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SUSTAINABLE AND ENERGY EFFICIENT COMMERCIAL RETROFIT:
Case Study of Perkins+Will Atlanta Office

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ABSTRACT
Existing buildings tend to undergo performance degradations, change in use, and unexpected faults or malfunctions over time. These events often result in significant deterioration of the overall system performance, inefficient operation and unacceptable thermal comfort conditions. However, a building does not have to be new to be efficient. Today's leading building owners are retrofitting buildings, and converting existing buildings into models of sustainability. Commercial retrofit offers significant opportunities for energy efficiency and sustainability in the built environment. Design of energy-efficient and high-performance commercial retrofit requires that building performance and simulation tools are used and integrated with the design process. The objective of this research is to provide building researchers and practitioners with a better understanding of how to effectively conduct commercial retrofit to promote energy conservation and sustainability.

The review of literature identified several general design strategies in the successful completion of sustainable and energy efficient retrofit projects. However, there is not a lot of existing literature that focuses on specific case studies. Therefore, this article discusses a particular building in detail to discuss applicable design strategies, retrofitting design and the impact on energy consumption. A detailed case study review of 1315 Peachtree Street, Atlanta, GA demonstrates some of the barriers that are currently present achieving energy efficiency and sustainability in commercial retrofits, and strategies that were used to overcome those barriers.

KEYWORDS: sustainable retrofit, energy efficiency, building performance analysis, energy modeling, simulations

1.0 INTRODUCTION:
Existing buildings tend to undergo performance degradations, change in use, and unexpected faults or malfunctions over time[1]. These events often result in significant deterioration of the overall system performance, inefficient operation and unacceptable thermal comfort conditions. A study supported by the U.S. Department of Energy identified more than 100 types of faults that may happen in commercial building services systems and these faults can account for 2–11 percent of the total energy consumption of commercial buildings[2]. Perhaps one of the most impactful ways of furthering the cause of sustainability is through the implementation of energy retrofit programs[3].

Whilst sustainability is already an important driver in the new building sector, refurbishment of commercial building are moving this agenda forward[4]. Despite recent improvements in energy efficiency being made in new buildings, it is important that the existing commercial building sector also take action to meet emission reduction targets. The objectives and challenges of such action will reduce the risk of the sector becoming obsolete due to high energy use and poor environmental performance[5].

Retrofitting an existing building can often times be more cost effective than building a new facility. Since buildings consume a significant amount of energy (40 percent of the nation's total U.S. energy consumption), particularly for heating and cooling (32 percent of the energy consumed by buildings)[6], and because existing buildings comprise the largest segment of the built environment, it is important to initiate energy conservation retrofits to reduce energy consumption and the cost of heating, cooling, and lighting buildings. But, conserving energy is not the only reason for retrofitting existing buildings. The goal should be to create a high-performance building by applying the integrated, whole-building design process, to the project during the schematic design phase that ensures all key design objectives are met. Designing major renovations and retrofits for existing buildings to include sustainability initiatives will reduce operation costs and environmental impacts, and can increase building adaptability, durability, and resiliency[6].

The objective of this article is to provide building researchers and practitioners with a better understanding of how to effectively conduct commercial retrofit to promote energy conservation and sustainability. The research questions include:

- How to improve existing commercial buildings and their energy consumption?
- What are the appropriate sustainable and energy efficient retrofit strategies?
- How can positive environmental impacts and energy savings be initiated through retrofits?

This article reviews the existing literature, research and studies, and it also discusses strategies available for sustainable and energy efficient commercial retrofit. A detailed case study review of 1315 Peachtree Street, Atlanta, GA demonstrates some of the barriers that are currently present achieving energy efficiency and sustainability in commercial retrofit and strategies that were used to overcome these barriers.

2.0 LITERATURE REVIEW

"Green Retrofitting" is a term used to describe the process of renovating the systems and structure of a building to improve efficiency, reduce resource consumption, and create improved indoor air quality. The US Green Building Council (USGBC) takes this analysis a step further and includes the premise that retrofitting does not end with the installation of energy efficient systems, but also includes continued maintenance of this equipment in order to sustain these improvements over time[3].

Reusing the existing building stock, particularly as a result of performance upgrading, has been identified as having an important impact on sustainability of the built environment[7]. Retrofitting aged buildings can significantly reduce their energy use[8] and "work to the outside of the envelope is likely to be sufficient for most existing buildings"[9]. It should be noted that performance retrofits and the restoration of the existing building stock are inherently sustainable. Every time we reuse a building instead of tearing it down and building a new one in its place we:

- Keep construction debris out of landfills
- Preserve the existing embodied energy of the building
- Prevent the need to use new construction materials that are energy intensive, including aluminum, glass, steel and concrete[10].

A review of literature demonstrates that the most commonly implemented strategies for energy efficiency of retrofitted buildings include improved heating, ventilation and cooling systems (HVAC), improved insulation, and lighting[11]. The energy efficiency of a building is limited by how the building is designed, engineered, constructed, operated and maintained. Achieving greater energy efficiency in an existing building depends on several factors, including the building envelope, system types and efficiency, energy end use, such as plug loads, and building operation and maintenance practices. The efficiency of the building envelope impacts the energy load for the building, including the required energy used to heat, cool and ventilate. Simple strategies to reduce heating and cooling loads include appropriate insulation, optimizing window glazing area, minimizing the infiltration of outside air, and using an opaque roofing material. Additionally, the envelope impacts the lighting load for the building, depending upon how much natural daylight penetrates through windows into the interior spaces[12].

Recent research efforts to improve energy modeling and diagnostics for existing buildings have focused on devising methods based on digital photogrammetry or three-dimensional (3D) laser scanning and thermal imagery. Thermography is a relatively new and powerful tool for building investigations, which helps to identify defects such as missing insulation, moisture in walls, ventilation losses, and thermal bridges[13].

In exploring applicable net-zero energy design approaches for commercial retrofits, rethinking towards the net-zero energy building concept and all the possible strategies that can be integrated into an existing building, it is necessary to consider comprehensive methods for sustainable design, commercial retrofit, and renewable energy systems. Achieving net-zero energy goals in commercial retrofits with available technologies is challenging. However, with careful attention to adaptive design strategies, building envelope treatment, passive design approaches, appropriate HVAC systems and utilization of renewable energy sources it is possible to achieve that goal. Energy modelling and simulations, which uncover the energy saving potentials for every energy-saving measure, are beneficial tools in retrofit design and should be widely applied. Local resources, environment, and human activity should be considered during the decision making process, contributing to develop an integrated building system that enables new opportunities for energy saving and building performance improvements[14].

The review of literature identified several general design strategies in the successful completion of sustainable and energy efficient retrofit projects. However, there is not a lot literature on specific case studies. Therefore, this article focuses on one particular building in detail to discuss applicable design strategies, what was done and the impacts on energy consumption.

2.1 Sustainable and Energy Efficient Retrofit Technologies

Building envelope is the most effective predictor of the energy which is used for heating, cooling, lighting and ventilation of the buildings[15]. Because of being in direct interaction with the external environment conditions, building envelope is defined as the interface of energy loses. For reducing the energy use in buildings, the energy requirements of buildings must be minimized, the efficiency of energy use must be increased and systems must be set up which support the use of sustainable energy sources[15]. Energy efficient and sustainable commercial retrofit technologies can be categorized into three groups, they are, supply side management, demand side management, and change of energy consumption patterns, i.e. human factors[8].

