensors are only a single unit, making them noninvasive and easy to install. This unit includes a combination of infrared and ultrasonic motion detection (Nassetta, 2013). The infrared motion detector is used to recognize large, full-body motions such as walking or standing up, while the ultrasonic motion detector is used to recognize subtler actions such as typing or turning the pages of a book.

Depending on the budget allocated for such a project, another option to decrease use of lighting might be light-level sensors. These sensors are connected to a dimmer and adjust the brightness based on the amount of natural light detected in the area, ideal for large open spaces like lobbies or conference rooms (U.S Department of the Interior, 2014).

2.5.3 Heat-insulating window films

A large contributor to wasted heating and air conditioning energy is old or inefficient windows. Most of the windows in the Radisson-Slavyanskaya are the same windows that were installed during construction in 1990. The windows themselves are double-paned and the frames, in some places, are in poor condition, allowing for unwanted heat loss and creating drafts in the building (Oleskowicz-Popiel, 2014). The windows, though slightly tinted, are not optimally designed to keep heat and ultraviolet light out during summer months.

Retrofitting the hotel's windows with light filtering films could greatly reduce heat transfer through the windows and thus energy spending. Such films work by reducing the amount of light and heat coming through the window through either polarization, tinting, or coating with a thin layer of reflective aluminum particles (Figure 19). All three options work to filter sunlight and to block ultraviolet radiation and infrared heat energy (Almutawa, 2013).

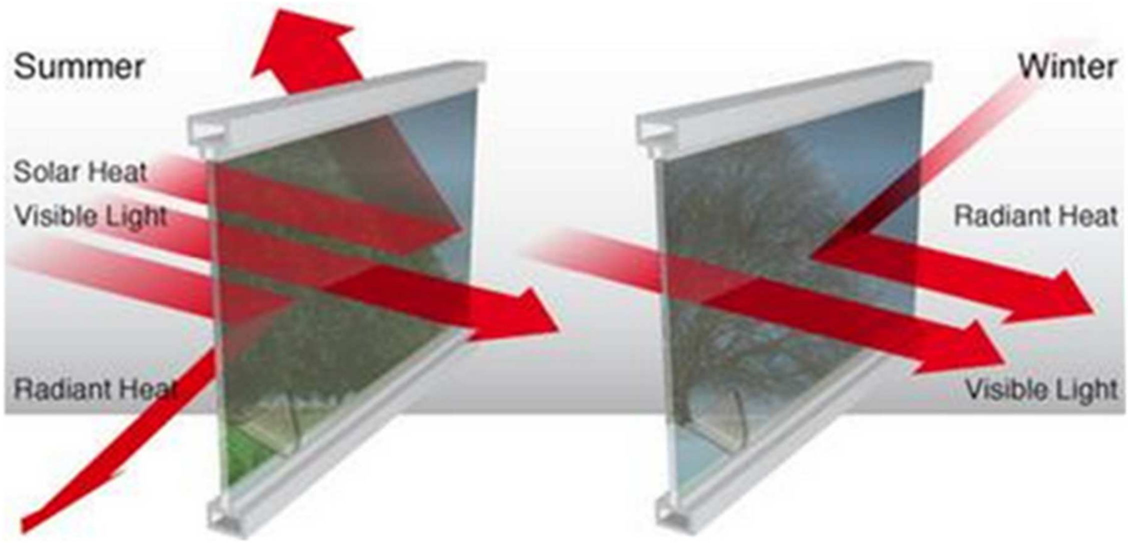


Figure 19: Diagram of window films blocking solar and radiant heat

There are a large variety of different light filtering films currently on the market. Each type of film has a different set of attributes affecting its performance including tint, internal and external reflectiveness, and visible light transmittance. Internal reflectiveness affects the visibility through the window at night when the lights are on inside. The visible light transmittance affects how much light enters the room from outside. Tint and external reflectiveness affect the degree to which solar and radiant heat are rejected, determining the energy savings for that particular film. There is an inverse relationship between heat loss/gain reduction and tint and reflectiveness. A high reflectiveness and tint will make the room darker but the film will have high solar heat gain reduction. An example of the relationships between these characteristics is depicted in Appendix G. With the correct combination of these characteristics, window films can greatly reduce heat exchange through windows.

2.6 Conclusion

The information presented throughout this chapter serves to give a comprehensive overview of many factors leading up to our project. In order to come up with the best possible ideas for reducing resource use and expenditure due to energy at the Radisson-Slavyanskaya, we first looked into previous efforts in the tourism industry for sustainability. The energy audit data we collected and were provided, together with interview data from our Russian project partners and Radisson-Slavyanskaya management, was the next step in determining an initial direction for our project. Finally, the information on various technical systems at the Radisson-Slavyanskaya Hotel was gathered to provide us with a background on potential improvements for these systems.

3. Methodology

The purpose of this study was to gauge the extent and effectiveness of sustainable practices in the Radisson-Slavyanskaya Hotel. By employing data on the hotel's current practices, we suggested new practices or extensions of current practices to improve the sustainability of the hotel. Furthermore, using the energy audit of the hotel, we aimed to establish a correlation between environmental impact of the hotel practices and economic success of the hotel. By establishing this relationship, we were able to work toward the following objectives, which are discussed throughout this chapter:

1. Identify upgrades to Radisson-Slavyanskaya sustainability
2. Analyze potential solutions for sustainable impact
3. Analyze potential solutions for economic impact
4. Develop a long-term plan for the Radisson-Slavyanskaya

The most robust standard for sustainable development in eastern European countries is LEED certification. LEED does not have criteria specific to hotel buildings, but the models used to certify existing buildings can be modified to accommodate for the practices of a hotel. The main areas of hospitality management which play into sustainability are construction, customer services and supply sourcing (US Green Building Council, 2009). The analysis used in this methodology was developed by project team based on the standards outlined in the LEED documentation.

3.1 Objective 1: Identify short-term sustainable changes for Radisson-Slavyanskaya

After identifying the areas in which the Radisson-Slavyanskaya was lacking with respect to sustainability, we came up with a list of potential sustainable changes to be implemented throughout the hotel. Each intervention fell into one of two main categories: upgrades in technology and shifts in policy or mindset. We considered a wide range of possibilities in structural and engineering improvements, from small refinements like low-flow faucets, showerheads, and toilets to large-scale remodeling projects, including use of energy recovery systems and revamping current insulation and windows. In the second category, our ideas on changes in the hotel's mindset ranged from use of sustainable sourcing to integrating guests, employees, and management into a comprehensive way of sustainable thinking.

We examined this list of possible changes with an eye toward determining which would ultimately provide the most benefit to the hotel, its guests, and the surrounding environment, while also being most financially feasible especially in the short-term. As we had already preliminarily identified the ideas as being beneficial, we looked at the information gained in our interviews to determine which aligned with the priorities and limitations outlined by the management in Objective 1 and which would make sense in Moscow's sustainability culture. **[RQ1]**

- **[RQ 1.1]** What physical systems in the hotel are affected by the proposed solution?
- **[RQ 1.2]** Does each proposed solution work within the limitations outlined by the management of the Radisson-Slavyanskaya Hotel?
- **[RQ 1.3]** Does each proposed solution work in conjunction with the current infrastructure for sustainability in Moscow?

While some solutions might have been more impactful either environmentally or economically, our strategy was designed to find the best balance between practical improvement and environmental vision. Taking into account all opinions is the best way to ensure realistic changes for the better, which in turn will set the stage for future development and shifts in mindset with widespread benefit. Given the scope of this project, we believe that this method will prove reliable in identifying viable short-term implementations as well as far-reaching, more extensive developments.

3.2 Objective 2: Analyze potential solutions for sustainable impact

Once data had been collected on the hotel's operations and we determined potential sustainable improvements or changes in processes, we analyzed each possibility to gauge the feasibility of its implementation. Each policy or developmental modification was evaluated for its impact on the hotel's economic situation and as its effectiveness at improving the hotel's influence on the environment and society. This investigation ensured that any ideas suggested to hotel management were ultimately for the benefit of the hotel, its guests, and its staff as well as for the surrounding community--which often go hand-in-hand (Bohdanowicz, 2011).

With this end goal in mind, we researched how best to evaluate the environmental impact of specific activities. Such methods could include analysis of indicators like water usage, energy consumption, or waste production coupled with long-term, big-picture studies on previous implementations of similar solutions. We compared the expected effects of our prospective solutions to data gained from the energy audit discussed above, and determine relative strength of impact of each possibility. Special consideration was given to the requirement that the resultant activities by the hotel should not simply reduce negative impact, but actively create positive impact (D. Rosbach, personal communication, March 31, 2014; McDonough, Braungart, & Bollinger, 2007). In order to measure the impact of each proposed solution on the sustainability of the hotel, we had to answer the following questions for each. **[RQ2]**

- **[RQ 2.1]** Does the proposed solution decrease usage of resources within the hotel?
- **[RQ 2.2]** Does the proposed solution positively or negatively impact the surrounding community or environment?
- **[RQ 2.3]** Does the proposed solution promote use of environmentally friendly products or materials in the hotel?

This analysis included triple bottom line (TBL) evaluation, which specifically looks at environmental and social concerns as other "bottom lines" in cost-benefit analysis (A.

Trapp, personal communication, April 2, 2014). This investigation provided quantitative results that were useful in determining the effects each procedure might have on different aspects of the hotel's standard operating procedures.

3.3 Objective 3: Analyze potential solutions for economic impact

With our technical research on possible solutions for the Radisson-Slavyanskaya, we needed to address the financial feasibility of such solutions. Although there are many upgrades to the hotel that will address the environmental facet of sustainability, they are not appropriate solutions unless they support economic sustainability as well. Not only are capital costs of purchasing equipment important, but insight into effects of the product on future finances. The process of analyzing the economic impact of the potential solutions involved the consideration of the following research questions. **[RQ3]**

- **[RQ 3.1]** What are the costs associated with implementing this solution?
- **[RQ 3.2]** What is the payback period for each solution?
- **[RQ 3.3]** Will each proposed solution have a positive economic effect on the hotel?

Suitable cost of equipment is crucial to the practicality of a proposed solution. Before conducting financial calculations on our suggested installation of new chillers, cooling towers, window films, and room occupancy sensors, we first had to gather pricing information on such products. Potential suppliers and companies were determined based product selection, availability in Moscow, and responsiveness to our inquiries. Using the pricing and specification information obtained, we calculated the energy savings and potential profitability of implementing these upgrades at the Radisson-Slavyanskaya. Calculation of payback periods allowed us to determine what positive or negative impacts the operation and maintenance costs of the product would have on the savings discovered through a reduction in energy use. To count for the progress of technology in the hotel industry, we evaluated three financial indicators: NPV (net present value), PP (payback period), and ROI (return on investments). These values, when examined along with the notion of discounted cash flow (DCF), adjust for the fluctuating value of money over time and the useful lifetime of each piece of technology.

3.4 Objective 4: Develop a long-term plan for the Radisson-Slavyanskaya

Based on our background research and understanding of hotel systems, we developed a set of potential solutions that could possibly be implemented in the Radisson-Slavyanskaya's future. This plan consists of two parts: technical upgrades and program recommendations. The proposed technical upgrades range across a wide variety of systems such as lighting, piping, and the HVAC system. The program recommendations are focused on raising awareness for sustainable development and on improving the hotel's image as a sustainable member of its community. These solutions were designed to not only reduce resource usage like the short term solutions, but to improve the hotel's sustainability in a more holistic fashion.

4. Results and Analysis

Through our research, we have determined that there are three main technological improvements which could be made at the Radisson-Slavyanskaya for maximum impact on environmental sustainability in the short-term. These upgrades focus on the HVAC and lighting systems of the hotel, as categorically these are the two biggest consumers of electricity in the hotel. Specifically, we suggest that the hotel install low-E window films for better insulation, upgrade the A/C chillers to more efficient models, and retrofit occupancy sensors in parts of the hotel. Additionally, we have also created a long-term plan for the hotel which includes more extensive technical improvements along with changes in hotel policy which are evidenced to improve all facets of the Radisson-Slavyanskaya's sustainability. The environmental and social impacts of these changes, as well as detailed financial analysis for the suggested short-term improvements, are detailed here.

4.1 Analysis of low-E window films

We found that installing light-filtering window films on window interiors can be implemented within the limitations of the Radisson-Slavyanskaya Hotel, and will decrease environmental impact and boost energy savings. The ease of installing such films, coupled with their insulating properties, will serve to ultimately decrease the hotel's cost of operations and ensure this retrofit will pay for itself over time.

4.1.1 Practicality of window film installation

The installation of window films is very simple. The process includes cutting the larger piece of film to a size slightly larger than the window, coating the window in the application solution, applying the film to the window, and cutting away the excess material ("Instructions for applying Window Film", 2012). The simplicity of this process ensures that maintenance staff members of the Radisson-Slavyanskaya could easily be trained toa apply the window films themselves, thereby further cutting down on expenses. The ease of installation also means that no rooms or sections of the hotel would need to be closed for renovation.

There is no maintenance required for the window films, apart from the normal washing of the windows. The windows films have a lifespan of about ten to twenty years (Elmore Associates, 2014). This time period dovetails with the goals of the Radisson-Slavyanskaya, as full-scale window replacements could become a reality by the end of this period.

4.1.2 Energy savings of low-E window films

The chosen window film must meet the following criteria in order to be an effective solution for the Radisson-Slavyanskaya Hotel.

- The film should provide all-year-round energy savings
- The film should not make the rooms darker
- The film should have the shortest payback period possible

The ideal option that meets all of the requirements is the LLumar EnerLogic window film. It is a technological breakthrough that appeared on the US market in 2011. The film is of neutral color; it transmits 70% of visible light and helps to reduce the winter heat losses by more than 40%. However, this type of film is not yet available in Moscow.

Another film that fits the above requirements is the LLumar Low-E window film. LLumar's film has high visible light transmittance—around 70%—and generates year-round energy savings. The specific characteristics of both types and various color options of LLumar films are outlined in Figure 20 below.

	% Visible Light Transmittance	Emissivity	Solar Heat Gain Coefficient	% Total Solar Energy Rejected	% Summer Solar Heat Gain Reduction	% Winter Heat Loss Reduction
Clear Glass	*90*	*0,84*	*0,86*	*14*	*0*	*0*
			EnerLogic Llumar			
LEP-35 SR CDF (Warm Neutral)	33	0,07	0,24	76	72	42
LEP-70 SR CDF (Warm Neutral)	70	0,09	0,51	49	41	41
			Low-E Llumar			
E-1220 SR CDF (Silver)	12	0,36	0,15	85	82	25
LE-35 SR CDF (Silver/Gold)	31	0,33	0,27	73	68	26
LE-50 SR CDF (Silver/Gold)	49	0,36	0,42	58	51	23

Figure 20: Comparison of Low-E and EnergLogic film

To calculate the energy savings from the window films, we had to first calculate the energy costs associated with the heating and air conditioning systems. The data used for estimating the actual costs of energy for heating and air conditioning was taken from the energy audit provided by the hotel and is presented in Figures 21 and 22. Note the huge heat loss through the building envelope during the heating period, which indicates the great need for improvement in this area.

HEATING	*Figure (Gcal)*	*Cost (rub.)*
Thermal energy needs for heating the building during the heating season	4,970.6	6,396,484.86
Common heat loss through the building envelope during the heating period	6,355.7	8,178,919.82
Annual heat consumption at the object	9,215.62	11,859,247.14

Figure 21: Calculated annual heating costs for the Radisson-Slavyanskaya

AIR CONDITIONING	*Figure (kWh per annum)*	*Cost (rub.)*
Annual electricity consumption by A/C system	1,052,187	3,831,362.80
Annual electricity consumption by individual A/C	807,143	2,939,076.10
Total annual electricity consumption by A/C	1,859,330	6,770,438.91

Figure 22: Calculated annual air conditioning costs for the Radisson-Slavyanskaya

Installation of LLumar Low-E window films will provide an estimated energy savings of 4.2% annually for the Radisson-Slavyanskaya. We determined this by considering a number of factors, including glass area, type of windows, and climatic conditions. We input these factors into a calculator provided by the firm VISTA, which manufactures a film similar to LLumar's Low-E model. This method of calculation gave us the most precise look at potential environmental benefit of LLumar window films.

4.1.3 Financial analysis of LLumar Low-E window films

In our market research on low-E window films we focused on the firm Solarex, which is the official dealer that works with LLumar. There are other companies in Russia that distribute similar energy saving film, but these companies do not provide any performance characteristics for their films. Consequently the quality of these films was impossible to asses and therefore warranted no further consideration.

We contacted Solarex to obtain the price list for its goods and services (see Figure 23). To ensure the given prices were optimal, we compared the numbers from Solarex with prices from Ultra Solar Block, another window film company. It is evident that the discrepancy between the prices offered by two firms is not that large, so we can safely assume that the cost of LLumar film is close to the market average.

	Price per unit (rub.)	*Unit size (m^2)*	*Number of units*	*Cost of film (rub.)*	*Delivery (rub.)*	*Cost of installment (rub.)*	*Overall cost (rub.)*
Ultra Solar Block							
Sky Blue	20 000	45,6	132,26	2 660 000	0	1 809 300	4 469 300
Llumar Low-e							
LE-35 SR CDF LE-50 SR CDF (Silver/Gold)	16 780	45,6	132,26	2 231 740	0	1 981 200	4 212 940

Figure 23: Price list comparison for window film

The cost for installation provided by multiple firms in Russia was too high to allow for return on investment. Therefore, we instead recommend that hotel maintenance staff observe the first 1,000 square meters of installation in order to be trained for the rest of the installation, and performed our analysis with this in mind. Taking into account the calculated energy savings and the adjusted price of purchasing and installing the window film, we calculated the expected payback period for the Low-E film and the EnerLogic film to be around eight and three years, respectively. The EnerLogic film saves nearly twice as much energy as the Low-E film, so theoretically this type of film is a much better option for the Radisson-Slavyanskaya Hotel; however, if this is unobtainable, the Low-E window film is a viable alternative (Figure 24).

Type of film	*% of energy savings*	*Amount saved annually*	*Payback period*
Low-E film	4.20%	782,446.81 руб.	8.11
EnerLogic film	7.20%	1,341,337.40 руб.	3.37

Figure 24: Payback period for EnerLogic and Low-E Film

Based on the findings presented here, we recommend the installation of low-E window films in the Radisson-Slavyanskaya Hotel as a means to improve sustainability and reduce resource use. Specifically, we recommend retrofitting either LLumar Low-E or EnerLogic film to decrease expected load on the hotel's HVAC system. Such an improvement is viable as a short-term solution as it does not require extensive renovation, and will more than pay for itself throughout the lifetime of the film.

4.2 Analysis of air conditioning system upgrades

The central air condition system of a can be one of the highest users of resources, in the form of both electricity and water. In the Radisson-Slavyanskaya, the cooling towers and chillers constituted six pieces of equipment with potential for effective upgrades. The four chillers used in the Radisson-Slavyanskaya are the Johnson Controls York model YLCS-0720-SA, while the two cooling towers used are EvapCo model LSTA-8P-123. The chillers in the basement are paired off in parallel configuration, and each pair corresponds to one of the two cooling towers on the hotel's 8th floor roof. The current screw chiller installed at the hotel use R-134a refrigerant.

At the Radisson-Slavyanskaya Hotel, the chillers alone accounted for 16.4% of the total electricity use per year in 2012 (see Appendix E). The hotel's two cooling towers draw 37 kW each. The cooling towers, in addition to consuming electricity also lose 46.5 liters of water per minute in each of the two open circuit cooling towers. Such significant figures of resource consumption highlighted the air conditioning system and particularly the chillers as an area for impactful improvement in the hotel.

4.2.1 Discussion of technical limitations and benefits of chillers and cooling towers

We were able to narrow down our options for chillers and cooling towers using the limitations of some types and benefits of other types of systems. Absorption chillers were soon determined to be impractical, as they are by nature less efficient than air- or water-cooled chillers. Therefore they use a higher amount of equivalent energy in steam than electric-powered chillers use in electricity, going against the principles of economic and environmental sustainability which are core to this project.

Air-cooled chillers were also eliminated from our final analysis, due primarily to their smaller cooling capacity. Though they generally have a lower initial cost than water-cooled chillers, air is inherently less efficient as a mode of heat transfer than water. Additionally, because of their location on the roof or exterior of the building, air-cooled chillers have a shorter life span due exposure to environmental conditions, and so would not be a sound investment especially in such a harsh climate as Moscow.

The factors discussed above leave water-cooled chillers as the best option for the hotel. A water-cooled chiller will also be the easiest for the hotel to integrate into existing system because the current chillers are water-cooled models. The four main categories of water-cooled chillers were analyzed, and we determined a magnetic bearing centrifugal chiller to be the best choice for the hotel in terms of environmental sustainability, low maintenance, and long life span.

As compared to scroll and reciprocating chillers, screw and centrifugal chillers are capable of far greater cooling capacities and so are more appropriate for larger buildings like the Radisson-Slavyanskaya. Of these two, centrifugal chillers—especially those with magnetic bearings—prove to be longer-lasting and more efficient than screw chillers. Magnetic bearing centrifugal chillers have higher EER and IPLV than screw chillers due to their frictionless design. Finally, almost all new magnetic centrifugal chillers use R-134a, currently the most environmentally friendly refrigerant available.

The selection of an appropriate cooling tower is also critical to the successful operation of the central air conditioning system. While open-circuit systems serve their purpose, closed-circuit cooling towers do not evaporate process water, and so are more water efficient. Hybrid cooling towers could further optimize on this technology by combining dry and closed-circuit cooling. This serves to avoid water use during cooler weather when the air-conditioning load is not as high, which would be especially useful in a cooler climate like Moscow.

Given the data presented above, we have determined that significant strides could be made in reducing resource use at the Radisson-Slavyanskaya Hotel by upgrading the chillers and cooling towers of the air conditioning system. Specifically, we recommend installation of magnetic bearing centrifugal chillers together with closed-circuit or hybrid water cooling towers as replacements for the current systems in place at the hotel. This new technology would decrease energy and water use by the hotel's air conditioning system, while employing the most environmentally-friendly cooling agents and byproducts.

4.2.2 Financial analysis of chiller and cooling tower upgrades

In our preliminary analysis, due to high up-front costs of purchase and installation, we discovered that upgrades to cooling towers at the Radisson-Slavyanskaya would not pay off in the short-term. Therefore we decided to focus our detailed financial analysis on chiller upgrades, and suggest that further research be done into the specific benefits and costs of cooling tower upgrades as part of the hotel's long-term plan.

The chillers currently in use at the Radisson-Slavyanskaya Hotel are in different stages of depreciation. Because the time required for the delivery of the new equipment is eight weeks, we assume that all the calculations of cash flows should begin on January 1, 2015. Before purchasing the new chillers, the old ones must be sold. Market analysis shows that they can be sold at a ten percent discount of the total residual value. The addition of the imposed value added tax (VAT) results in a final profit from selling the old chillers. See Appendix J for numerical results for these and following calculations, and Appendix I for a glossary of financial terms.

The purchase price of each new chiller is 83,610 rubles, or 2,448,766 rubles for all four chillers. Accessories, as well as the delivery, installation and removal (of the old chillers) add to the final cost of the system. All the prices include VAT = 18%. The ruble to euro (initial currency) exchange rate is assumed to be 48 rubles per euro. The difference between the accrued and the input VAT is equal 2,985,623 rubles. This amount will be refunded, so we subtract it from the investment required and get the final sum of 17,038,182 rubles.

The profitable part of the project is derived from the savings on electricity and taxes. The old chillers' electricity consumption is 672.4 kW whereas the new chillers require only 528 kW in total. That is a 21.48% reduction in the electricity consumption, which results in an annual savings of 373,377 kWh and approximately 1,956,495 rubles per year. The analysis of the electricity tariffs in Moscow during 2008-2014 shows the annual growth rate of 12% and allows estimating the forecasts of the future tariffs. This growth during the next 10 years results in a savings for the hotel of 40,443,858 rubles over these 10 years.

According to the Russian legislation, fixed assets purchased before 2010 are subject to 2.2% property tax. Property acquired after that time, is free of this tax. The tax base is calculated as half of the amount of the residual values of assets at the beginning and end of the year. Because three of the four chillers have not yet depreciated, this property tax will continue for another two, three, and ten years respectively. Because the chillers will be sold and replaced with new ones, there will no longer be tax on the old chillers. As a result, longer depreciation times are a positive due the amount of saved money that would have been spent on taxes instead. As depreciation reduces the tax base (thus, reducing the amount of the 20% income taxes paid), we treat bigger depreciation to be a profitable part of our project.

Described in Appendix I is a set of financial terms that describe the “profitability” of a project. These terms are designed to indicate whether or not a project is financially feasible or beneficial to the investor. For this project, we need to consider a large amount of factors that did not come into play during analysis of our other short term solutions. The factors include changes in property tax and depreciation. To determine how these factors affected the financial impact of replacing the chillers, we used the following calculations. The formula of discounting cash flow for each year is:

$$PV_{CF_n} = \frac{CF_n}{(1+r)^{n-2014}}$$

The discounted cash flows (DCF) of years 2015-25 are displayed in Figure 25.

Year	Price value of discounted cash flow (rubles)
2015	1,813,658
2016	2,201,976
2017	2,569,807
2018	2,905,812
2019	3,250,686
2020	3,635,218
2021	4,064,173
2022	4,542,883
2023	5,077,323
2024	5,674,186
2025	6,343,401

Figure 25: Discounted cash flows for the years 2015 to 2025

The DCF is used to calculate the net present value (NPV). The net present value of the project is the sum all cash inflows and cash outflows (investments). This total is 5,185,361 rubles. This value is greater than zero, so the project can be accepted.

To determine the payback period of the project, we calculated the cumulated discounted cash flow (CDCF). The year in which the CDCF becomes positive is the year of the payback, and was calculated to be approximately eight years.

The calculated return on investment (ROI) for this project is 30.43%. This is a very good figure for this type of investment.

$$\text{ROI} = \frac{\sum PV - Investments}{Investments} * 100\% = \mathbf{30.43\%}$$

The profitability index (PI) of this project is 1.3. Since this value is greater than one, this project can be accepted as a financially attractive proposal.

$$\text{PI} = \frac{\sum PV}{Investments} = \mathbf{1.3}$$

The internal return on investment (IRR) has a calculated value of 14.96%. This value is close to the market average in the hotel sector.

IRR **= 14.96%**

Overall, investing in replacing the current chillers with water cooler magnetic bearing centrifugal chillers will have positive monetary returns for the hotel compared to the average returns for similar investments.

4.3 Analysis of occupancy sensor lighting systems

Lighting accounts for 20% of the energy use in the Radisson-Slavyanskaya Hotel. In the year 2011, over nine million rubles were spent on lighting alone in the hotel. We determined that installing occupancy sensors in certain areas of the hotel will help decrease lighting costs by preventing lights being left on when rooms are not in use. Such upgrades are feasible and easy to install in the short term but also have extended long-term value for the hotel.

4.3.1 Practicality of lighting system upgrades

Installation of occupancy sensors throughout the hotel is noninvasive and straightforward, requiring minimal extra expenditure by the Radisson-Slavyanskaya. The old light switch is dismounted from the wall, disconnecting the power and ground wires. The new motion sensor light switch connects directly to the power wires that were previously connected to the old switch. The new switch can then be mounted to the wall ("How to Install a Motion-Sensor Light Switch", 2014). All of the motion detection technology is integrated into the switch unit, so there is no extra installation required.

We recommend installation of occupancy sensors primarily in Radisson-Slavyanskaya guest bathrooms for several reasons. First, there is little to no obstruction of motion and occupancy sensors in such a small and enclosed space. Furthermore, while the lighting in the main part of Radisson-Slavyanskaya guest rooms is controlled by individual lamps, bathroom lighting is controlled by a single switch. This centralization decreases the cost of switch replacement and time to upgrade the lighting system throughout the hotel.

4.3.2 Energy savings of occupancy sensor light switches in bathrooms

To calculate the energy saved by installing occupancy sensor switches, we had to account for each light fixture and the wattage of the corresponding bulbs. The standard guest room bathroom has two bulbs that are 18 watts (W) and two bulbs that are 12W. Since the calculator can only take on wattage, we added the total wattage and divided by the number of bulbs to get the average wattage. We also took into the efficiency of each bulb, known as the ballast multiplier, which was found to be 87% for an 18W CFL (Benya, 2014). This figure was used to calculate the actual electricity consumption of each bulb.

According to the official statistics, average hotel room bathroom lights are left on for eight hours a day. However, average person uses hotel bathroom for one hour a day, which is 12.5% of those 8 hours (Chen 2003). This means that in each room, the bathroom lights are using 175 kilowatt-hours (kWh) of energy per year. This translates to a significant 64,904 kWh saved by the Radisson-Slavyanskaya per year, as shown below in Figure 26. Thus the installation of occupancy sensor lighting controls throughout the hotel will save 3% annually on energy usage due to lighting.

Number of fixtures	4
Bulbs per fixture	1
Wattage per bulb (W)	15
Ballast multiplier (5%)	87
Total wattage of lamps connected to the sensor (kW)	0.112
Total Yearly Operating hours	2920
Occupancy Rate (%)	12.5
Annual Total Energy used per Room (kWh)	175
Energy Saved per Room (kWh)	152
Total Building Energy Saved (kWh)	64,904

Figure 26: Calculated energy savings for occupancy sensing light switches

4.3.3 Financial analysis of ABB Basic 55 occupancy sensors

The first step in calculating financial feasibility of occupancy sensors was to research the market to find firms whose products would comply with Radisson-Slavyanskaya's requirements. Research of the Russian electric appliance market revealed that the best model was the ABB Basic 55 made by the German company Busch-Komfortschalter. This switch is easy to install and has a detection radius of 15 m (Figure 27). We contacted the firm's official retailer, Presitg Electro-materials, and learned that the model is available in Russia. The price per switch is 2,014 rubles. This price is near the market average of approximately 2,000 rubles.

Figure 27: Busch-Komfortschalter ABB Basic 55 occupancy sensor

The hotel has its own maintenance staff which can install the switches, so there are no external installation costs. There are 427 guest bathrooms in the hotel, so at a price of 2,014 rubles per switch, the total cost to replace switches in all of the guest rooms is 859,978 rubles.

For calculating the amount of savings these sensors provide and the payback period of the whole operation, we used the *Occupancy Sensor Savings Estimator* provided by Arkansas Industrial Energy Clearinghouse (ArkansasIEC, 2013). We found that installation of occupancy sensor switches would result in saving up to 87.5% of electricity used to light guest bathrooms. This translates to an annual savings of 484 rubles per room (Figure 28).

Total operating hours	2920
Room occupancy rate (%)	12.5
Average annual cost of energy (rubles)	1.6816
Average annual demand rate	42336.924
Cost of sensor installation (rubles)	2,014
Cost to operate lights without occupancy sensors (rubles)	57,450
Cost to operate lights with occupancy sensors (rubles)	56,966
Annual energy cost savings per room (rubles)	484
Simple payback period (years)	4.2

Figure 28: Calculated cost and payback period of motion detection light switches

We also had to account for a portion of the guests being environmentally aware and thus turning off lights without the help of occupancy sensors. If this represents 25% of the guest population, the adjusted amount saved will be approximately 155,008 rubles. This figure implies a payback period on initial investment of 8.47 years.