Energy efficient and sustainable commercial retrofit technologies for supply side management include building electrical system retrofits and alternative energy supply systems to provide electricity and/or thermal energy for buildings such as solar hot water, solar photovoltaics (PV), wind energy, geothermal energy, etc.

Energy efficient and sustainable commercial retrofit technologies for demand side management consist of the strategies to reduce building heating and cooling demand, and the use of energy efficient equipment and low energy technologies. The heating and cooling demand of a building can be reduced through retrofitting building fabric and the use of other advanced technologies such as air tightness and windows shading. Low energy technologies may include advanced control schemes, natural ventilation, heat recovery, thermal storage systems, etc.

In a sustainable commercial retrofit, existing building performance assessment and diagnostics are used to benchmark building energy use, identify system operational problems, and find energy conservation opportunities. Energy audits and surveys enable identification of energy use and costs, from which energy cost and consumption control measures can be implemented and reviewed[16].

2.2 Building Performance and Simulations Tools

Performance analysis, energy modeling and simulations are used during the design process to understand and quantify performance of different design strategies. These methods are also required to inform design in energy efficient and sustainable adaptive reuse[17]. Reliable estimation and quantification of energy benefits are essential in a sustainable building retrofit decision-support system for prioritization of retrofit measures. The performance of different retrofit measures is commonly evaluated through energy simulation and modelling. There are a number of whole-of-building energy simulation packages, such as EnergyPlus, eQUEST, DOE-2, ESP-r, BLAST, HVACSIM+, TRNSYS, etc., that can be used to simulate the thermodynamic characteristics and energy performance of different retrofit measures.

Building information modeling (BIM) can also be used to predict the energy performance of retrofit measures by creating models of existing buildings, proposing alternatives, analyzing and comparing building performance for these alternatives and modelling improvements[18]. Energy simulation plays an essential role in analyzing the performance of retrofit measures. Since different models (and tools) offer different prediction reliabilities with different uncertainties, the model (and tool) selection and its parameter identification are essential to ensure reliable estimates.

2.3 Sustainable and Energy Efficient Commercial Retrofit Strategies

The principles of energy efficiency and the technologies available for a commercial retrofit will be virtually identical to those for new construction, and the challenge for the retrofit project is to select those technologies that maximizes the use of what already exists, exploit the potential of the building and integrate new technologies that complement these and make the building as energy efficient as possible[4]. Some of the sustainable and energy efficient commercial retrofit strategies are given below:

- Recommission all energy and water systems to determine they are operating at optimum performance; then upgrade energy and water systems to minimize consumption.
- Develop a plan to optimize the recycling and reuse of demolition debris and construction waste to minimize waste sent to landfills.
- Evaluate occupancy patterns, then apply daylight, HVAC and lighting sensors in appropriate locations. Incorporate energy efficient lighting into the project as appropriate for the tasks and functions of the spaces.
- Determine if natural ventilation and fresh air intake are feasible alternatives to reduce heating and cooling loads.
- Investigate renewable energy options that can offset the purchase of fossil fuel-based energy.
- Consider solar shading devices for windows and doors, including those that generate electricity by photovoltaic (PV) devices.
- Replace existing windows with high-performance windows appropriate for climate and exposure. If building requires security upgrade, evaluate blast resistant windows and films. If building is located in a high noise area, evaluate windows that also include adequate exterior to interior noise reduction.
- Analyze the benefits of distributed generation if the building is in a campus cluster or can share the on-site energy produced with adjacent buildings.
- Balance the project's sustainable goals with its security goals including protecting the building and its occupants from natural and man-caused disasters.
- Certain site renovations can improve the energy performance of the building including reducing the heat island effect.
- Determine if a cool roof or green roof are cost-effective ways to reduce heat island effect and stormwater runoff.
- Employ Energy Star and/or a green building rating system for existing buildings like LEED for Existing Buildings: Operations and Maintenance (LEED EBOM) or Green Globes for Existing Buildings to gage the building's level of performance.
- For historic buildings, update systems appropriately to maintain a balance between the need for energy and water savings with the character of the original building fabric.
- Take the opportunity afforded by the building renovation to incorporate sustainable operations and maintenance practices and switch to green cleaning products and methods.
- To ensure a newly renovated building continues to perform as designed, measure the performance of the building regularly.
- If not already metered, plan on installing meters for electric, gas, water and other utilities. Smart meters and submeters are preferable to monitor real-time consumption, control demand and increase tenant accountability (cost control)[6].

3.0 CASE STUDY: 1315 PEACHTREE STREET

1315 Peachtree is a commercial retrofit of a 78,956 square foot 1985 office structure transformed into a high performance civic-focused building. Located in the heart of Midtown Atlanta across from the High Museum of Art, the new building continues to house the Peachtree Branch of the Atlanta-Fulton County Public Library and introduces a new street-level tenant space occupied by the Museum of Design Atlanta (MODA). The Perkins+Will Atlanta office occupies the top four floors with office space for up to 240 employees.

Considering the warm humid temperate climate of Atlanta with hot summers and no dry season, an integrated design approach was followed to evaluate and maximize the energy reductions of the building. Solar studies and energy modeling informed decisions regarding daylighting, glazing replacement, glazing materials and shading systems. These studies, along with lighting analysis, were critical to inform the load calculations and sizing and selection of the HVAC systems. Local psychrometric chart informed the design decisions of HVAC systems to ensure four major factors that determine comfort zone in the building: air temperature (dry bulb temperature or DBT), humidity (relative humidity RH), air movement (velocity fpm or m/s), and internal quality of air.

Atlanta's psychrometric chart shows that the best single cooling design strategy is sun shading, which accounts for 16.8 percent of the hours. It has the advantage of being able to be combined with all the other cooling strategies. The next most effective cooling strategy is natural ventilation, which accounts for 16.4 percent of the hours. Because Atlanta is relatively humid in the summer, direct evaporative cooling could account for only 3.2 percent of the hours. Conventional air conditioning is the only other option for cooling all of the hours that fall outside of these zones on the psychrometric chart.

On the heating side, 25.7 percent of the hours would be comfortable indoors purely because of internal loads (lights, appliances, and people). Passive solar direct gain with low mass could add an additional 9.7 percent of the hours, but if the building was high mass then passive solar direct gain could create comfort conditions for only about 10 percent of the hours. If wind protection was provided, it could improve thermal comfort for only 1.2 percent of the hours per year. Because it is humid in Atlanta in the summer, 13 percent of the hours would be too humid for human comfort so some form of dehumidification would be required. But, even under the best of passive heating conditions at least 27.9 percent of the hours per year will require combined heating and humidification.

The “living lab” energy and HVAC equipment include a high-efficiency scroll chiller, twin microturbines, a unique adsorption chiller, dedicated OAS and energy recovery wheel and a photovoltaic array.

The design of the HVAC systems combines elements never before used in this hot/humid climate, including radiant heating/cooling, under-floor air distribution, chilled beams, microturbines, an adsorption chiller, 7.2 kW photovoltaic panels and an energy recovery wheel. Energy recovery and desiccant dehumidification strategies were used to reduce ventilation cooling loads. Lighting systems were designed for minimum egress level ambient lighting coupled with LED task lighting, controlled by an occupancy and daylight sensing system. Rainwater is captured and used in a grey-water system. Microturbines produce hot water for building heating and cooling, building hot water and almost 40 percent of building electricity. At the time of certification, this was the highest scoring LEED BD+C 2009 project in the world.

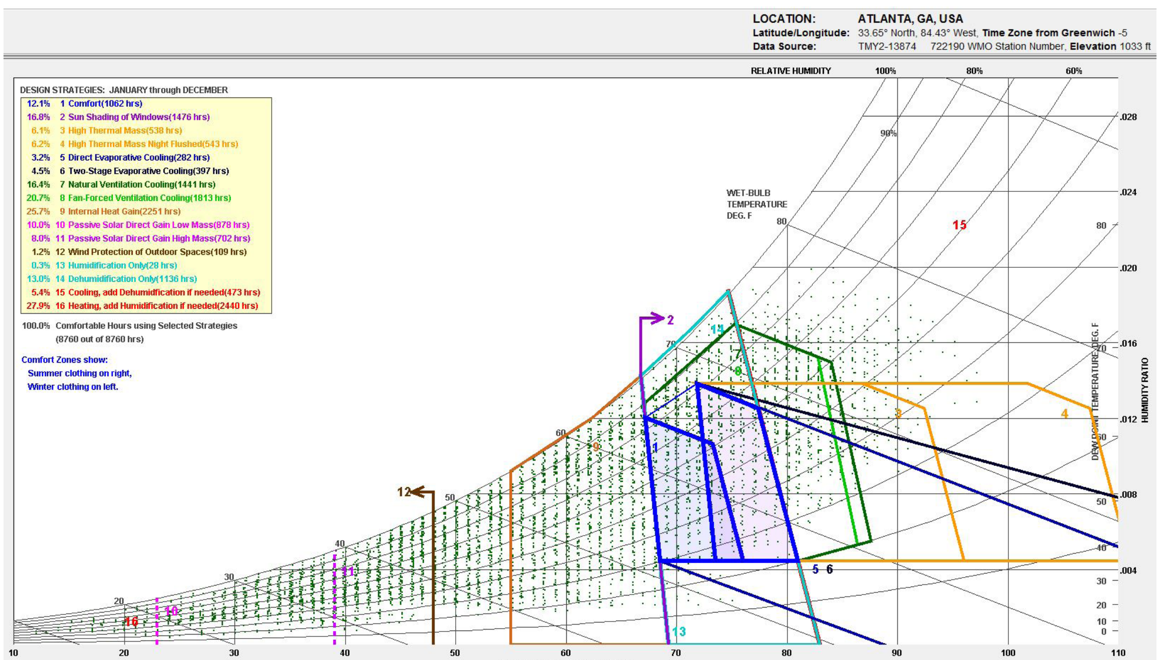


Figure 1: Psychrometric chart for Atlanta climate.

Figure 2: Before and after views of 1315 Peachtree Street. After photo credit Eduard Hueber © Arch Photo, Inc.

3.1 Building Performance and Simulations Tools

Ecotect was the primary environmental modeling tool, and IES VE was used for daylight modeling. The building automation and monitoring system monitors and records continuous, real-time data for all energy use; chilled, hot and condenser water; microturbines; rainwater collection; CO_2 levels; temperature; and humidity. Since many sustainability strategies used are not commonly found in the region, the owner felt it was important to track performance and share results in order to better inform future design.

3.2 System Solutions

Of the project's stated goals, meeting the 2030 Challenge with a greenhouse gas (GHG) reduction target of at least 60 percent had the largest influence on the system solutions. It was determined from concept phase analysis that to attain the desired reduction in GHG, partial energy source substitution was required. Since approximately 95 percent of the power sold by Georgia Power is generated by burning coal, the utility power for this building is very carbon intensive. The solution involved a cogeneration strategy using natural gas-fired microturbines to provide power, hot water for heating and cooling from a hot water driven adsorption chiller. This combined solution extracts the maximum amount of energy from the natural gas source, which has much lower carbon intensity than coal and resulted in a 67 percent decrease in CO_2 emissions.