As the final step, we calculated return on investment, in order to find out if the project is profitable. The return on investment formula is depicted in Figure 29.

$$ROI = \frac{Gain\ from\ investment\ -\ Cost\ of\ investment}{Cost\ of\ investment}.$$

Figure 29: Equation for return on investment

If we calculate ROI for a five year period, it will be equal to:

$$ROI_5 = \frac{(206668*5)-859978}{859978} = 0.201589$$

Similarly, return on investment for 10 year period will be:

$$ROI_{10} = \frac{(206668*5)-859978}{859978} = 1.403178$$

As we can see, both indicators are positive, which means that the project is acceptable in terms of investment and following gains. The payback period of 8.47 years is also in compliance with the requirements of the hotel management.

Therefore we assert that installation of occupancy sensors in Radisson-Slavyanskaya guest bathrooms will provide a positive impact on the hotel's environmental and economic standing, while also being beneficial to the experience of its patrons. The updated technology in the sensors ensures that hotel guests will have a positive opinion of the technology, as the impact on their stays will be minimal. Furthermore, the projected savings of energy and money make the retrofit a worthwhile lasting investment for the hotel, while their ease of installation serves to verify their short-term viability.

5. Conclusions and Recommendations

Sustainable thinking is becoming increasingly popular in the global hotel industry. Our research has shown that sustainable thinking and practice can be of immense benefit to all involved parties in many ways, from positive impact on guests' stays to betterment of the surrounding environment to a definite reduction of hotel expenses. Therefore, we recommend that the Radisson-Slavyanskaya Hotel begin taking action toward this global trend to stay abreast of sustainable development in Moscow. As our research findings discussed in previous sections support, this will decrease the hotel's expenses, increase customer satisfaction, and make the hotel most competitive in the Russian tourism industry as sustainability becomes a widespread phenomenon. In particular, we advocate the following changes:

1. Revamping the hotel windows by *retrofitting with low-E window film*
2. Decrease energy usage by *upgrading the air conditioning chiller units* to magnetic bearing centrifugal models
3. *Installing room occupancy controls* when possible
4. *Making sustainability a primary concern* in future renovations and policies

5.1 Installation of low-E window films

Heating and cooling accounts for a large portion of energy expenses in commercial buildings, including hotels. A lot of excess energy is wasted in heating and cooling rooms to compensate for heat lost or gained through old or inefficient windows. To combat these extra expenses, **we recommend that the Radisson-Slavyanskaya purchase LLumar Low-E energy saving window films from SolarEx and retrofit this film to all windows in the hotel.**

The Low-E window films reduce heat transfer through the glass by reflecting or filtering up to 85% of solar energy, including ultraviolet (UV) radiation and infrared heat energy. The reduction of heat loss and gain will normalize the indoor climate of the building and improve the comfort of guests and employees. The films will also help reduce fading of furniture from UV radiation. This may cause a slight change in external appearance of the building. The tint may also affect the brightness of rooms depending on what direction the windows are facing. However, such changes should be negligible, especially considering that the windows of the Radisson-Slavyanskaya are already slightly tinted.

The films will provide year round energy savings averaging at 4.2%. This will save a total of 782,446 rubles per year in heating and cooling costs. The cost per square meter of film is 368 rubles. This makes the total cost, including installation, 4,212,940 rubles. Assuming that the hotel pays for installation of 1,000 m^2 of installation and trains their own staff to install the rest of the film, this investment will pay off in 8.11 years (Figure 30).

Total Cost	Yearly Energy Savings	Yearly Cost Savings	Estimated Payback Period
4,212,940 rubles	4.2%	782,446 rubles	8.11 years

Figure 30: Summary of Low-E Window Film cost analysis

In general, given the above cost analysis and energy savings data, we assert that the LLumar Low-E Window Films are a viable and effective upgrade at the Radisson-Slavyanskaya Hotel. Their ease of installation coupled with their efficiency and reasonable price mean they can be easily implemented to work towards decreasing resource use and improving sustainability at the Radisson-Slavyanskaya Hotel.

5.2 Upgrades to the Radisson-Slavyanskaya air conditioning system

The air conditioning system of a building is often the single largest consumer of electricity. Because such a large portion of electricity use is concentrated in a small number of components, the air conditioning system is a prime candidate for energy savings. There are two main components of a centralized air conditioning system: the chillers and the cooling towers. The chillers use a refrigerant and vapor compression cycle to remove the heat from the building, while the cooling towers help expel the extracted heat outside of the building. The current system in the Radisson-Slavyanskaya, while not wholly obsolete, is outdated. Advances in chiller and cooling tower technology in the past twenty-five years have led to more efficient units that can significantly reduce the hotel's electricity and water usage.

The current chiller uses a rotary screw compressor. This technology is still used in chillers today, but new features such as variable speed drives allow newer chillers to work more efficiently at less than peak loads. While rotary screw compressors have been in production for many years, they are not at the forefront of energy efficient designs. Chillers with centrifugal compressors not only use less electricity, but also last longer and require less maintenance due to their design. To further enhance efficiency, centrifugal compressors equipped with magnetic bearings eliminate oil as a lubricant, and therefore the friction and heat transfer losses associated with oil. Because of the higher efficiency, longer life, reduced maintenance costs, and due to the old age of the current chiller, centrifugal water-cooled chillers with magnetic bearings and a variable speed drive motor are a superior option to the current chillers.

A critical component for water-cooled chillers is a cooling tower. Cooling towers are installed on the roof or outside of the building and expel the heat from the chiller to the outside air. The current pair of cooling towers use direct type cooling. This method results in the loss of water due to evaporation, and well as contamination of the water when it is exposed to the environment. A newer style of cooling tower uses indirect cooling where evaporation and contamination are eliminated. Some indirect cooling towers, called hybrid cooling towers, take advantage of low cooling loads and switch to cooling with air instead of water, further decreasing water usage.

Although the above recommendations are the most ideal for the hotel in terms of energy efficiency and long-term sustainability, in the short-term they are not necessarily the best options financially for the hotel. The high initial cost of the hybrid closed-circuit cooling towers offset the energy savings enough to cause an unacceptably long payoff period. Due to this reason we do not recommend upgrading the current cooling towers as part of a short-term plan for the Radisson-Slavyanskaya.

However, replacing the chillers in the basement with water cooled magnetic bearing centrifugal chillers will result in positive financial returns. Taking into account the fact that the old chillers are not yet fully depreciated and can be sold to offset the cost of the new chillers, the total cost of purchasing and installing the chillers will be 17,038,182 rubles. Annually, the savings due to reduced water and energy use will be approximately 373,377 kWh or 597,403 rubles. Additionally, the hotel will save approximately 41 million rubles in taxes over the next ten years by selling the old chillers. Using these figures, the payback period will be 8 years (Figure 31).

Total Investment	Annually Energy Saved	Annual Energy Cost Savings	Money Saved in Taxes over 10 years	Payback Period
17,038,182 rubles	373,377 kWh	597,403 rubles	40,443,858 rubles	8 years

Figure 31: Summary of cost analysis for magnetic bearing centrifugal chillers

Thus upgrading the air conditioning system, and particularly the chillers, of the Radisson-Slavyanskaya Hotel will generate both short- and long-term savings for the hotel due to reduced electricity use by the whole system. The expressed interest of hotel management in this project along with favorable financial and environmental analysis for chiller upgrades combine to ensure the feasibility and advantages of this project as the hotel moves toward sustainability.

5.3 Retrofitting with occupancy sensor lighting controls

Lighting accounts for 20% of electricity costs in the Radisson-Slavyanskaya Hotel. In order to reduce these costs, **we recommend that the Radisson-Slavyanskaya Hotel install ABB Basic 55 wall-mounted motion-detecting light switches in each guest bathroom.**

On average, guests leave the bathroom lights on for 8 hours per day, which wastes 153 kWh of electricity per room per year. Installation of ABB Basic 55 light switches in the guest bathrooms will ensure that the lights will not be left on for any extended period of time. The installation of the wall mounted sensors is simple and inexpensive, and requires no alterations to the wiring inside the walls. However, if the technology is not implemented properly, they can be a nuisance for people using the rooms in which they are installed. If both types of sensors (ultraviolet and infrared) are installed correctly, however, this should not be a concern.

The price per switch is 2,014 rubles. There are no extra installation costs since the installation can be done by the technicians in the hotel, making the total up-front cost of the project 859,978 rubles. The switches will save 87% of the energy used by bathroom lighting saving 484 rubles per room and 155,008 rubles for the entire hotel yearly. Assuming 25% of the hotel guests are environmentally aware and will not leave their lights on for 8 hours a day, the payback period for this investment is 8.47 years (Figure 32).

Total Cost	**Yearly Energy Savings**	**Yearly Cost Savings**	**Estimated Payback Period**
859,978 rubles	87%	155,008 rubles	8.47 years

Figure 32: Summary of ABB Basic 55 light switches cost analysis

As shown above, installation of ABB Basic 55 light switches throughout Radisson-Slavyanskaya guest bathrooms will be both profitable for the hotel and cause reduction in electricity use. It is a viable solution in the short-term due to its ease of installation and immediate payback period, and will continue to be valuable in the long term. This technological upgrade is a sound investment for the Radisson-Slavyanskaya Hotel, and will ultimately contribute to improvement of the hotel's sustainability.

5.4 Long-term upgrades at the Radisson-Slavyanskaya

In our research to develop a short-term plan of technological upgrades for the Radisson-Slavyanskaya Hotel, we also explored a number of options which were beyond the scope of our project but ultimately could help the hotel move toward sustainability. These improvements constitute the long-term plan we have presented the hotel, and are detailed here.

5.4.1 Long-term technical upgrades

In addition to short term solutions to improve the sustainability of the Radisson-Slavyanskaya Hotel, there are a number of broad-spectrum, large scale changes that could be made to the economic and environmental benefit of the business. Most of these changes are not possible currently or in the near future as they are physically demanding and also require massive overhaul of current operational procedures at the hotel. We recommend that the management of the Radisson-Slavyanskaya Hotel consider the following changes as resources and time become available:

- Install variable refrigerant flow units to replace central A/C and heating
- Replace windows with more energy efficient models
- Replace incandescent and CFL bulbs with LED bulbs
- Use Aquatherm recyclable PVC-free piping
- Design and implement a grey water reclamation system

Reducing heating and air conditioning costs

The largest consumer of energy in the hotel is HVAC systems. To reduce costs from energy use, **we recommend that the hotel invest in Variable Refrigerant Flow units to replace the current centralized HVAC system**. This would allow each room to have control over its own temperature. Combined with occupancy sensors, this could allow the heating and cooling to be adjusted depending on use and occupancy of the room or the weather outside. The system is easily integrated into existing ducted systems and can be easily controlled by one interface (Mitsubishi, 2012). Another way to cut down expenses related to heating and cooling is to **replace the windows with newer more energy efficient models**. This will cause less heat loss during cold months and will keep rooms cooler during months of increased sunlight. Optimally, the hotel should choose low-E glazed, tempered, double-paned window glass. The low-E treatment is virtually undetectable but still blocks unwanted heat transfer. The hotel will also have the option to choose tinted or reflective windows to further decrease unwanted sunlight into the building. By fitting the renovated building with new window fixtures, the hotel will save money on heat loss during the cold months and increase guest comfort in areas that were previously drafty (U.S. Department of Energy, 2012).

Reducing Lighting Costs

We recommend the installation of LED bulbs wherever possible. After large scale changes are made in and around the building, specifically in updating nearby voltage transformers, our research strongly supports the use of LED lights over CFL lights. LED bulbs will last 5 times longer than CFL bulbs under the proper operating conditions—50,000 hours as opposed to 10,000 (Dulley 2007). While replacing the bulbs will only slightly reduce the energy usage per light fixture, the principal purchase costs will be greatly reduced due to the fact that the bulbs will need to be replaced on a much less frequent basis.

Reducing water usage and improving sustainability of water-using systems

To enhance guest comfort and improve function of aerators and low-flow water fixtures, **we recommend that the hotel implement sustainable piping solutions**. Aquatherm Green Pipes are PVC free, recyclable and do not leech contaminants into potable water. Aquatherm offers many solutions that are catered to specific piping functions. Although, the non-PVC plastic piping needs to be replaced more often, it is recyclable and releases less harmful toxins into the air during production. The hotel could also invest in better insulation for the replacement piping to cut down on heat loss. Once better piping is installed, low flow water fixtures will allow for lower water consumption with no loss of guest comfort due to discoloration or odors (Ormandy 2014).

Grey water reclamation, while it might not be immensely beneficial in an economic sense, will greatly improve the sustainability of the building and the surrounding area. By reusing non-potable water produced by the building, strain is reduced on the city to process that water and provide more clean water to the hotel. Reusing gray water also reduces the water use of the building. **We recommend that the management of the Radisson-Slavyanskaya Hotel consider implanting a grey water reclamation program while planning major renovations.**

5.4.2 Long-term program and policy recommendations

The second part of the long term plan for the Radisson-Slavyanskaya Hotel includes recommendations for programs that could be implemented in the hotel as a means to improve the hotel's status as a sustainable member of the community. These programs have the potential to raise awareness for the sustainable development movement and to improve the hotel's sustainability from the ground up. We recommend that the Radisson-Slavyanskaya Hotel implement the following programs:

- Start a sustainability training program for employees
- Provide guests with informational materials about the hotel's sustainable efforts
- Begin purchasing materials and goods that comes from sustainable sources

Employee sustainability training

While technical improvements made at the hotel can certainly have a large impact and are often the easiest to quantify, hotel employees play the central role in hotel operations. Due to the large number of employees required for cleaning, maintenance, and management, proper employee training is critical to running the hotel efficiently. With simple changes to hotel operations, and even individual employee actions, the Radisson-Slavyanskaya can expect significant improvements in environmental sustainability. Employees with knowledge of their particular environmental impact when working on everyday tasks are more likely to complete such tasks in a more environmentally-sensitive manner. Cleaning staff and facilities managers in particular can benefit from sustainability training, as their jobs inherently deal with the most energy consuming systems at the hotel.

A comprehensive employee training program educating employees on energy saving strategies most relevant to their work has the potential to reduce energy use and otherwise positively affect environmental footprint at the hotel for minimal costs. Additionally, new employee orientations which highlight hotel's focus on environmental sustainability can help new employees adjust their work mentality to begin improving the Radisson-Slavyanskaya's sustainability profile from the outset.

Guest informational materials

As part of the service industry, The Radisson-Slavyanskaya deals primarily with guests, as opposed to material production. The hotel's success depends almost entirely on guest satisfaction and potential guest interest in the hotel. Because of this, any measure the hotel takes to improve the image of the hotel will result in positive returns. Due to growing trends in the global hotel industry, many hotel chains are making a point to display their efforts in environmental sustainability to their patrons. As we found in our questionnaire administered at the Radisson-Slavyanskaya, a large majority of guests responded positively to the idea of supplemental information detailing the hotel's steps taken to reduce environmental impact. Providing guests with this type of information will increase interest in the hotel and satisfy more environmentally-conscious guests.

Sustainable sourcing

The holistic view of sustainability involves more than the end user of a certain product or energy source. Tracing a product back to its manufacturing process is key to ensuring the product not only operates in an environmentally friendly fashion, but was made with that in mind as well. Proper sustainable business practices of the company behind the product in question confirm that care was taken during the product's manufacture to minimize energy usage and waste. It is recommended that the Radisson-Slavyanskaya buy from product manufacturers which employ such environmentally sustainable techniques. While the method of a product's manufacture may not directly affect the hotel's environmental impact, purchase of unsustainably produced products indirectly harms the environment.

Not only does the manufacture of a product consume energy, but so does the transportation of raw materials to the manufacturer and the delivery of finished products from the manufacturers to the end user. The closer the origin of the product is to the purchaser, the less energy is used for transportation. This is why obtaining products from local sources is important to increasing the indirect environmental sustainability of the Radisson-Slavyanskaya Hotel. When new products are being selected for widespread use at the hotel, including consumables used by guests, effort should be made to purchase such goods from nearby sources. In general, sourcing products from local, sustainable sources will help improve the Radisson-Slavyanskaya sustainable image and reduce its overall environmental impact.