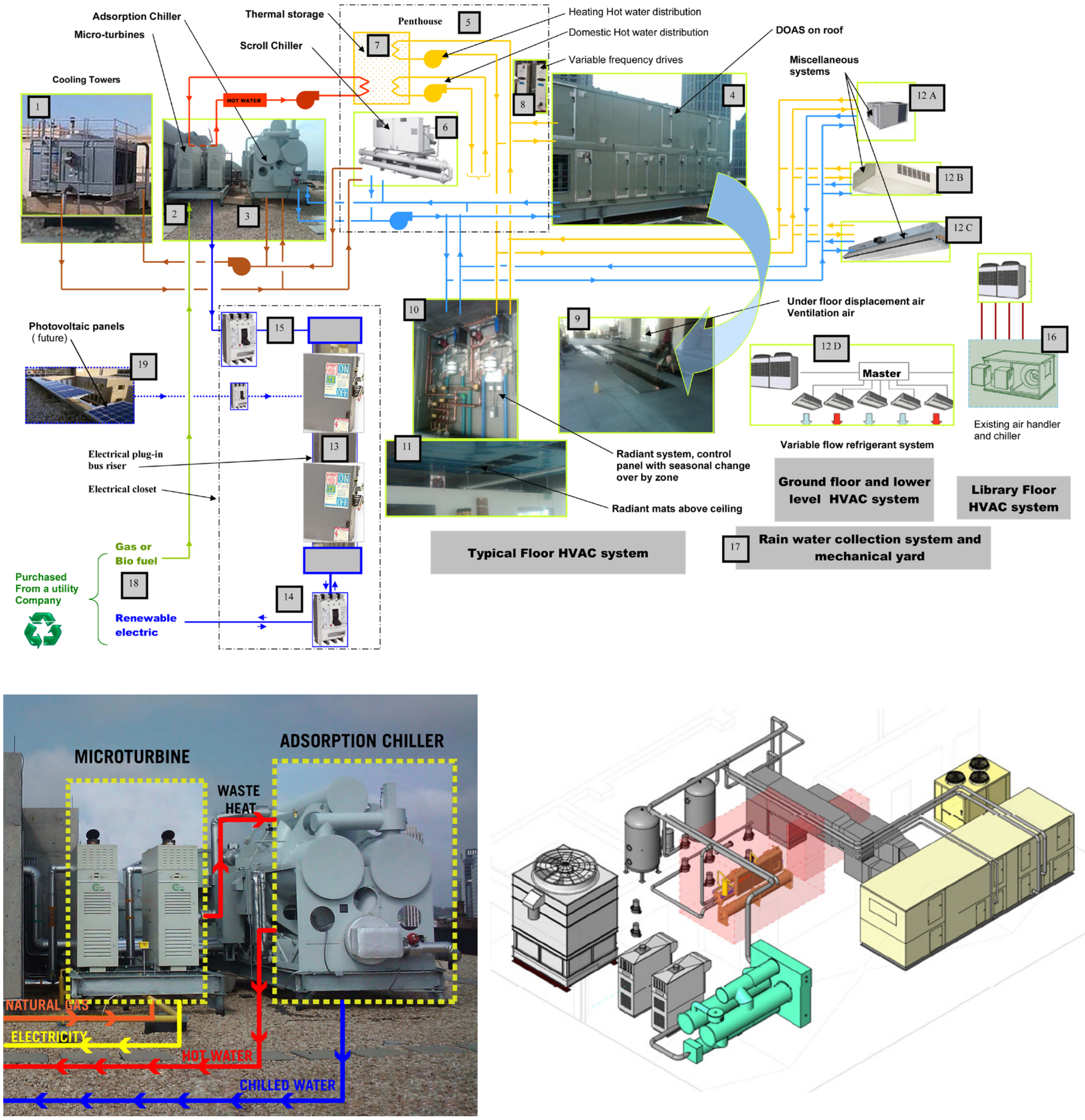


Figure 3: a) 1315 Peachtree Street overall system components diagram. b) MEP Tri-generation or CCHP: Combined Cooling, Heating & Power. c) The “living lab” energy and HVAC equipment include a high-efficiency Scroll Chiller, twin microturbines, a unique Adsorption chiller, Dedicated OAS, energy recovery wheel, and a photovoltaic array (not shown in the diagram).

The generation and distribution of electricity from the power grid often has a transmission loss of up to 65 percent. By generating distributed power on-site through a tri-generation system, waste heat is captured and used for both heating and cooling, thereby achieving much greater efficiencies. In addition, the switch to natural gas as a primary fuel source to generate building electricity reduces CO_2 that would be generated from the local coal-burning power plants.

The building is still connected to the grid and relies on grid electricity when there is insufficient demand within the building for the heating and cooling that the tri-generation system provides. This flexibility has contributed to 58 percent cost reduction and 68 percent greenhouse gas reduction for the project. The system also includes an adsorption chiller designed to cool water by using a silica gel media instead of refrigerants and the "waste" heat from two microturbines. Adsorption is the adhesion of atoms, ions, or molecules from a gas, liquid, or dissolved solid to a surface. This process creates a film of the adsorbate on the surface of the adsorbent. This process differs from absorption, in which a fluid (the absorbate) is dissolved by or permeates a liquid or solid (the absorbent), respectively. Adsorption is a surface-based process while absorption involves the whole volume of the material.

Significant energy efficiency is achieved by using water rather than air to heat and cool the space. Cold and hot water is pumped through small capillary mats in the metal ceilings panels throughout. A heat recovery unit, also referred to as an enthalpy wheel, exchanges heat and humidity from one air-stream to another on the rooftop. Rather than discard used building air, an enthalpy wheel salvages useful energy and transfers it to incoming, fresh air. This saves energy by reducing the need for cooling in the summer and heating in the winter. Using the waste heat from the microturbines and the adsorption chiller produced "free" heating and cooling water achieved for the radiant heating and cooling system. As adsorption chillers have no liquid desiccants, by not using chemicals such as lithium bromide and ammonia, the potential for hazardous material leaks, aggressive corrosion, and chemical testing requirements are eliminated. Also, adsorption chillers use municipal tap water as the refrigerant, compared to absorption chillers that require distilled water.

In hot/humid climates, radiant systems are rarely used because the warm, moist outside air would produce condensation on the cool-water tubing. Utilizing radiant heating and cooling system (water-filled blue BEKA mats above suspended ceiling tiles) and a low-velocity underfloor air distribution system help carefully balance temperature and humidity in hot/humid climate. The design team had to work very closely to make sure the system was balanced between the amount of exposed concrete, the size and spacing of the radiant mats and the number and location of any operable openings.

Figure 4: Radiant heating and cooling system (water-filled blue BEKA mats above suspended ceiling tiles).

Figure 5: a) Heat recovery unit, also referred to as an “enthalpy wheel”. b) Raised floor system with underfloor air distribution. c) 7.2 kW Photovoltaic array on roof.

3.3 Energy Usage

Project lighting utilizes either LED or T-5 Fluorescent lamps for maximum efficiency, with Lighting Power Densify (LPD) of 0.55 W/sf. Pendant direct/indirect studio lights are individually controlled with daylight and occupancy sensors. Corridors use only light borrowed from project team rooms. In addition, most employees operate laptop computers with flat-screen monitors and computational node “clouds” to further reduce plug-load energy use. The radiant system, using water as the energy transmission source is more efficient than air-based systems. Humidity and condensation issues preclude the use of operable windows in most of the studio areas. The modeled energy usage showed that all these would contributes to total Energy Usage Intensity (EUI) of 97 kBtu/sf/yr and net EUI of 28 kBtu/sf/yr. Significant reduction (51 percent) from national median EUI for this building type would be achieved.

3.4 Light and Air Management

West façade was redesigned with high-performance low-e glazing with fixed vertical and horizontal sunscreens to prevent solar heat gain and glare from the west. This was modeled to reduce solar heat gain on this face by about 94 percent compared to the existing configuration. The 5th floor atrium allowed to reshape the structure with minimal impact and provide connections between the floors of the office as well as add an exterior terrace, creating a variety of spaces to support a creative and collaborative atmosphere for office-wide meetings and events. A steel trellis and motorized shade system protects from too much sun penetrating the space.

Air is delivered at very low velocity through a raised floor plenum, maximizing the ventilation air-delivery effectiveness. This system is inherently more comfortable than air-based systems due to the radiant cooling and heating effect and the lack of drafts.

Natural daylight with occupancy and daylight sensors and usable outdoor space reduced the amount of energy needed for lighting by 67 percent. Daylighting at levels that allow lights to be off during daylight hours is 84 percent, and views to the outdoors exist in 98 percent of regularly-occupied areas.

3.5 Water Efficiency

Rainwater from the roof and the 5th-floor terrace is captured and stored in an underground 10,000-gallon cistern. It is filtered, treated with ultraviolet light, and then pumped to all flush fixtures in the building. Excess water is used for irrigation or released into bioswales, and 76 percent of rainwater from maximum anticipated 2-year 24 hour storm event can be managed onsite. More than 172,000 gallons of water are captured annually and used on-site, thereby reducing the demand for municipally supplied potable water. No potable water is used for irrigation.