5.5 Conclusion

This study is a guide for hotels looking to improve their status as a sustainable member of the community as well as reduce costs related to sustainable practices. The long-term impact of the changes to systems and policies explored throughout this report will not only financially benefit the Radisson-Slavyanskaya Hotel, but will also help push the surrounding community toward sustainability. More and more businesses and consumers are placing importance on reducing environmental impact. Potential clients and the rising work force in Moscow are going to experience huge shifts in mindset regarding the preservation and enhancement of the environment. The Radisson-Slavyanskaya Hotel has the opportunity to use its building, practices, and employees' attitudes to be an example of sustainable progress to its clients, associates and fellow Moscow businesses. We strongly recommend that the management use this opportunity to take a proactive first step and become a leading member of the sustainable development movement in Moscow.

6. Appendices

Appendix A: Sponsor Description

The Radisson Blu Slavyanskaya Hotel and Business Center in Moscow, Russia was the first western style luxury hotel to open after the fall of Soviet Russia. It is located in central Moscow along the banks of the Moskva River, across from the Kievskaya metro station. The hotel's 427 rooms range in amenities from a standard room to the presidential suite, with free wireless internet available in all rooms. Dining options include Mediterranean style, Japanese style, and traditional Russian style restaurants. The Radisson Blu brand is made up of 275 hotels.

Radisson's parent company is the Carlson Rezidor Hotel Group. Formerly two separate companies, Rezidor and Carlson merged in 2012. Carlson Rezidor now manages over 1,300 hotels in over 100 countries. Rezidor was formerly the hotel branch of SAS Airlines based in Scandinavia. In 2006 SAS Carlson started from the Gold Bond Stamp Company in Minneapolis, Minnesota by Curtis L. Carlson. In 1973 Gold Bond Stamp Company was rebranded to Carlson Companies Inc. due to the move towards the hospitality sector.

Appendix B: Manager Interview

1. How familiar are you with environmentally and economically sustainable methods of operation within the hotel industry?
2. Do you think sustainable development is important? For what reasons?
3. What kinds of sustainability practices (if any) are currently implemented in your hotel?
4. What (if any) plans do you have toward sustainability in the future?
5. How important to you is the environmental side of sustainability?
6. How important to you is the economic side of sustainability?
7. How much are you willing to pay in the short term to increase sustainability in the long term?
8. Is your customer base affected by your hotel's sustainability?
9. Are your employees interested or willing to look into changing their routines with sustainability in mind?
10. Do you find that guests are interested in energy use reduction programs (i.e. not washing bedding every day)?
11. How important is it being more environmentally friendly than competing hotels?
12. What (if any) significant changes have you done in the past to increase sustainability
    - How successful were they?
13. Is it more important to appear sustainable to guests or to simply reduce energy use "behind the scenes" (advertising)?
14. On what time interval does your hotel undergo significant construction/renovation or management changes?
    - Specifically regarding energy use?
15. What non-economic challenges might you face when implementing new energy efficient practices or equipment?
16. How important are official awards for sustainability?

Appendix C: Guest Survey

Dear Guest,

We hope you have enjoyed your stay at Radisson Slavyanskaya Hotel. To make your stay even more satisfactory, we invite you to take part in the future developments planned at the hotel. A joint study between the Financial University in Moscow, Russia and the Worcester Polytechnic University in Massachusetts, USA is investigating trends between hotel guests and environmental sustainability.

We ask that you will take the time to fill out this brief questionnaire at your convenience. Your answers will provide insight into guest satisfaction with the environmentally sustainable efforts of the Radisson Slavyanskaya hotel. Thank you for your time.

1. How much importance do you place on environmental sustainability in general?

☐ Very important ☐ Somewhat important ☐ Not very important
☐ Not important ☐ I don't care
☐ I don't know about environmental sustainability

2. How important to you is environmental sustainability when choosing a hotel?

☐ Very important ☐ Somewhat important ☐ Not very important
☐ Not important ☐ I don't care

3. Are you traveling internationally?
☐ Yes ☐ No, I live in Russia

4. If you are visiting for business purposes, did your company encourage you to choose an environmentally sustainable hotel for your stay?

☐ Yes, my company supports the choice of "green" hotels
☐ No, my company does not care about the environmental sustainability of a hotel
☐ I am not on a business trip

5. Would you be interested in knowing the ways in which your hotel actively supports environmental sustainability?
☐ Yes ☐ No

Уважаемый гость,

Мы искренне надеемся, что Вам понравился отдых в отеле «Radisson Славянская». Чтобы сделать Ваше пребывание еще приятнее, мы предлагаем Вам принять участие в формировании долгосрочной стратегии развития нашей гостиницы. Финансовый Университет при правительстве Российской Федерации совместно с Вустерским политехническим институтом (Массачусетс, США) проводит исследования в области экологической устойчивости гостиничного бизнеса.

Мы попросили бы Вас ответить на некоторые вопросы. Ваши ответы позволят нам лучше понять Вашу точку зрения относительно концепции устойчивого развития, что в будущем позволит нам, с учетом Ваших пожеланий, воплотить наши проекты.

1. Как Вы оцениваете значимость экологической устойчивости в целом?

☐ Очень важно ☐ Достаточно важно ☐ Не очень важно
☐ Вообще не важно ☐ Меня это не интересует
☐ Я не знаю, что такое экологическая устойчивость

2. Насколько важен для вас вопрос экологической устойчивости при выборе отеля?

☐ Очень важен ☐ Достаточно важен ☐ Не очень важен
☐ Вообще не важен ☐ Меня это не интересует

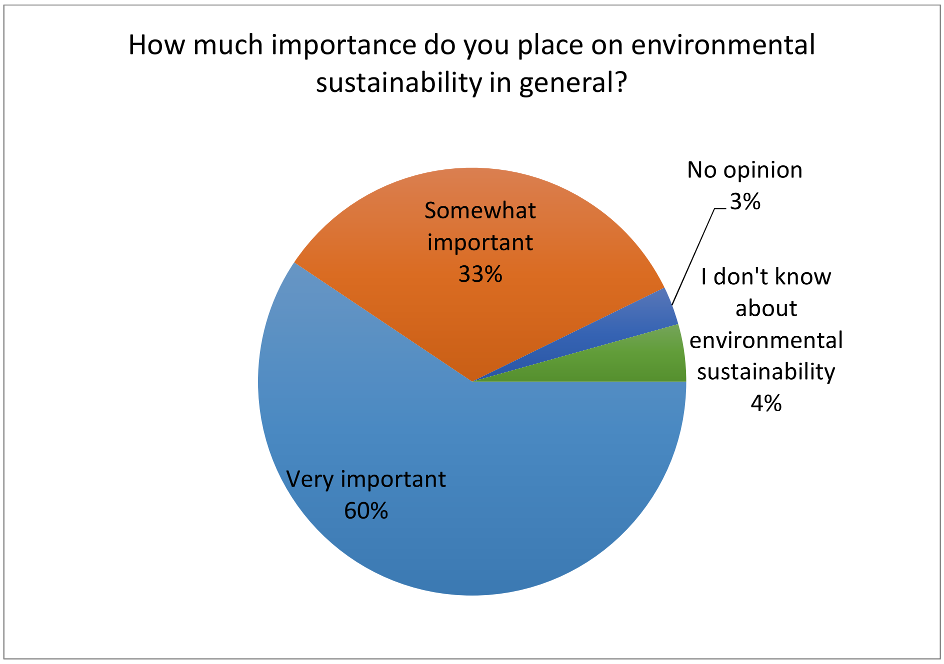
3. Вы иностранный турист?
☐ Да ☐ Нет, я из России

4. Если Вы в командировке/деловой поездке, ориентировался ли Ваш работодатель на политику экологической устойчивости при выборе отеля?

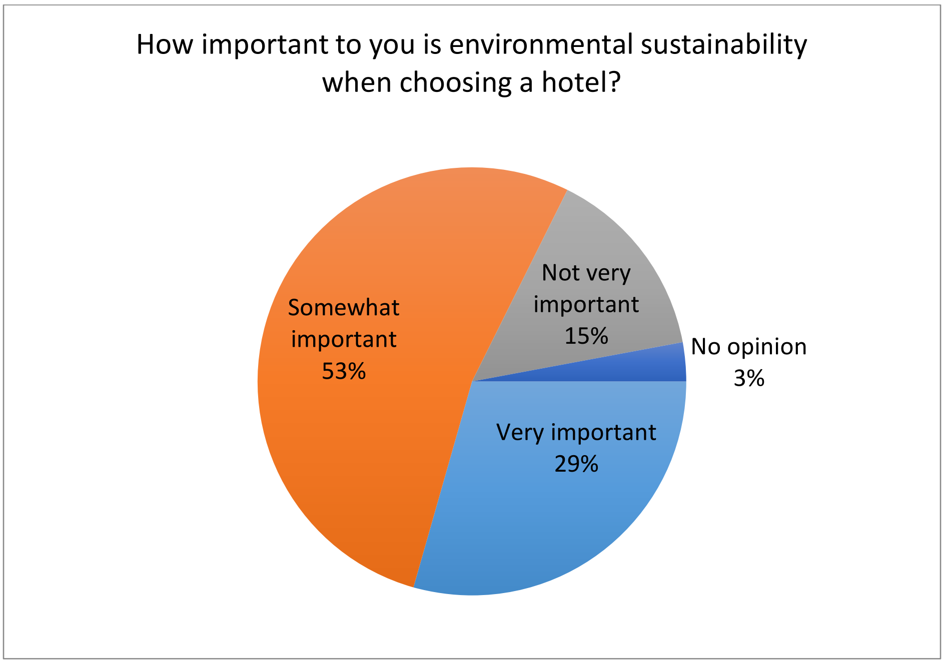
☐ Да, моя компания поддерживает выбор сотрудниками «зеленых» отелей
☐ Нет, моя компания не заостряет на этом внимание
☐ Я не в командировке

5. Было бы Вам интересно узнать, какие шаги делает наш отель для поддержания экологической устойчивости?
☐ Да ☐ Нет

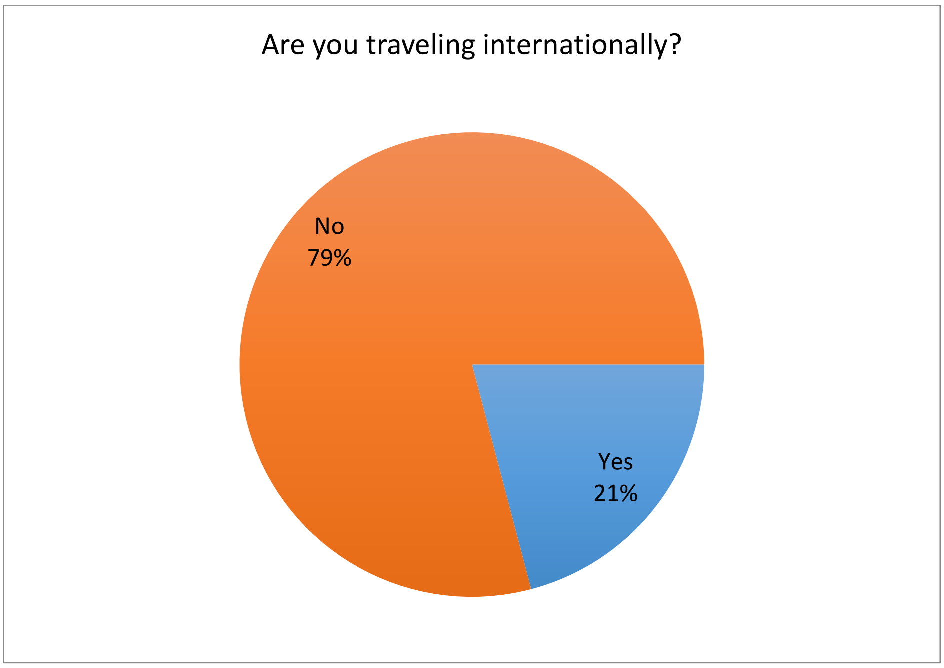
Appendix D: Guest Survey Results and Analysis



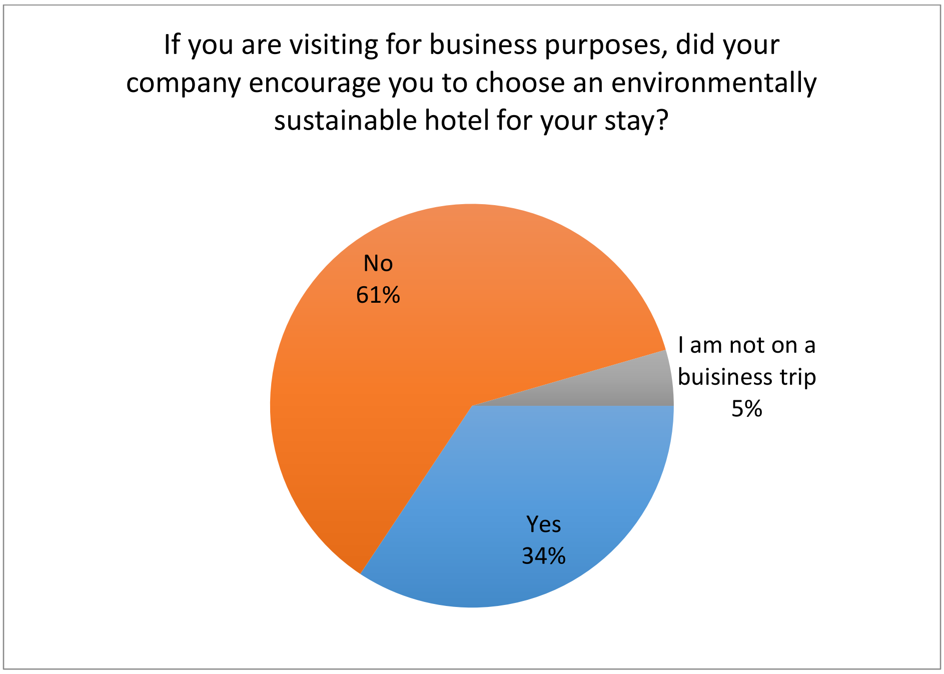
The results from this question show that ninety-three percent of Radisson-Slavyanskaya guests think that environmental sustainability is at least somewhat important. There were zero answers of “Not Very Important” and “Not Important”. This may be due to the fact that the large majority guests that visit the Radisson-Slavyanskaya hotel are environmentally conscious, or that the questionnaire participants may be responding to the social desirability bias (see section below: “Limitations of the Questionnaire”) and selecting “Somewhat Important” or “Very Important”, instead of the more negative options. Either way, the results from this question show that Radisson-Slavyanskaya hotel guests have the mindset that environmental sustainability in general is a good principle. Because of these guest opinions, Radisson-Slavyanskaya should realize that any step taken towards increase environmental sustainability has the possibility of increasing guest satisfaction.



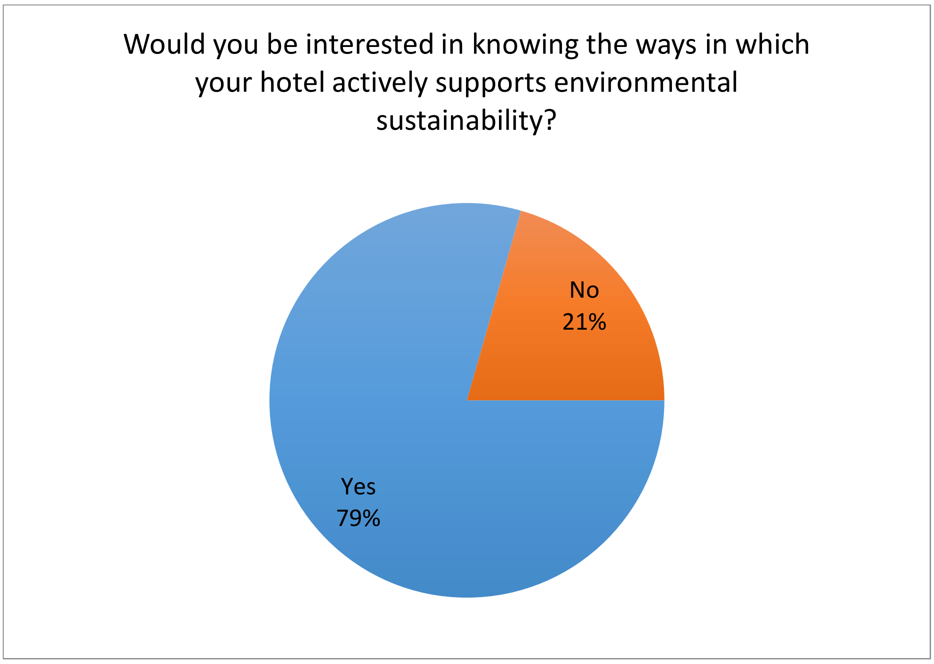
The results from this question show that eighty-two percent of Radisson-Slavyanskaya guests think that the environmental sustainability of a hotel is at least somewhat important. Compared to the question about environmental sustainably in general, this question received more answers on the less important side of the spectrum.



This chart gives a breakdown of foreign versus domestic (Russian) guests at the hotel. Over three quarters of the guest who responded to our questionnaire were Russian, an understandable amount considering Russia's size. Due to Moscow being the capitol of Russia and it's large population of 11.6 as million people as of 2011 ("City population by sex, city and city type"), inherently more business related work is conducted in Moscow than elsewhere in Russia. Similarly, the amount of foreign guests is not surprising, given the international nature of the Radisson-Slavyanskaya, and its dedicated business center.



The results from this question further back up the notion that the Radisson-Slavyanskaya hotel as a business first, tourist second type of hotel. Indeed, only three percent of guest who responded to the questionnaire were visiting for reasons other than company business. Interestingly, a significant amount (thirty-four percent) of responders said that their company encouraged the choice of an environmentally sustainable hotel. Although this response is not in the majority, company policy may overrule personal opinion, leading to more business people staying at more environmentally sustainable hotels. If this is a trend, Radisson-Slavyanskaya can potentially benefit from this factor in choosing a hotel due to its large number of guest visiting on business trips.



The aim of this question was to determine if guests of the hotel would appreciate advertising and supplemental information on sustainability. The clear majority (seventy nine percent) of guests would be interested in such materials. There is a potential for increase in guest satisfaction at the Radisson-Slavyanskaya hotel if environmental initiatives and other information were provided to or displayed for the guests.

Appendix E: Tables of Energy Audit Data

	Duvet Covers [kg]	Sheets [kg]	Pillow Cases [kg]	Towels [kg]	Sports Club [kg]	Restaurant White [kg]	Restaurant Color [kg]	Rags/Mops [kg]	Curtains and Cushion Covers [kg]	Uniforms [kg]	Total [kg]
January	5405	5847	2385	11074	7036	3763	3098	4080	8354	3543	54585
Febuary	6056	13384	3280	13828	7440	4288	2504	4550	336	3401	59067
March	7650	7602	3218	15040	6914	6596	2620	4160	130	3136	57066
April	6120	7650	3260	13330	7015	3988	2890	4922	338	3684	53197
May	7008	4208	3330	14426	6985	4770	2205	6685	1524	3643	54784
June	6796	8374	3664	14842	7440	4088	2030	4920	640	3587	56381
July	6896	7174	3178	13890	6595	3866	1583	3640	130	3498	50450
August	8042	8397	3897	15345	6660	6053	2322	4694	100	3501	59011
September	5396	5464	2932	11252	7025	2825	1606	4526	2302	3650	46978
October	8432	9276	3970	17128	7436	7588	2718	4320	100	3691	64659
November	7577	8285	4188	15488	4627	5744	2672	4368	466	3604	57019
December	7792	8326	4265	14883	0	5275	2480	4662	1756	3573	53012
Total	83170	93987	41567	170526	75173	58844	28728	55527	16176	42511	666209
Average per month	6930.83	7832.25	3463.92	14210.50	6264.42	4903.67	2394.00	4627.25	1348.00	3542.58	55517.42

Radisson hotel laundry use for 2013

	2007			2008			2009			2010			2011		
Month	kWh	Rubles	Rubles/ kWh	kWh	Rubles	Rubles/ kWh	kWh	Rubles	Rubles/ kWh	kWh	Rubles	Rubles/ kWh	kWh	Rubles	Rubles/ kWh
January	1054900	1818750.98	1.7241	1054470	2207094.29	2.0931	998530	2426284.12	1.7241	935260	2688055.08	1.7241	908440	2929439.39	1.7241
Febuary	1028680	1773545.13	1.7241	1040000	2176807.36	2.0931	896850	2179216.35	1.7241	882420	2536186.26	1.7241	869110	2796182.04	1.7241
March	1090320	1879818.53	1.7241	1060850	2176775.5	2.0519	1014080	2464068.38	1.7241	967710	2781320.48	1.7241	949480	3747972.6	1.7241
April	1084120	1279261.6	1.1800	1067390	2234136.93	2.0931	952250	2313830.38	1.1800	899860	2586311.02	1.1800	981730	3583790.05	1.1800
May	1248520	2152570.83	1.7241	1168220	2445182.6	2.0931	1086140	2639163.8	1.7241	1120010	3219049.86	1.7241	1057540	4250166.9	1.7241
June	1278080	2203535.17	1.7241	1199810	2511303.12	2.0931	1135980	2761340.18	1.7241	1176990	3382817.56	1.7241	1157610	4742672.31	1.7241
July	1254180	2162329.23	1.7241	1276250	2671298.46	2.0931	1200220	2916361.76	1.7241	1363040	3917548.71	1.7241	1291590	4767375.89	1.7241
August	1347780	2323704.8	1.7241	1156890	2421467.95	2.0931	1066870	2592340.47	1.7241	1255800	3609327.43	1.7241	1130070	3943792.13	1.7241
September	1097300	1891852.74	1.7241	1043720	2184593.64	2.0931	1033800	2511985.13	1.7241	949820	2729902.35	1.7241	946750	3258918.89	1.7241
October	1127890	1944592.89	1.7241	1037710	2172014.2	2.0931	959200	2330717.88	1.7241	940870	2704178.93	1.7241	935520	3220262.79	1.7241
November	1103390	1902352.49	1.7241	957680	2004504.68	2.0931	948050	2303624.98	1.7241	940560	2677420.81	1.7241	932500	3902867.29	1.7241
December	1155070	1991453.88	1.7241	1012570	2119394.07	2.0931	962180	2337958.85	1.7241	989080	2842740.55	1.7241	947450	3310329.98	1.7241
Total	13870230	23323768.27	1.6816	13075560	27324572.8	2.0897	12254150	29776892.28	1.6816	12421420	35674859.04	1.6816	12107790	44453770.26	1.6816

Electricity use per month for the years 2007-2011

	2007			2008			2009			2010			2011		
Month	Gcal	Rubles	Rubles/ Gcal	Gcal	Rubles	Rubles/ Gcal	Gcal	Rubles	Rubles/ Gcal	Gcal	Rubles	Rubles/ Gcal	Gcal	Rubles	Rubles/ Gcal
January	1169.16	764302.6262	653.719	1154.4	878342.1568	760.865	1368.26	1219870.831	891.549	1742.18	1909709.77	1096.161	1396.57	1797257.103	1286.908
Febuary	1711.35	1118746.342	653.722	1277.33	971873.6532	760.863	1431.49	1276243.479	891.549	1662.3	1822148.436	1096.161	1645.54	2117658.586	1286.908
March	1437.44	939681.967	653.719	1000.42	971873.6532	971.466	1391.48	1240572.598	891.549	1280.68	1403831.474	1096.161	1418.89	1825980.887	1286.908
April	747.69	882.27774	1.180	615.48	468295.8148	760.863	950.08	847042.8692	891.549	617.03	676364.2236	1096.161	800.21	1029792.785	1286.903
May	569.85	372521.693	653.719	437.73	333052.994	760.864	336.61	300104.3142	891.549	276.81	303431.6192	1096.173	239.36	308030.4332	1286.892
June	250.71	163894.7902	653.723	314.47	239269.662	760.866	239	213080.211	891.549	208.39	228428.9902	1096.161	181.46	233519.7462	1286.894
July	213.92	139843.7824	653.720	190.46	144911.1154	760.848	209.18	186494.221	891.549	145.39	159370.8472	1096.161	151.75	195289.5752	1286.916
August	178.73	116836.756	653.705	184.07	140051.4742	760.860	209.51	186788.4304	891.549	119.73	131243.3524	1096.161	149.45	192321.9696	1286.865
September	339.53	221957.5516	653.720	328.31	249799.2622	760.864	240.02	213989.5898	891.549	283.85	311145.3028	1096.161	244.46	314211.462	1285.329
October	673.82	440490.9202	653.722	519.3	395115.92	760.863	649.99	579497.9292	891.549	915.06	1003053.088	1096.161	768.16	988551.254	1286.908
November	1261.52	824680.8544	653.720	897.18	682634.248	760.867	1033.23	921175.1774	891.549	852.96	934981.4842	1096.161	1079.74	1389523.467	1286.906
December	1188.81	777145.6046	653.717	1442.85	1097809.578	760.862	1627.38	1450889.013	891.549	1910.97	2094730.784	1096.161	1140.03	1467109.871	1286.905
Total	9742.53	5880985.165	603.640	8362	6573029.532	786.059	9686.23	8635748.663	891.549	10015.35	10978439.37	1096.161	9215.62	11859247.14	1286.864

Steam use per month for the years 2077-2011. We believe there was an error in the data supplied in the audit for April 2007 and March 2008. The cost in rubles for steam for these two months is incorrect.

	2007			2008			2009			2010			2011		
Month	m^3	Rubles	Rubles/ m^3	m^3	Rubles	Rubles/ m^3	m^3	Rubles	Rubles/ m^3	m^3	Rubles	Rubles/ m^3	m^3	Rubles	Rubles/ m^3
January	9711	268942.26	27.695	9627	287063.66	29.819	11337	393303.2	34.692	10908	485896.86	44.545	10419	547716.41	52.569
Febuary	10883	301400.33	27.695	13993	417251.67	29.819	11331	393095.05	34.692	10663	474983.34	44.545	10936	574894.58	52.569
March	14262	394980.39	27.695	12102	417251.67	34.478	12324	427544.21	34.692	11447	509906.62	44.545	11976	629566.34	52.569
April	14176	16727.68	1.180	12931	385584.32	29.819	11688	405480.1	34.692	11787	525051.92	44.545	12075	634770.68	52.569
May	15193	420764.06	27.695	13280	395637.01	29.792	15051	522149.29	34.692	12428	553605.26	44.545	12347	649069.44	52.569
June	16529	457764.04	27.695	13928	416923.67	29.934	13776	477916.99	34.692	13519	602203.86	44.545	13424	705686.26	52.569
July	14812	410212.42	27.695	14301	426435.8	29.819	14931	517986.25	34.692	15789	703321.01	44.545	12704	667836.58	52.569
August	12806	354657.05	27.695	13216	394082.62	29.819	13273	460466.92	34.692	12529	558104.31	44.545	12207	641709.78	52.569
September	13220	366122.61	27.695	13454	401179.44	29.819	13269	460328.15	34.692	11666	519661.97	44.545	12557	660108.93	52.569
October	12346	341917.53	27.695	12409	370019.01	29.819	9236	320415.31	34.692	13149	585722.21	44.545	10018	526636.24	52.569
November	11305	313087.45	27.695	10869	324098.36	29.819	10550	366000.6	34.692	12463	555164.34	44.545	11161	586722.61	52.569
December	12943	358451.21	27.695	11890	354543.15	29.819	10671	370198.33	34.692	13293	592136.69	44.545	11885	624782.57	52.569
Total	158186	4005027.03	25.318	152000	4590070.38	30.198	147437	5114884.4	34.692	149641	6665758.39	44.545	141709	7449500.42	52.569

Water use per month for the years 2077-2011. We believe there was an error in the data supplied in the audit for April 2007 and March 2008. The cost in rubles for water for these two months is incorrect.

Name of system in Hotel	Installed Capacity [kW]	Actual Consumption [kW/year]
Telephone exchange system	20	59567
Kitchen etc	34	101265
Ventilation Fans	60	178707
Kitchen Refrigeration	102	303795
Thermal Curtains	121	360384
Elevators	229	682050
Individual AC units	271	807143
Water pumps	344	1024565
AC system	454	1052187
Chillers	764	1975487
Lighting	1050	2435014
Kitchen Appliances with heating elements	1113	3037626

Breakdown of electricity use in the hotel

Type	Mercury Vapor	Metal Halide		Fluorescent					Halogen	Incandescent		
Wattage	125W Mercury Vapor	1000W Metal Halide	125W Metal Halide	8W	12W	16W	18W	36W	35W Halogen	25W	40W	Total
Outdoors	119	27	38	0	130	36	0	4	12	0	0	366
Offices	0	0	0	0	0	0	0	280	1204	0	0	1484
Guest Rooms	0	0	0	247	5573	216	1093	1675	2416	1304	2424	14948
Utility Rooms	0	0	0	106	0	0	18	1410	0	0	0	1534
Etc.	0	0	0	0	0	0	0	284	0	0	0	284
Total	119	27	38	353	5703	252	1111	3653	3632	1304	2424	18616
Total Per Type	119	65		11072					3632	3728		

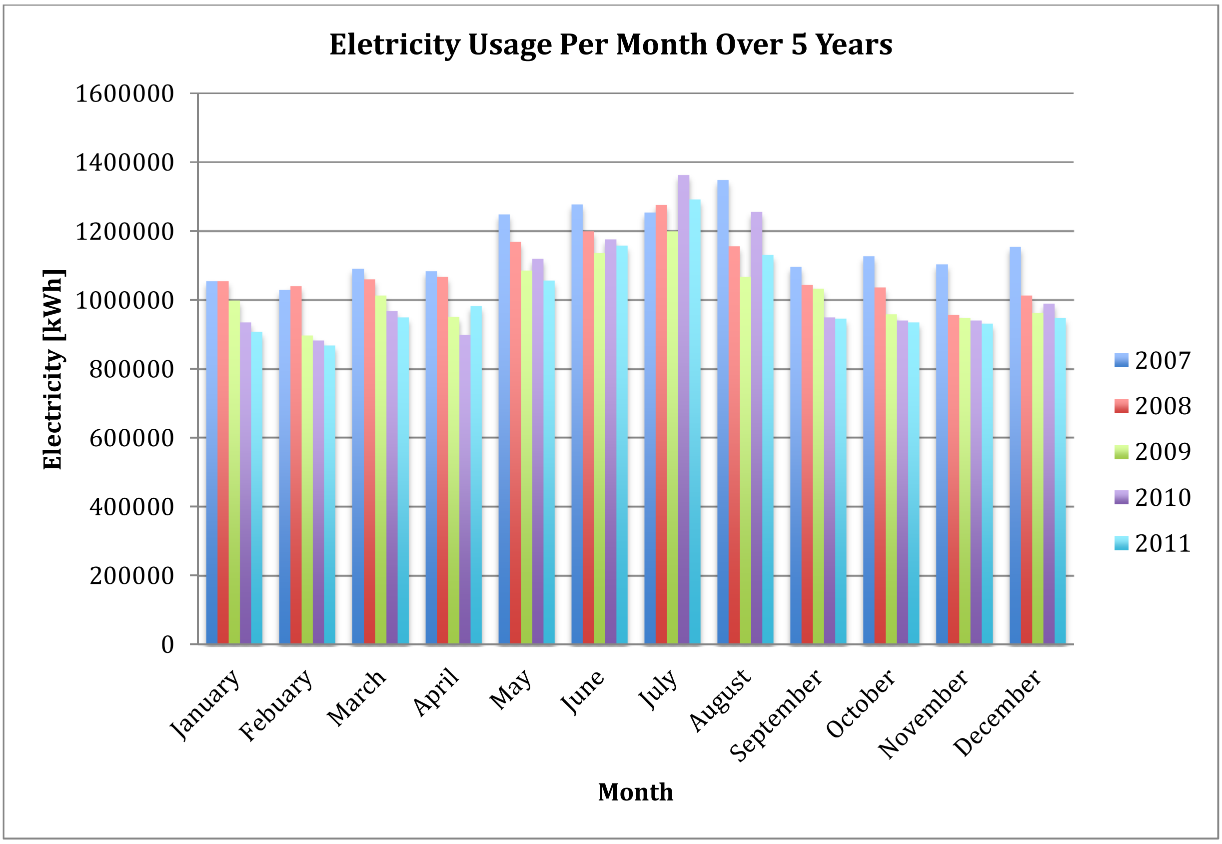
Type and number of lights installed at the hotel