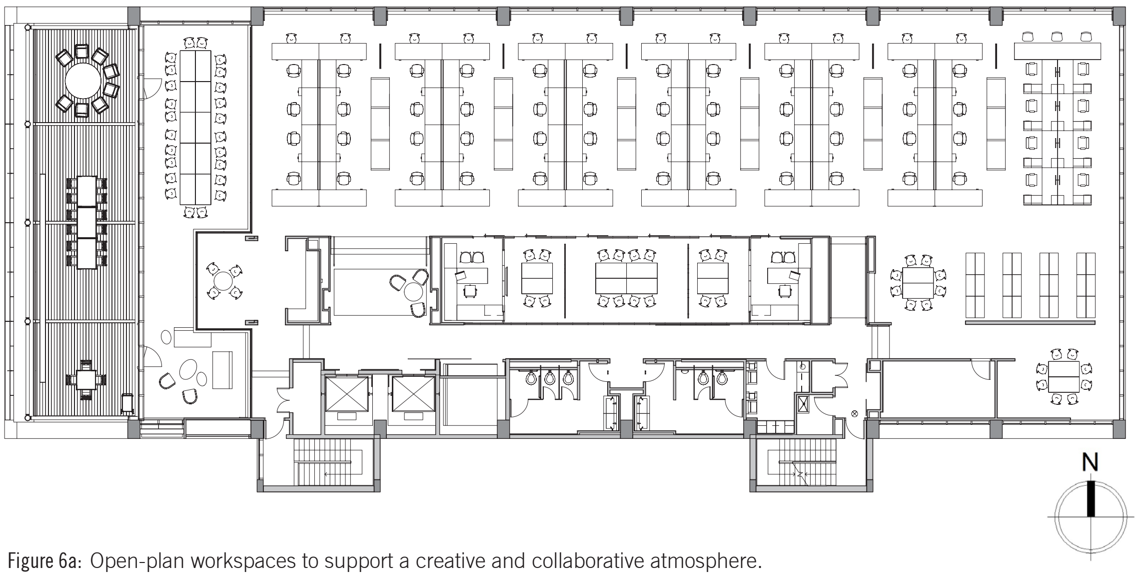
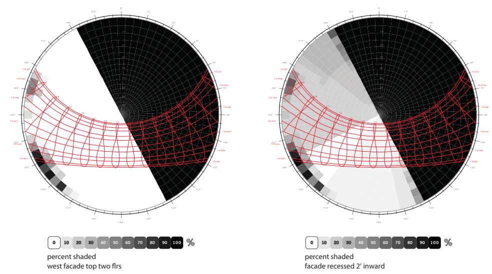


Figure 6a: Open-plan workspaces to support a creative and collaborative atmosphere.



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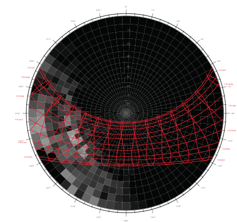
19:00	0%						

workday envelope

- 0% shaded, 100% exposed
- 1-49% shaded, 50-99% exposed
- 50-99% shaded, 1-49% exposed

Figure 6b: Existing condition shading study: west façade study without shading.



jan		feb		mar		apr		may		jun	
Local	Shading	Local	Shading	Local	Shading	Local	Shading	Local	Shading	Local	Shading
6:00		6:00		6:00		6:00		6:00	100%	6:00	100%
6:30		6:30		6:30		6:30	100%	6:30	100%	6:30	100%
7:00		7:00		7:00		7:00	100%	7:00	100%	7:00	100%
7:30		7:30		7:30	100%	7:30	100%	7:30	100%	7:30	100%
8:00	100%	8:00	100%	8:00	100%	8:00	100%	8:00	100%	8:00	100%
8:30	100%	8:30	100%	8:30	100%	8:30	100%	8:30	100%	8:30	100%
9:00	100%	9:00	100%	9:00	100%	9:00	100%	9:00	100%	9:00	100%
9:30	100%	9:30	100%	9:30	100%	9:30	100%	9:30	100%	9:30	100%
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10:30	100%	10:30	100%	10:30	100%	10:30	100%	10:30	100%	10:30	100%
11:00	100%	11:00	100%	11:00	100%	11:00	100%	11:00	100%	11:00	100%
11:30	100%	11:30	100%	11:30	100%	11:30	100%	11:30	100%	11:30	100%
12:00	100%	12:00	100%	12:00	100%	12:00	100%	12:00	100%	12:00	100%
12:30	100%	12:30	100%	12:30	100%	12:30	100%	12:30	100%	12:30	100%
13:00	100%	13:00	100%	13:00	100%	13:00	100%	13:00	100%	13:00	100%
13:30	100%	13:30	100%	13:30	100%	13:30	100%	13:30	100%	13:30	100%
14:00	100%	14:00	100%	14:00	100%	14:00	100%	14:00	100%	14:00	100%
14:30	100%	14:30	100%	14:30	100%	14:30	100%	14:30	100%	14:30	100%
15:00	100%	15:00	100%	15:00	100%	15:00	100%	15:00	100%	15:00	100%
15:30	100%	15:30	90%	15:30	100%	15:30	100%	15:30	100%	15:30	100%
16:00	90%	16:00	90%	16:00	90%	16:00	100%	16:00	100%	16:00	100%
16:30	86%	16:30	80%	16:30	90%	16:30	100%	16:30	100%	16:30	100%
17:00	48%	17:00	80%	17:00	80%	17:00	100%	17:00	100%	17:00	100%
17:30	100%	17:30	41%	17:30	80%	17:30	70%	17:30	100%	17:30	100%
		18:00	60%	18:00	70%	18:00	90%	18:00	90%	18:00	100%
						18:30	47%	18:30	80%	18:30	80%
								19:00	76%	19:00	71%
										19:30	86%

jul		aug		sep		oct		nov		dec	
Local	Shading	Local	Shading	Local	Shading	Local	Shading	Local	Shading	Local	Shading
6:00	100%	6:00	100%	6:00		6:00		6:00		6:00	
6:30	100%	6:30	100%	6:30	100%	6:30		6:30		6:30	
7:00	100%	7:00	100%	7:00	100%	7:00	100%	7:00		7:00	
7:30	100%	7:30	100%	7:30	100%	7:30	100%	7:30	100%	7:30	100%
8:00	100%	8:00	100%	8:00	100%	8:00	100%	8:00	100%	8:00	100%
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9:00	100%	9:00	100%	9:00	100%	9:00	100%	9:00	100%	9:00	100%
9:30	100%	9:30	100%	9:30	100%	9:30	100%	9:30	100%	9:30	100%
10:00	100%	10:00	100%	10:00	100%	10:00	100%	10:00	100%	10:00	100%
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11:00	100%	11:00	100%	11:00	100%	11:00	100%	11:00	100%	11:00	100%
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12:00	100%	12:00	100%	12:00	100%	12:00	100%	12:00	100%	12:00	100%
12:30	100%	12:30	100%	12:30	100%	12:30	100%	12:30	100%	12:30	100%
13:00	100%	13:00	100%	13:00	100%	13:00	100%	13:00	100%	13:00	100%
13:30	100%	13:30	100%	13:30	100%	13:30	100%	13:30	100%	13:30	100%
14:00	100%	14:00	100%	14:00	100%	14:00	100%	14:00	100%	14:00	100%
14:30	100%	14:30	100%	14:30	100%	14:30	100%	14:30	100%	14:30	100%
15:00	100%	15:00	100%	15:00	100%	15:00	100%	15:00	90%	15:00	100%
15:30	100%	15:30	100%	15:30	100%	15:30	100%	15:30	90%	15:30	90%
16:00	100%	16:00	100%	16:00	100%	16:00	90%	16:00	80%	16:00	86%
16:30	100%	16:30	100%	16:30	100%	16:30	100%	16:30	80%	16:30	48%
17:00	100%	17:00	100%	17:00	100%	17:00	90%	17:00	41%	17:00	100%
17:30	100%	17:30	100%	17:30	70%	17:30	51%	17:30	60%		
18:00	100%	18:00	90%	18:00	90%	18:00	47%			workday envelope	
18:30	80%	18:30	85%	18:30	85%						
19:00	71%	19:00	85%								
19:30	86%	19:30	90%								

0% shaded, 100% exposed
1-49% shaded, 50-99% exposed
50-99% shaded, 1-49% exposed

Figure 6c: Redesigned condition shading study: west façade with multiple shading levels.