	Average monthly temperature [degrees centigrade]					Average over 5 years [degrees centigrade]
Month	2007	2008	2009	2010	2011	
January	-1.6	-5.8	-5.6	-14.5	-7.5	-7
February	-10.9	-1.4	-5.3	-8.3	-11	-7.38
March	4.8	2	-0.5	-0.9	-1.9	0.7
April	5.9	9.6	5.1	8.5	6.6	7.14
May	15.9	11.5	13.7	16.9	14.8	14.56
June	17.5	15.8	17.4	18.9	19.2	17.76
July	19	19.2	18.9	26.2	23.5	21.36
August	20.4	17.6	15.7	21.9	18.8	18.88
September	11.8	11	13.8	11.7	12.2	12.1
October	7	9	5.8	3.9	6.7	6.48
November	-2	2.3	2.3	2.6	0.2	1.08
December	-1.9	-1.7	-6.5	-7.5	-0.1	-3.54
Yearly average for winter months (November-March)	-2.32	-0.92	-3.12	-5.72	-4.06	

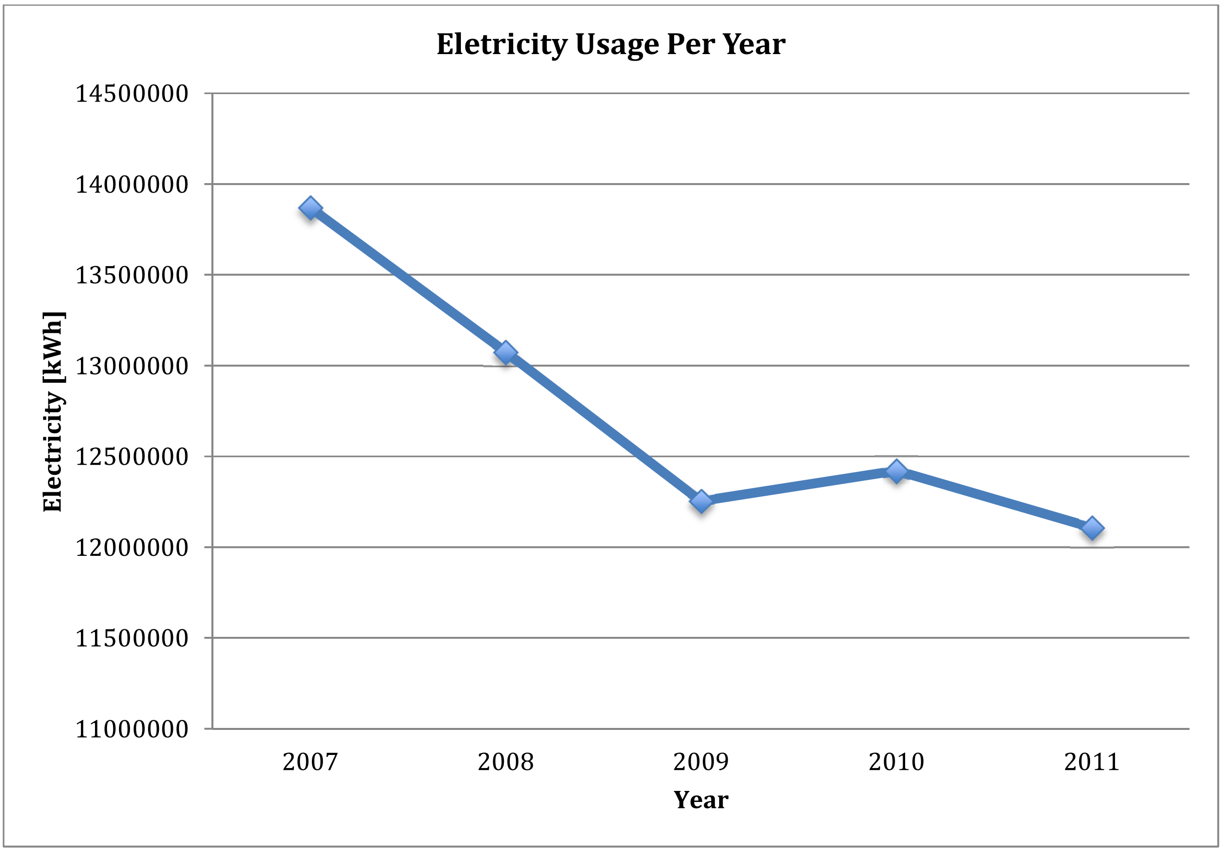
Historical temperature data for Moscow

Appendix F: Graphs of Energy Audit Data

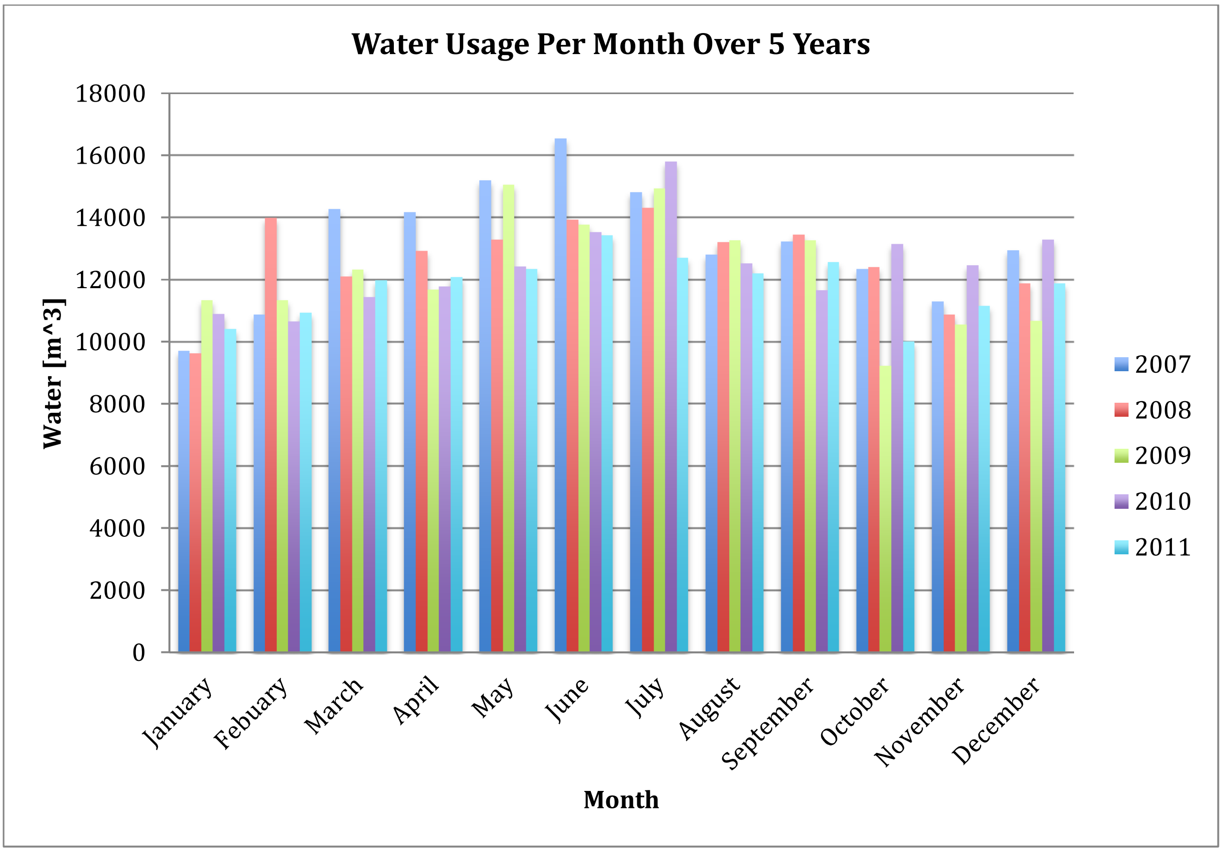
The historical data from the energy audit, as well as current electricity usage and lighting types provided insight into long-term trends and a clearer picture of current energy usage. Understanding the three utilities used by the hotel - electricity, water, and steam - was critical to highlighting the energy usage problems of the hotel. Knowledge of what systems were using the most energy and when allowed us to focus our efforts on such systems. This would allow any change we propose to have the greatest impact on the improvement of the environmental sustainability of the hotel. Starting with electricity, below are charts detailing energy use both per month and per year for 5 years (2007-2011).



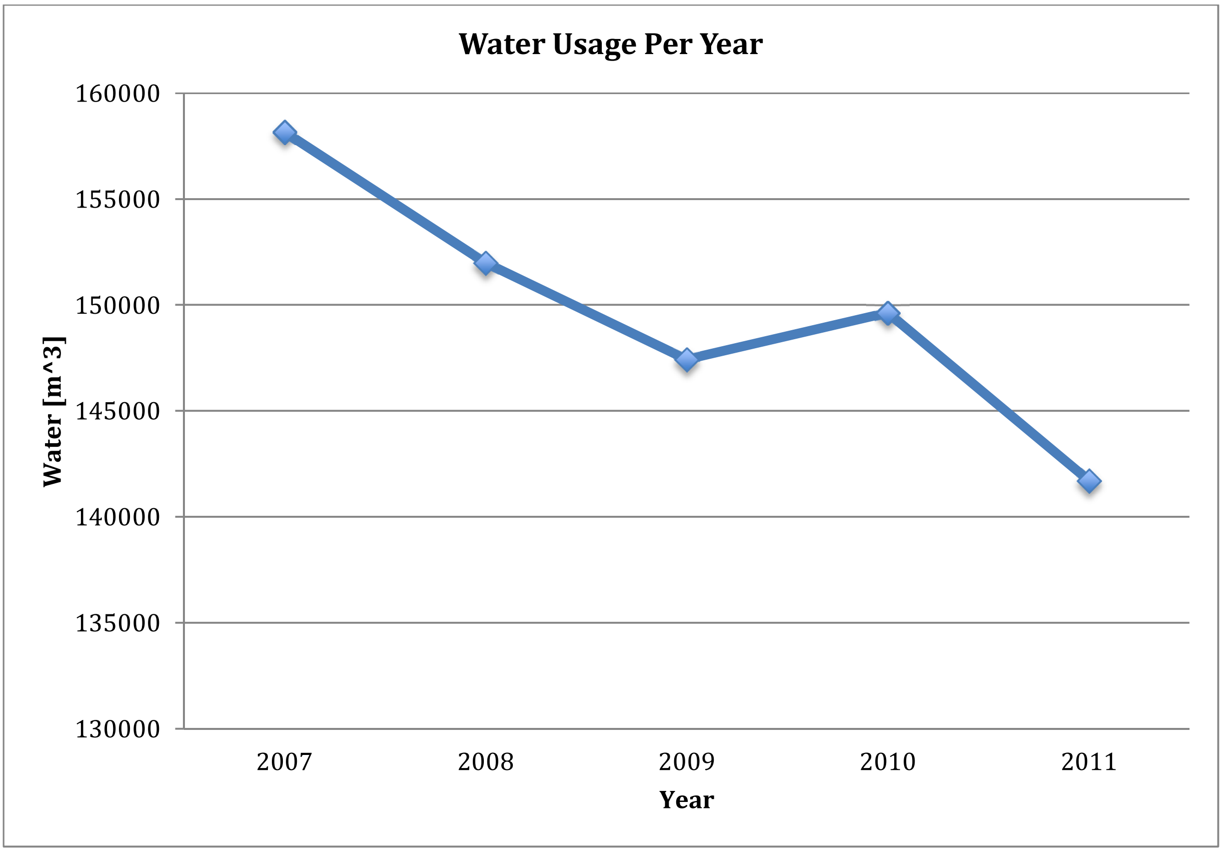
A clear trend in this chart is the increase in electricity usage during the summer months, peaking around July. This can attributed to the air-conditioning system being in highest demand during this season due to the high outdoor temperatures. As the electricity usage of the air conditioning system, especially the chillers, is relatively high, the high usage is expressed in this chart. The fact that chiller use is evident among all other systems means focusing on this system in particular will have a significant impact on the electricity usage of the hotel.



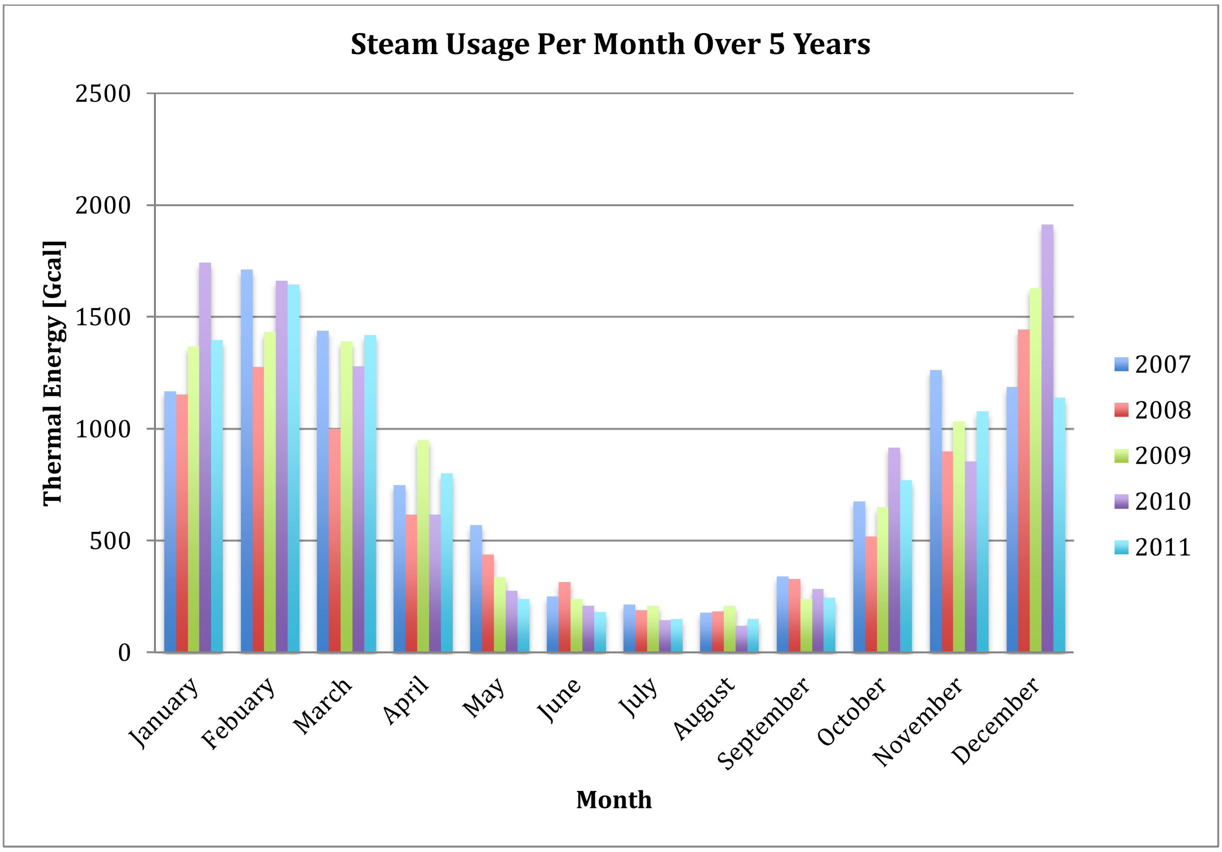
In general, electricity use by the hotel has dropped over the year 2007-2011, showing a definite downward trend. This shows that the hotel has been taking steps on its own to reduce its electricity usage, as hotel occupancy has not changed enough during these five years to warrant such a trend.



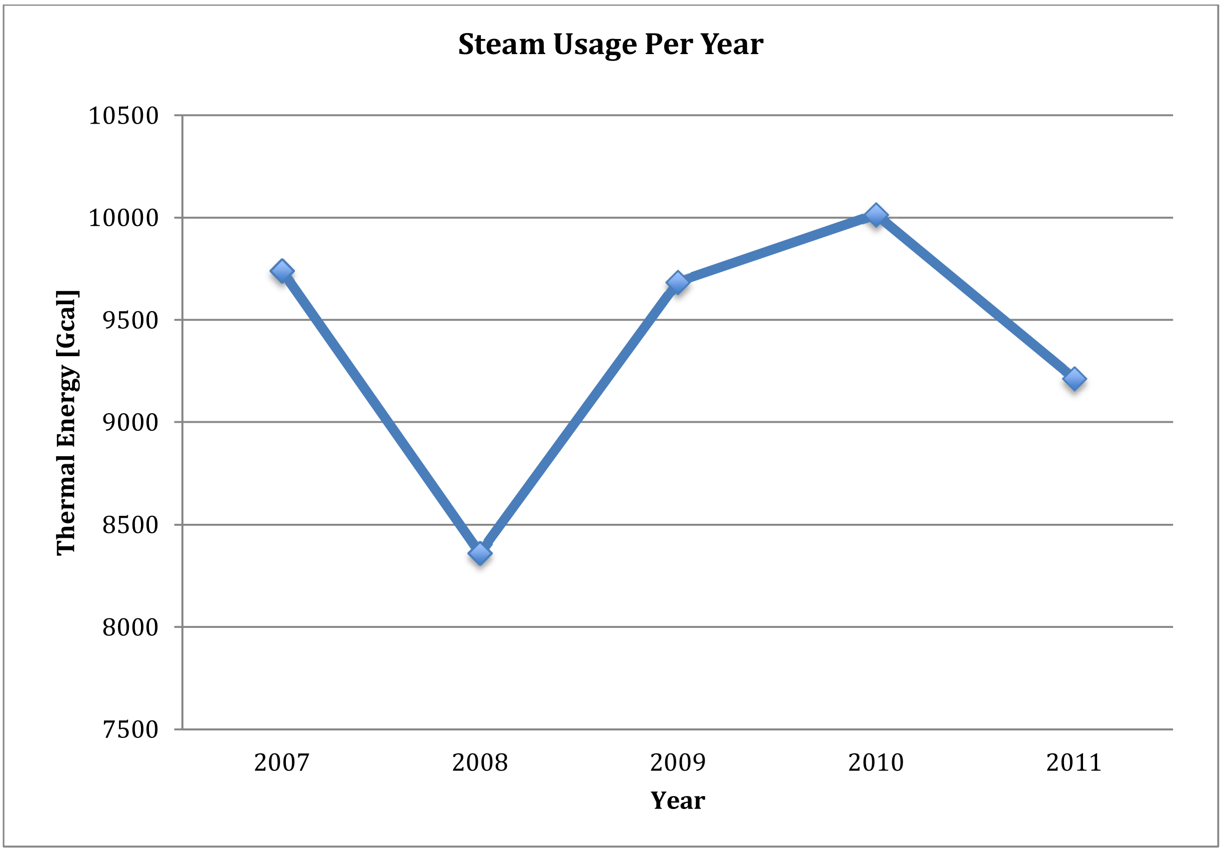
There is no obvious trend present in this chart. However, since water usage is mostly based on the amount of occupants in the hotel, and not the seasonal temperature, its use should remain relatively constant over the course of a year. The winter months, especially January and February show the most significant reduction in water use, possible due to the reduction in occupancy during these times of harsh weather in Moscow. The Radisson-Slavyanskaya, being primarily a business hotel is not affected as heavily by the seasonal climate as a more tourist oriented hotel would be.



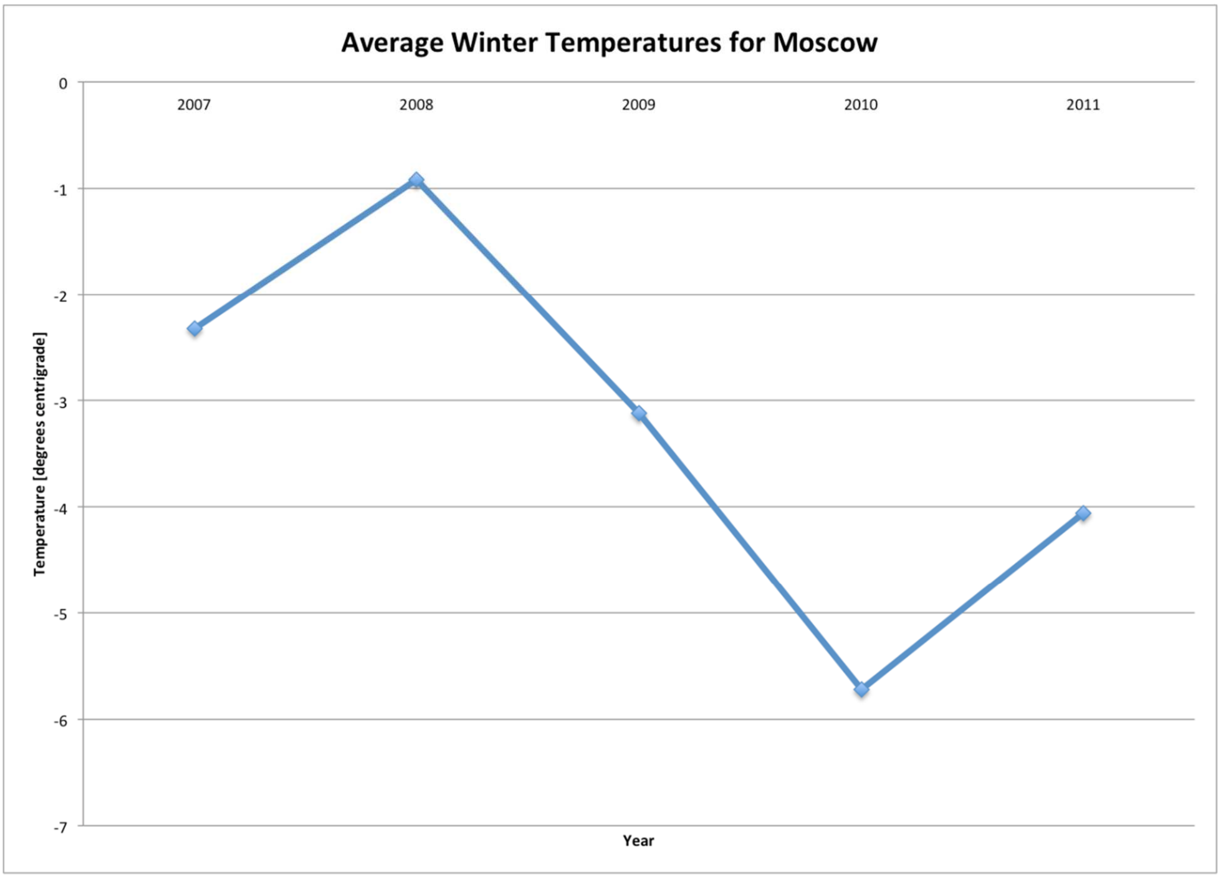
Similar to electricity usage, water usage shows a clear downward trend. This is most likely due to the hotel's efforts in reducing water consumption, including the installation of dual flush toilets.



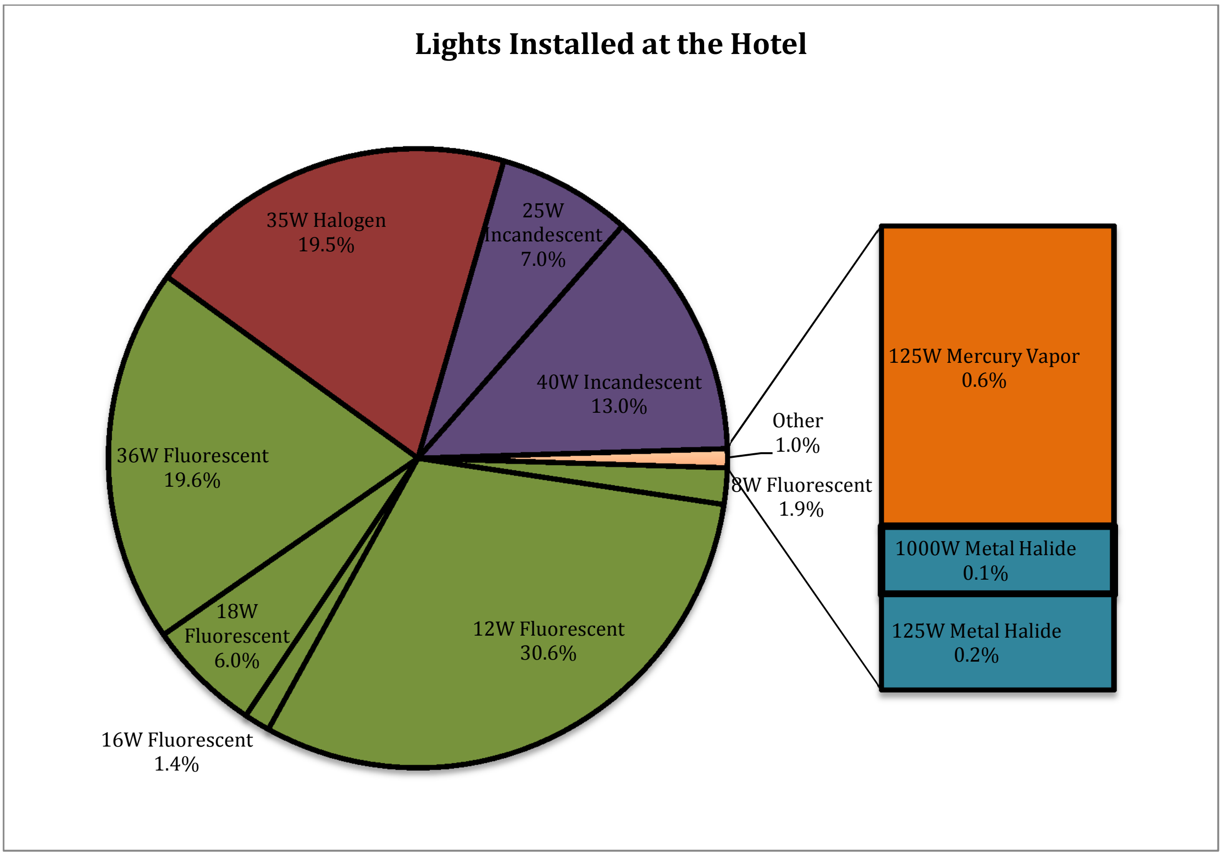
Of the three energy usage charts, steam displays the most extreme trend. Steam use during winter months is up to six times a much as during summer months. Because steam is used solely to heat water for use as hot DHW and hot water for heating the building, it is required more during cold weather. The large difference in usage between summer and winter months shows that most of the steam is used for heating the building and not for DHW. Considering the harsh winters in Moscow, this extreme trend is not surprising.



The long-term steam use trend is not downwards as electricity and water are. As explained above, steam is used primarily to produce hot water for heating the building. Therefore, steam use is dependent on the severity of winters, which can vary greatly year to year. See below for a chart describing the average winter temperatures for each year.



This chart shows that the average winter temperature in Moscow for the years 2007 to 2011 varies significantly. The winter months were defined as January, February, March, November, and December for each year. These are the months that the steam usage is the greatest (see above). The average winter temperatures correspond fairly well to the average steam usage per year. The year 2008, in which steam usage was relatively low, had a relatively mild winter, with an average temperature of -0.92 degrees centigrade. The year 2010, in which steam usage was relatively high, had a relatively cold winter, with an average temperature of -5.72 degrees centigrade. This correlation between winter temperature and steam usage shows that steam usage is highlighted depended of winter temperate. Therefore any trend in steam usage would have to account for detailed winter temperatures as well.



This chart breaks down the type and number of lights installed at the hotel. The majority of lights are fluorescent with the remaining indoor lights being either halogen or incandescent. The metal halide and mercury vapor light are installed outside of the building and used to illuminate parking lot or exterior of the building. Although these to types of lights are relatively high wattage, they are relatively few of them, making their overall wattage contribution not very significant. As explained above, the incandescent lights are necessary in the lobby for dimming purposes. Halogen bulbs are installed above the entrance to every guest room. While it is possible to replace these with lower wattage CFL bulbs, their electricity usage, especially compared to electricity usage of the entire hotel is relatively small. The current problems with the hotel electricity supply and wiring scheme make it difficult to make minimally invasive changes to the lighting