Figure 6d: A steel trellis and motorized shade system prevent solar heat gain and glare from the west.
Photo credit Eduard Hueber © Arch Photo, Inc..

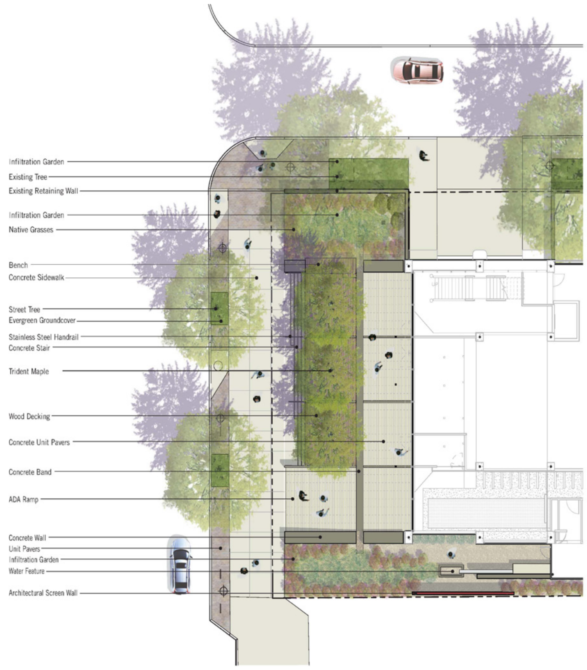

Figure 7a: Vegetation and bioswales around the site.

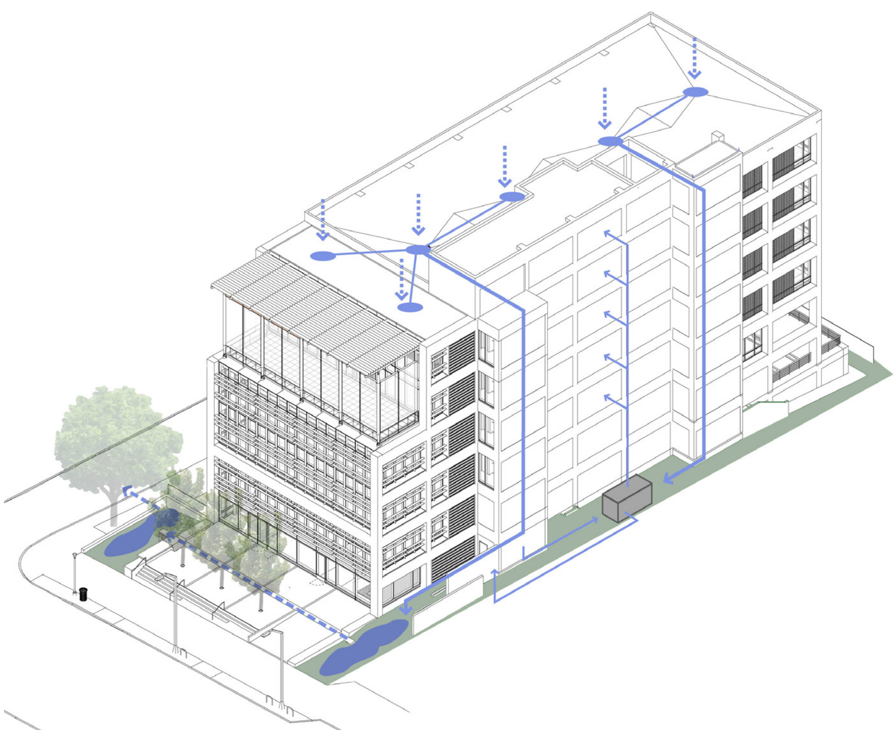

Figure 7b: Rainwater collection and distribution diagram.

Figure 7c: 10,000-gallon cistern under construction.

Since the cistern is not visible, a publicly visible water feature adjacent to the civic plaza recirculates captured rainwater or sends overflow water to the bioswales, where it naturally recharges the aquifers. Vegetation within the bioswales improves the quality of water that enters, while soil designed to support infiltration reduces the quantity of water that reaches the storm sewer system. Other water-saving features used are low-flow flush fixtures, including 1.23 gal/flush toilets and 0.125 gal/flush urinals, and sensors on flow fixtures that prevent faucets from being accidentally left running. All these contribute to 77 percent reduction of regulated potable water.

A civic plaza featuring seating and a demonstration garden is an added amenity for the community. A concept of renewing the existing landscape while creating inviting new ground level spaces on the public side of the building was adopted.

3.6 Materials and Construction

In order to reduce the amount of demolition and construction waste sent to the local landfills, the team set a target that 75 percent of waste generated would be reused, repurposed, recycled or otherwise diverted. Approximately 80 percent (630 tons) of demolition and construction waste was diverted from landfills or recycling yards to more than 20 local nonprofit organizations.

(a)

(b)

Figure 8a&b: Use of daylighting, with occupancy and daylight sensors, reduces lighting energy by 67 percent over code.
Photo credit Eduard Hueber © Arch Photo, Inc.

Figure 8c: Corridors use only light borrowed from project team rooms. Photo credit Eduard Hueber © Arch Photo, Inc.

Simulated daylight:

Day light - rooms detail analysis

Room name	Floor	Working plane (ft)	Room Area(ft^2)	Average daylight(fc)	Area exceeding 025 fc (ft^2)	Area exceeding 500 fc (ft^2)	% Area meeting requirements[5] (%)	Area meeting requirements[5] (ft^2)	LEED® Pass
Sort A-Z	Hi/Lo	Hi/Lo	Hi/Lo	Hi/Lo	Hi/Lo	Hi/Lo	Hi/Lo	Hi/Lo	Pass/Fail
Apply		2.5	107	25	75	75	75	75	
sp-106-RECEPTION	bldg-stry-2	2.50	578.8	254.4	572.9	0.0	99.0	572.90	yes
sp-311-BREAK_ROOM	bldg-stry-3	2.50	147.9	280.9	147.9	0.0	100.0	147.85	yes
sp-312-WORKROOM	bldg-stry-3	2.50	246.7	16.6	52.9	0.0	21.4	52.87	yes
sp-313-OFFICE	bldg-stry-3	2.50	138.5	69.1	124.6	0.0	90.0	124.63	yes
sp-314-OFFICE	bldg-stry-3	2.50	139.9	82.3	133.9	0.0	95.7	133.89	yes
sp-315-WORKROOM	bldg-stry-3	2.50	561.6	180.9	557.6	0.0	99.3	557.57	yes
sp-316-OFFICE	bldg-stry-3	2.50	139.8	97.1	135.8	0.0	97.1	135.77	yes
sp-319-RESOURCE_CENTER	bldg-stry-3	2.50	863.4	104.2	733.9	0.0	85.0	733.85	yes
sp-321-WELLNESS_ROOM	bldg-stry-3	2.50	91.3	80.9	73.0	0.0	80.0	73.00	yes
sp-322-OFFICE	bldg-stry-3	2.50	5769.2	63.9	4981.9	0.0	86.4	4981.92	yes
sp-323-ATRIUM	bldg-stry-3	2.50	1348.5	244.1	1332.8	0.0	98.8	1332.80	yes
sp-411-BREAKROOM	bldg-stry-4	2.50	141.2	224.5	141.2	0.0	100.0	141.19	yes
sp-412-OFFICE	bldg-stry-4	2.50	249.4	3.3	0.0	0.0	0.0	0.00	no
sp-413-WORKROOM	bldg-stry-4	2.50	137.1	42.8	88.1	0.0	64.3	88.11	yes
sp-414-OFFICE	bldg-stry-4	2.50	139.9	80.8	129.9	0.0	92.9	129.89	yes
sp-415-WORKROOM	bldg-stry-4	2.50	561.6	184.3	557.6	0.0	99.3	557.57	yes
sp-416-OFFICE	bldg-stry-4	2.50	139.8	99.1	137.8	0.0	98.6	137.77	yes
sp-421-HR	bldg-stry-4	2.50	104.3	80.9	83.4	0.0	80.0	83.40	yes
sp-423-MEETING	bldg-stry-4	2.50	535.8	111.5	465.9	0.0	87.0	465.91	yes
sp-424-OPEN_OFFICE	bldg-stry-4	2.50	5784.1	60.1	4856.8	0.0	84.0	4856.85	yes
sp-425-ATRIUM	bldg-stry-4	2.50	855.1	132.3	851.1	0.0	99.5	851.09	yes
sp-511-BREAKROOM	bldg-stry-5	2.50	126.3	25.8	42.8	0.0	33.9	42.79	yes
sp-512-OFFICE	bldg-stry-5	2.50	139.3	83.2	133.3	0.0	95.7	133.33	yes
sp-513-WORKROOM	bldg-stry-5	2.50	560.4	38.5	342.3	0.0	61.1	342.25	yes
sp-514-OFFICE	bldg-stry-5	2.50	139.9	144.5	139.9	0.0	100.0	139.91	yes
sp-515-MEETING	bldg-stry-5	2.50	965.8	124.1	947.7	4.0	97.7	943.67	yes
sp-516-Room	bldg-stry-5	2.50	5210.3	55.4	3926.5	0.0	75.4	3926.52	yes
sp-517-ATRIUM	bldg-stry-5	2.50	1202.8	181.9	1200.9	0.0	99.8	1200.86	yes
sp-611-BREAK_ROOM	bldg-stry-6	2.50	294.2	257.8	294.2	0.0	100.0	294.22	yes
sp-612-OFFICE	bldg-stry-6	2.50	142.3	87.9	126.0	0.0	88.6	126.04	yes
sp-613-WORK_ROOM	bldg-stry-6	2.50	560.4	170.2	550.4	0.0	98.2	550.41	yes
sp-614-OFFICE	bldg-stry-6	2.50	139.5	97.8	133.5	0.0	95.7	133.54	yes
sp-616-WORK_ROOM	bldg-stry-6	2.50	318.9	264.7	318.9	0.0	100.0	318.89	yes
sp-617-OPEN_OFFICE	bldg-stry-6	2.50	5618.7	76.3	5160.3	0.0	91.8	5160.32	yes
sp-P18-PRINT_OFFICE	bldg-stry-1	2.50	89.2	0.0	0.0	0.0	0.0	0.00	no
sp-P19-PRINT_ROOM	bldg-stry-1	2.50	827.2	0.0	0.0	0.0	0.0	0.00	no
Overall results for selected spaces			35008.6	91.8	29475.6	4.0	83.4	29471.59	Pass

Total area of day lit regularly occupied space(s)	29471.6 ft^2
Total area of regularly occupied space(s)	35008.6 ft^2
Percentage of regularly occupied space that is day lit	84.2 %

Figure 8d: Daylight simulation result from IES VE.

In addition, building materials were rigorously screened to be free of known or suspected toxic substances, including PVC. As a result, materials are 75 percent free of added halogenated compounds, contained 40 percent recycled content and 37 percent were extracted/ manufactured within 500 miles of the project site. Wood sourced from FSC-certified forests comprises 82 percent of the total used. The board room conference table is made from cherry baseboards salvaged during the building demolition.

4.0 BENEFITS AND BARRIERS TO COMMERCIAL RETROFIT

Carbon footprint reduction is one key reason for retrofitting an office building. The re-use of an existing building's fabric retains a fair amount of the energy embodied in the original construction[19]. Several economic benefits have been identified to justify the choice of retrofit over a complete redevelopment for office buildings[20]:

- A better balance of risk and return
- Quick delivery back to market
- Lower construction times and costs: depending on the level of retrofit, office retrofit can be from 10 to 75 percent quicker and cheaper than new build
- Maximized value of an existing asset and retaining useful attributes of the original building (e.g. car parking allocation and permitted development density and massing).

On the other hand, some key barriers were found in the commercial property market that prevent owners and developers from investing in retrofits[21]:

- A lack of access and availability of capital funds
- Poor provision of viable business cases for up taking retrofit interventions. The issue of 'split incentive', whereby the owner absorbs most of the costs while the occupiers benefit from energy savings, thus having no incentive for energy conservation
- Unclear criteria and processes for assigning and evaluating the responsibilities of those carrying out the retrofitting interventions
- A lack of appropriate technological knowledge about possibilities, issues and constraints associated with specific retrofit actions. Endemic skills shortage in the built environment sector
- Insufficient focus from policy makers on current building stock, as compared to new buildings.

Some of the major challenges faced and overcome in 1315 Peachtree Street retrofit project are:

- **Greenhouse gas reduction target of 60 percent:** The 2030 Challenge greenhouse gas reduction target of 60 percent was the largest challenge for the system solutions. This was overcome through the design of the HVAC systems that combines elements never before used in this hot/humid climate, including radiant heating/cooling, under-floor air distribution, chilled beams, microturbines, an adsorption chiller, 7.2 kW photovoltaic panels and an energy recovery wheel. This combined solution extracts the maximum amount of energy from the natural gas source, which has much lower carbon intensity than coal and resulted in a 67 percent decrease in CO_2 emissions.
- **Large amount of glazing facing west:** Large amount of glazing along the west facade of the existing building contributed to high solar heat gain and glare. Solar studies and energy modeling informed decisions regarding daylighting, glazing replacement, glazing materials and shading systems. West façade was redesigned with high-performance low-e glazing with fixed vertical and horizontal sunscreens to prevent solar heat gain and glare from the west. At the upper levels, a steel trellis and motorized shade system prevent solar heat gain and glare. This was modeled to reduce solar heat gain on this face by about 94 percent compared to the existing configuration. Also, natural daylight with occupancy and daylight sensors and usable outdoor space reduced the amount of energy needed for lighting by 67 percent.
- **Use of radiant systems in hot/humid climate:** Use of radiant systems in hot/humid climate was another challenge as the warm, moist outside air could produce condensation on the cool-water tubing. Utilizing radiant heating and cooling system and a low-velocity underfloor air distribution system help carefully balance temperature and humidity in hot/humid climate. The design team had to work very closely to make sure the system was balanced between the amount of exposed concrete, the size and spacing of the radiant mats and the number and location of any operable openings. Significant energy efficiency is achieved by using water rather than air to heat and cool the space.