Appendix G: Example Window Film Attributes from Llumar

WINDOW FILM PERFORMANCE DATA | Architectural: North America

LLumar

Solar Control Window Film	% Total Solar Transmittance	% Total Solar Reflectance	% Total Solar Absorptance	% Visible Light Transmittance	% Visible Reflectance (exterior)	% Visible Reflectance (interior)	Winter U-value	Shading Coefficient	% Ultraviolet Ray Protection (wavelengths 280-380nm)	Emissivity	Solar Heat Gain Coefficient	% Total Solar Energy Rejected	Light-to-Solar Heat Gain Ratio (LSG)	% Summer Solar Heat Gain Reduction	% Winter Heat Loss Reduction	% Glare Reduction
Clear Glass	83	8	9	90	8	8	1.03	1.00	29	0.84	0.86	14	1.05	0	0	0
Reflective Series	Reflective films feature reflectance on both interiors and exteriors for superior reduction in summer cooling costs and heat retention in winter. Providing a high level of glare and heat control, they are scratch-resistant, shield 99% of ultraviolet rays, and provide excellent heat rejection.															
RN-07G SR CDF (One-Way Mirror)	6	53	41	5	60	14	0.91	0.2	99	0.59	0.16	84	0.31	80	12	94
R-15B SR CDF (Bronze)	10	35	55	10	19	60	0.94	0.28	99	0.70	0.24	76	0.42	72	9	89
R-15BL SR CDF (Blue)	10	38	52	11	25	62	0.94	0.29	99	0.70	0.25	75	0.44	71	9	88
R-15G SR CDF (Gray)	9	33	58	7	13	61	0.94	0.29	99	0.7	0.25	75	0.28	71	9	92
R-15GO SR CDF (Gold)	11	50	39	14	52	64	0.94	0.25	99	0.70	0.21	79	0.67	75	9	84
R-20 SR CDF (Silver)	12	54	34	16	62	62	0.94	0.25	99	0.71	0.21	79	0.76	75	9	82
R-35 SR CDF (Silver)	21	43	36	28	46	49	0.96	0.4	99	0.73	0.31	69	0.9	60	7	69
R-50 SR CDF (Silver)	36	29	35	48	28	26	0.97	0.54	99	0.75	0.46	54	1.04	46	6	47
Dual-Reflective Series	Dual-Reflective films are highly reflective on the exterior, lower on the interior, which helps provide clear day and night views. Traditionally specified on commercial buildings, Dual-Reflective films are also popular for sunbelt residential applications. They are scratch-resistant, shield 99% of ultraviolet rays, and provide excellent heat rejection.															
DR-15 SR CDF (Warm Gray)	16	37	47	15	37	13	0.92	0.3	99	0.63	0.26	74	0.58	70	11	83
DR-25 SR CDF (Warm Gray)	25	26	49	22	27	13	0.92	0.41	99	0.61	0.35	65	0.63	59	11	76
DR-35 SR CDF (Warm Gray)	35	19	46	36	19	13	0.93	0.52	99	0.61	0.44	56	0.82	48	10	60
Low-E	Low-E film provides superior energy conservation by reducing winter heat loss through windows. It is scratch-resistant, shields 99% of ultraviolet rays, reduces glare, and has the highest heat rejection performance of all LLumar films. It is suitable for commercial and residential applications where summer and winter energy control are major concerns.															
E-1220 SR CDF (Silver)	8	58	34	12	66	70	0.77	0.18	99	0.36	0.15	85	0.8	82	25	87
Deluxe Series	Deluxe films are specified for commercial buildings where high levels of heat rejection and glare reduction are needed. Deluxe films are ideal for privacy applications and exterior aesthetics. They are scratch-resistant, reduce 99% of ultraviolet rays, and come in gray and bronze.															
DL-05G SR CDF (Gray)	14	25	61	6	13	13	0.92	0.35	99	0.62	0.3	70	0.2	65	11	93
DL-15B SR CDF (Bronze)	27	13	60	14	8	8	0.98	0.45	99	0.77	0.39	61	0.36	55	5	84
DL-15G SR CDF (Gray)	26	15	59	16	9	10	0.99	0.45	99	0.78	0.42	58	0.38	55	4	82
DL-30GN SR CDF (Green)	29	20	51	30	17	17	0.98	0.53	99	0.76	0.46	54	0.65	47	5	67
Neutral Series	Neutral films reduce glare, provide moderate heat rejection, and are specified where a soft, neutral appearance is desired. These films are made with sputtered technology, creating a film that allows for very uniform visible light transmission. Neutral films are scratch-resistant and shield 99% of ultraviolet rays.															
N-1020 SR CDF (Neutral)	21	26	53	24	29	28	1.03	0.44	99	0.84	0.37	63	0.65	56	0	73
N-1040 SR CDF (Neutral)	36	16	48	40	18	15	1	0.59	99	0.81	0.5	50	0.8	41	3	56
N-1050 SR CDF (Neutral)	44	13	43	49	14	12	1.03	0.67	99	0.84	0.58	42	0.84	33	0	46
N-1065 SR CDF (Neutral)	65	9	26	67	10	9	1.03	0.82	99	0.84	0.71	29	0.94	18	0	26
N-1020B SR CDF (Bronze)	12	49	39	20	37	35	0.93	0.27	99	0.69	0.23	77	0.87	73	10	78
N-1035B SR CDF (Bronze)	25	37	38	37	25	23	0.94	0.41	99	0.71	0.36	64	1.03	59	9	59
Exterior Series	Exterior Series products are applied to the exterior face of the glazing and provide excellent heat rejection performance.															
NHE-20 ER HPR (Exterior Neutral)	22	23	55	25	24	27	1.04	0.45	99.9	0.84	0.38	62	0.66	55	-1	72
NHE-35 ER HPR (Exterior Neutral)	33	18	49	38	19	15	1.04	0.56	99.9	0.83	0.48	52	0.79	44	-1	58
RHE-20 ER HPR (Exterior Silver)	10	65	25	14	65	61	1.04	0.20	99.9	0.70	0.17	83	0.82	80	0	84
RHE-35 ER HPR (Exterior Silver)	18	54	28	25	52	48	1.04	0.30	99.9	0.68	0.26	74	0.96	70	0	72
RHE-50 ER HPR (Exterior Silver)	33	34	33	45	30	28	1.04	0.50	99.9	0.69	0.43	57	1.05	50	0	50
Specialty Series	AIR-80BL SR HPR is used where a combination of extremely low visible reflectance, high light transmission, and substantial reduction in solar infrared transmission is needed. AU-85UV SR HPR is the ideal solution for protecting valuables from sun damage. It provides the highest protection against harmful ultraviolet rays without altering glass aesthetics.															
AIR-80BL SR HPR (Clear)	48	7	45	79	9	9	0.99	0.71	99	0.75	0.61	39	1.30	29	4	12
AU-85UV SR HPR (UVCL-Clear)	81	9	10	89	9	9	1.03	0.97	99.9	0.83	0.84	16	1.06	3	0	1

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The solar performance data reported for LLumar architectural window films was captured using the National Fenestration Rating Council's (NFRC) standard guidelines for window film solar performance measurement as measured on single pane, 1/8 inch (3mm), clear glass. All values averaged from routinely accumulated quality control data. (01/14)

Appendix H: Glossary of Air Conditioning Technical Terms

Absorption Chillers: In an absorption chiller, the compressor is a thermal type, and consists of a generator and absorber. The generator uses heat from a hot water or steam source to boil the refrigerant out of a water and lithium-bromide solution to increase its pressure and temperature, similar to a mechanical compressor. ("How Absorption Cooling Works")

Air Cooled Chillers: Air-cooled chillers use air to absorb the heat from the refrigerant. Because they depend on large volumes of air to absorb heat, they are often self-contained units installed outside of the building. The refrigerant passes through a bundle of tubes over which air flows (a heat exchanger), absorbing the heat from the refrigerant.

Air Handling Unit (AHU): An AHU combines an air filter, air supply fan, and a cooling coil. The coils in the AHU contain the chilled liquid from the chiller, which cool down air passing over them. The now warmer liquid returns to the chiller and the cooling cycle repeats. (Owen, 2012)

Chiller Capacity: To convert between tons and kW, we use the following derivation:

> Latent heat of ice (energy extracted when freezing water into ice): 144 Btu per pound
> 1 ton = 2,000 lbs.
> Btu required to form one ton of ice in one day: 2000 lbs. x 144 Btu/lb. = 288,000 Btu
> Btu required to form one ton of ice per hour: 288,000 Btu / 24 hours - 12,000 Btu/hr.
> 1 kW = 3,412.142 BTU/hr.
> Therefore: 1 ton of refrigeration = 12,000 / 3,412.142 = 3.517 kW

Centrifugal Compressors: Centrifugal compressors differ from other types of compressors in that they are considered "dynamic" machines. This is because they transfer the angular momentum from a rotating impeller to a flowing fluid. Air-based centrifugal compressors are used in small jet engines following the same principles. Because of the simple drivetrain consisting of a motor directly spinning an impeller, centrifugal compressors are quite compact. One of the benefits of a centrifugal compressor is the ability to use frictionless magnetic bearings instead of the standard bearings, which use oil as a lubricant. This results in an increase in efficiency of about 10 percent ("YMC^2 Water-Cooled Magnetic Centrifugal Chiller") due to the elimination of two factors. Friction in the compressor drivetrain is eliminated, reducing the load on the motor. Also, oil is no longer required for lubrication, reducing maintenance costs.

Coefficient of Performance (COP): COP is the ratio of useful energy produced by the chiller in Btu, to the energy used by the chiller in Btu. A higher COP corresponds to a more efficient chiller.

Direct Cooling Towers: Direct cooling towers flow the liquid to be cooled down through a labyrinth of surfaces while air is forced against or across the flow of water by a fan. The labyrinth of surfaces is called “fill”, and aids in increasing the surface area upon which the evaporation can occur, thereby cooling the liquid.

Electric Chillers: In electric type chillers, the compressor is an electrically driven unit that can use a variety of compressor technologies.

Energy Efficiency Ratio (EER): EER is the ratio of cooling capacity in Btu/h to the power in watts used by the chiller. Similar to COP, higher EER values correspond to higher chiller efficiencies.

Hybrid Cooling Towers: Depending on the heat load and environmental conditions outside, hybrid cooling towers can either use water to cool the fluid from the chiller, or use air. While using air is less efficient, when cooling loads are minimal, air cooling can be more practical, and saves water in the process. Generally, hybrid cooling towers are more water efficient than normal open- and closed-circuit cooling towers.

Indirect Cooling Towers: Indirect cooling towers operate on the same principle as direct cooling towers, but the liquid is never exposed to the atmosphere. Instead, the liquid remains in bundles of tubes. Water is then sprayed over the tubes, while air is forced in the opposite direction. The water contacting the outside of the tubes absorbs the heat from the liquid inside of the tubes.

Integrated Part Load Value (IPLV): IPLV uses a weighted average of the EER at each of the chiller’s unloading stages. A high IPLV is generally better that a low value, but multiple factors may reverse this generalization. If a chiller has more unloading stages, the IPLV will be lower than a chiller with fewer unloading stages with all other factors equal. Therefore, IPLV cannot be directly compared unless factors such as unloading ability are taken into account. A chiller with more unloading stages has the ability to better match the cooling load required by the building, resulting in less overcooling of the conditioned air. **CITE**

Kilowatts per Ton (kW/ton): The kW/ton rating is the inverse of EER, in that it is the ratio of power required by the chiller in kW to the cooling energy produced by the chiller in tons.

The Montreal Protocol: The Montreal Protocol on Substances that Deplete the Ozone Layer, enacted on January 1, 1989, was the first international law designed to reduce the consumption and production of compounds that adversely affect the earth’s ozone layer. Since 1989, multiple amendments have been made to the protocol instating phase out plans for harmful compounds as new, more environmentally friendly compounds are developed. (“The Montreal Protocol on Substances that Deplete the Ozone Layer”)

Reciprocating compressors: Reciprocating compressors use a crankshaft powered by a motor with pistons that compress the refrigerant vapor coming from the expansion valve and release the high pressure vapor into the condenser. Because reciprocating compressors have multiple pistons, capacity can be easily lowered by reducing the number of pistons used to compress the refrigerant.

Screw Compressors: Screw type compressors use twin helical screws that use the principle of volume reduction as the refrigerant passes through the space in between the screws. One screw, the female, is fixed while the male screw it rotated by the compressor motor.

Scroll compressors: Scroll compressors use two spiral shaped scroll units manufactured 180 degrees out of phase. One of the scroll units is fixed, while the other one rotates in an orbital with respect to the first scroll. Refrigerant enters the outside of the spiral, and through volume reduction, increases in pressure and is released at the discharge point in the center of the spirals.

Vapor Compression Cycle: Refrigeration of the process fluid, or the fluid to be cooled, starts with high pressure, warm liquid refrigerant exiting the condenser. The refrigerant passes through an expansion device that reduces the pressure of the refrigerant causing it to reduce in temperature as well. At this point the liquid refrigerant is at a lower temperature than the process fluid. The refrigerant passes through the evaporator, in which it boils, absorbing the heat from the warm process fluid in the process via a heat exchanger (a bundle of tubes similar to a radiator). The now cold process fluid returns to the heat load of the building to be used for cooling the interior air. After passing through the evaporator, the low temperature and pressure vaporized refrigerant passes through the compressor, which increases the pressure, and therefore temperature, of the refrigerant. Now a high pressure hot vapor, the refrigerant must return to a liquid state in order to start the cycle again by running through either a cooling tower (explained in more detail below) if the chiller is water-cooled, or a bundle of tubes, which is, exposed a flow of air. The cycle then repeats with the now liquid refrigerant. ("The Vapour Compression Cycle")

Water Cooled Chillers: Water-cooled chillers use heat transfer with water to absorb heat from the refrigerant. Because of this, they require a separate cooling tower to remove heat from the refrigerant. A water-cooled chiller is usually installed in a machine room somewhere inside the building. In this case, the refrigerant passes through a heat exchanger with a liquid that is sent to the cooling tower. The cooling tower liquid absorbs heat from the refrigerant so it changes phase from a vapor to a liquid and is sent to the cooling tower, usually located on the roof of a building.

Appendix I: Glossary of Financial Terms

Cash Flow (CF): the amount of actual cash generated by business operations, which usually differs from profits shown

Cumulated Discounted Cash Flow (CDCF): the total discounted flows accumulated over a period of time

Depreciation -- an expense that is supposed to reflect the loss in value of a fixed asset. For example, if a machine will completely wear out after ten year's use, the cost of the machine is charged as an expense over the ten-year life rather than all at once, when the machine is purchased. Straight line depreciation charges the same amount to expense each year. Accelerated depreciation charges more to expense in early years, less in later years. Depreciation is an accounting expense. In real life, the fixed asset may grow in value or it may become worthless long before the depreciation period ends.

Discounted Cash Flow (DCF): a system for evaluating investment opportunities that discounts or reduces the value of future cash flow

Internal rate of return (IRR): Method that determines the discount rate at which the present value of the future cash flows will exactly equal investment outlay.

Net Present Value (NPV): Let us assume that there will be only one investment period in the project (CF_0). It will include the costs of dismantling of old chillers and coolers as well as purchase, delivery, installation costs, and overheads connected with the new equipment. The positive part of the total cash flows was formed using the savings on reduced costs associated with the technological upgrades (equal to the difference between previous costs and new costs). When assessing positive cash flows we can also take into account the expenses on maintaining the equipment and property tax, which will differ from the similar expenses associated with the old equipment.

$NPV = CF_0 + \sum_{i=1}^{n} \frac{CF_n}{(1+i)^n}$. If NPV ≥ 0 the project is acceptable.

Payback Period (PP): To calculate the payback period we calculated the cumulated discounted cash flow (CDCF) for each year-long period.

$CDCF_k = \sum_{i=1}^{k-1} DCF_i + DCF_k$

The period k in which CDCF will first change from negative to positive is the period of payback. In other words, that is the moment when initial investments will pay off.

Return on Investment (ROI): This indicator shows the percent benefit of profit from investments to initial investments. It was calculated using the following formula:

$ROI = \frac{CDCF_n - DCF_0}{DCF_0} * 100\%$

ROI = $\frac{\sum PV - Investments}{Investments} * 100\%$

ROI will be considered by the management of the hotel in comparison with other possible options for investing.

Profitability index (PI): also known as **profit investment ratio** (PIR) and **value investment ratio** (VIR), is the ratio of payoff to investment of a proposed project. It is a useful tool for ranking projects because it allows you to quantify the amount of value created per unit of investment.

The ratio is calculated as follows:

$$\text{Profitability index} = \frac{\text{PV of future cash flows}}{\text{Initial investment}}$$

Assuming that the cash flow calculated does not include the investment made in the project, a profitability index of 1 indicates breakeven. Any value lower than one would indicate that the project's PV is less than the initial investment. As the value of the profitability index increases, so does the financial attractiveness of the proposed project. If PI is greater than 1, accept the project. If PI is less than 1, reject the project.

Appendix J: Tables of Chiller Upgrade Cost Analysis

All monetary values in rubles	Residual value on October, 1 2014	Monthly depreciation	Months left	Residual value on January, 1 2015	Months left on January, 1 2015
Chiller 1	763,234	33,184	23	663,682	20
Chiller 2	950,380	6,837	139	929,868	136
Chiller 3	1,304,609	37,275	35	1,192,785	32
Chiller 4	Fully depreciated				
Total	3,018,222			2,786,335	
Proceeds from selling (10% discount)				2,507,702	
VAT = 18%				451,386	
Price of selling				2,959,088	

Depreciation and residual values for the four chillers installed at the hotel currently.

	Euros		Rubles	Including VAT = 18%
4 chillers	334,438		16,053,024	2,448,766
Accessories	1,193		57,274	8,737
Removal, installation, and delivery	133,775		6,421,210	979,507
RUB/EUR exchange rate		48		
Total price			22,531,507	3,437,010
Compensation of VAT				2,985,623
Investment required (equipment purchases)			**17,038,182**	

Purchase price of the new chillers.

Old chillers power input [kW]	672.4
New chillers power input, [kW]	528
Difference [kW]	144.4
Percent difference	21.48%

Old electricity consumption [kWh]	1,738,635
New electricity consumption [kWh]	1,365,258
Difference [kWh]	**373,377**

Energy savings between old and new chillers

Year	Forecast electricity rate [rubles/kWh]
2015	5.24
2016	5.87
2017	6.58
2018	7.37
2019	8.25
2020	9.24
2021	10.35
2022	11.59
2023	12.99
2024	14.55
2025	16.29

Forecast electricity rate for the Radisson-Slavyanskaya hotel from 2015 through 2025.

Year	Depreciation difference (rubles)
2015	-973,378
2016	-112,195
2017	475,335
2018	706,480
2019	788,527
2020	870,574
2021	952,622
2022	1,034,669
2023	1,116,716
2024	1,198,763
2025	1,294,485

Differences between the new and old" annual amounts of depreciation for 2015 through 2025