5.0 CONCLUSION

Although progress towards the adoption of energy efficient and sustainable building practice across the globe is encouraging, the sustainability movement mainly focused on transforming building practices for new construction. To date, however, sustainable building practices have underemphasized the importance of existing building retrofits across the globe[18]. Many existing structures were built before the establishment of energy efficiency codes. These buildings, which were designed according to the traditional approaches, are the primary consumers of energy and resources[15].

In most developed countries, more than 98 percent of the building stock consists of existing buildings[18]. Sustainable new construction, no matter how environmentally sensitive and energy-efficient, cannot by itself significantly change the environmental impact of the built environment[18]. Therefore, existing buildings must be subjected to a process of retrofit to create the intended ecological impact. The best opportunity for least environmental impact in retrofitting existing buildings is to retain as much of the structure as possible and upgrade and optimize systems, such as exterior glazing, HVAC, lighting and water[22]. Design of energy-efficient and high-performance building retrofit requires that building performance and simulations tools are used and integrated with the design process[23].

1315 Peachtree Street is a living model for small urban sites that emphasize sustainability. As for energy efficiency upgrades, the building makes use of natural daylighting, energy efficient lighting, lighting controls, passive sun shading on lower levels and an active, dynamic exterior sunshade on the building terrace level to control afternoon sunlight and heat gain. For climate control, the building uses raised flooring and a radiant heating and cooling system, microturbines and an adsorption chiller. Rainwater is collected in a 10,000 gallon cistern and used for landscape irrigation and low-flow toilets and urinals. Overall the building's carbon footprint is reduced by 68 percent and complies with the 2030 Challenge for reduced greenhouse gas emissions. In addition to LEED Platinum, the project is a recipient of the Urban Land Institute's Global Development of Excellence Award.

Most of the previous studies and research were carried out based on numerical simulations. The actual energy savings due to the implementation of the selected retrofit measures were not reported. More research and application work with practical case studies on commercial office building retrofits is needed. This can help to increase the level of confidence of building owners to retrofit their buildings for better performance.

REFERENCES

[1] Heo, Y., Choudhary, R., and Augenbroe, G., (2012) "Calibration of Building Energy Models for Retrofit Analysis under Uncertainty", *Energy and Buildings,* Vol. 47, pp. 550-560.

[2] Roth, K., Westphalen, D., Feng, M., Llana, P., and Quartararo, L., (2005) "Energy Impact of Commercial Building Controls and Performance Diagnostics: Market Characterization, Energy Impact of Building Faults and Energy Savings Potential", Final Report, TIAX LCC, Cambridge, MA.

[3] Pope, B., (2012). Creating a Framework for the Successful Implementation of Energy Retrofit Projects: A Detailed Case Study of Energy Retrofits in Atlanta's Chastain Park.

[4] Burton, S., (2014). *Sustainable Retrofitting of Commercial Buildings: Cool Climates,* New York, NY: Routledge.

[5] Hyde, R., Groenhout, N., Barram, F., and Yeang, K., (2012). *Sustainable Retrofitting of Commercial Buildings: Warm Climates,* New York, NY: Routledge.

[6] Paradis, R., (2012). Retrofitting Existing Buildings to Improve Sustainability and Energy Performance, Retrieved on 5/2016 from https://www.wbdg.org/resources/retro_sustperf.php.

[7] Bullen, P., (2007). "Adaptive Reuse and Sustainability of Commercial Buildings", *Facilities,* Vol. 25, No. 1/2, pp. 20-31.

[8] Ma, Z., Cooper, P., Daly, D., and Ledo, L., (2012) "Existing building retrofits: Methodology and State-of-the-Art", *Energy and Buildings,* Vol. 55, pp. 889-902.

[9] Mara, F., (2010). "Technical & Practice – Retrofit", *Architect's Journal,* pp. 37-40.

[10] BASF, "Improving the Performance of Existing Commercial Buildings: The Chemistry of Sustainable Retrofits", Report, Retrieved on 2/2016 from http://www.construction.basf.us/files/pdf/BASFSustainableRetrofit_whitepaper.pdf.

[11] Benson, A., et al. (2011). "Retrofitting Commercial Real Estate: Current Trends and Challenges in Increasing Building Energy Efficiency", UCLA Institute of the Environment and Sustainability.

[12] Peterson, K., and Gammill, R., (2010). "The Economics of Sustainability in Commercial Real Estate", Report, Retrieved on 5/2016 from https://foundation.ifma.org/docs/default-source/Whitepapers/foundation-economics-of-sustainability-in-commercial-real-estate.pdf?sfvrsn=2.

[13] Garmston, H., Fox, M., Pan, W., and Wilde, P. (2013). "Multi-Storey Building Retrofit with a Focus on the Façade Selection Process: A UK Commercial Office Case Study", *Proceedings of the 29th Annual Association of Researchers in Construction Management (ARCOM) Conference,* 2-4 September, Reading, UK, pp. 81-90.

[14] Aksamija, A., (2015). "Regenerative Design of Existing Buildings for Net-Zero Energy Use", *Procedia Engineering,* Vol. 118, pp. 72-80.

[15] Basarir, B., Diri, B., and Diri, C., (2012). "Energy Efficient Retrofit Methods at the Building Envelopes of the School Buildings", *Retrofit* 2012.

[16] Standards Australia, Australian/New Zealand Standard: Energy Audits (AS/NZS 3598:2000), Standards Australia International Ltd and Standards, New Zealand, 2000, ISBN: 0733735762.

[17] Aksamija, A., and Abdullah, A. (2013). "Building Technology Research in Architectural Practice: Lessons Learned from Implementations of Energy-Efficient Advanced Building Technologies", *Proceedings of the ACEEE 2013 Summer Study on Energy Efficiency in Industry*.

[18] Tobias, L., Vavaroutsos, G., et al., (2010). "Retrofitting Office Buildings to be Green and Energy-Efficient: Optimizing Building Performance, Tenant Satisfaction, and Financial Return", Urban Land Institute (ULI), Washington, DC.

[19] Botti, A., (2012). "Sustainable Retrofitting of Office Buildings in the UK".

[20] Addy, N., and McCallum, P., (2012). "Cost Model: Office Refurbishments", *Building Magazine,* pp. 48-59.

[21] Rhoads, J., (2010). "Better Buildings Partnership: Low Carbon Retrofit Toolkit", Report, Retrieved on 5/2016 from http://www.betterbuildingspartnership.co.uk/sites/default/files/media/attachment/bbp-low-carbon-retrofit-toolkit.pdf.

[22] Abdullah, A., Cross, B., and Aksamija, A., (2014) "Whole Building Energy Analysis: A Comparative Study of Different Simulation Tools and Applications in Architectural Design", *Proceedings of the ACEEE 2014 Summer Study on Energy Efficiency in Buildings*.

[23] Abdullah, A., (2015). "Adaptive Reuse: Energy Efficiency and Sustainability Measures", *Proceedings of the ACEEE 2015 Summer Study on Energy Efficiency in Industry*.