AN OCCUPANT–ORIENTED CIRCULAR MODEL FOR FACILITY MANAGEMENT STRATEGY

A Thesis

by

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ABSTRACT

Facility management (FM) concept should be re-considered for the next generation of strategic operations of buildings and should be human-focused. Traditional FM strategies are based on designs by the stakeholders and engineers and aim to have the optimum operational strategy from the financial point of view. However, this concept should include broad long-term strategic planning and focus on the users in a building, in addition to the daily tasks of building operations. The transdisciplinary innovation challenges in FM sector necessitate the consideration of human behavior during the process. The objective of this paper is to offer an optimum facility management strategy to make the actual residents of a building comfortable and productive. This can be achieved by designing a supportive management model for the core business processes. Our studies indicate that there are gaps between what building managers provide and what the users desire. This gap can only be closed by effectively considering different levels of behavior models. The study aims to design an optimum strategy for coupling human behavior models and building managers' decisions. Towards that end, we introduce a conceptual framework to enable the occupant engagement in buildings. The proposed "Circular Operation" model in a building is defined as a closed loop system which is actively engaging its users in the FM process. It is based on a business model replacing the end-of-life concept with linear frames, and increasing the building energy efficiency along with the comfort of the residents. The methodology is discussed with the help of multiple case studies based on qualitative research. This work provides guidelines for the managers by quantifying individual responses as a preliminary measure and by mapping user behavioral choices for the optimum operation strategy of a high performance, energy efficient and comfortable building.

Keywords: circular operation, facility management, user engagement, human behavior, comfort, health and safety, energy efficiency.

ÖZETÇE

Binaların tesis yönetimi (FM), yeni nesil bir operasyon stratejisi üretmek için yeniden düşünülmeli ve insan odaklı olmalıdır. Geleneksel FM, mühendisler tarafından tasarlanmakta ve finansal açıdan optimum operasyonel stratejiyi hedeflemektedir. Ancak, FM kavramı uzun vadeli stratejik planlamayı içermeli ve alışılagelmiş operayonel iş kalemlerine ek olarak, bir binadaki kullanıcıların ihtiyaç ve taleplerine odaklanmalıdır. FM sektöründeki bu disiplinler ötesi yaklaşım, süreç boyunca insan davranışının dikkate alınmasını gerektirmektedir. Bu tezin amacı, binanın gerçek sakinlerini en rahat ve üretken hale getirmek için optimum tesis yönetim stillerini araştırmaktır. Bu süreçte dikkat edilen husus, bina kullanıcılarını öncelik olarak benimsemiş bir tesis yönetimi modeli ile uzun vadede tesis sahibinin kurumsal stratejisini de desteklemektir. Ön çalışmalar, bina yöneticilerinin sağladığı hizmet ve kullanıcıların beklentileri arasında uyuşmazlıklar olduğunu göstermektedir. Bu uyuşmazlık sadece farklı davranış modelleri seviyeleri ile açıklanabilir. Tez, insan davranış modellerini ve bina yöneticilerinin kararlarını birleştirerek optimum stratejiyi bulabilir. Bu amaca yönelik olarak, bu çalışma "Dairesel Operasyon" modeline dayanarak binalarda kullanicilarin katılımını sağlamak için bir kavram haritası sunmaktadır. Burada, bir binadaki "Dairesel Operasyon", lineer iş modeline dayanan tesis yönetimi stratejisi aksine; sürdürülebilir, enerji verimliliğini artıran ve kullanıcıların sürece aktif olarak dahil olduğu kapalı bir döngü sistemi olarak tanımlanmaktadır. Metodoloji, nitel araştırmalarla çoklu vaka çalışmalarını birleştirerek uygulanır. Bu çalışma, kullanıcıların tepkilerini ölçerek ve davranışsal tercihlerini haritalayarak tesis yöneticilerini optimum operasyonel stratejiye yönlendirmeyi amaçlanmıştır.

Anahtar Kelimeler: tesis yönetimi, bina işletimi ve bakımı, yapılı çevre, döngüsel ekonomi, insan davranışı, kullanıcı etkileşimi, konfor, sağlık ve güvenlik, enerji verimliliği.

To my family, my love and friends…

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CHAPTER I

INTRODUCTION

This thesis discusses the human factor in operation of buildings to increase occupancy comfort, well-being and productivity while challenging energy efficiency concerns. A new facility management (FM) concept is introduced to achieve “Circular Operation” (CO) model by empowering the users in buildings as key decision makers. The new concept is designed to facilitate this transition for the next generation buildings. The concept is formulated over a framework based on transdisciplinary studies carried out at the Center for Energy, Environment and Economy (CEEE), at Özyeğin University, in Istanbul, Turkey. Several hard-core demonstration projects have been conducted at the Center, including NEED4B, BRICKER and TRIBE. All these projects, funded by the European Union Framework 7 (EU-FP7) and Horizon 2020 Programs, have started with a focus on integrated engineering and architecture practices. Later they have been extended to include human elements during the design, construction and renovation phases of three separate academic buildings. The post-construction phase of all these buildings also needs to be studied both from the user point of view as well as from the building operation point of view. This thesis outlines a new and transdisciplinary study for the latter.

In this Chapter, the significance of the research for the design of the next generation facility management tools is discussed. The details of the concept and the relevant background are outlined. The structure of the thesis is explained at the end.

1.1 Background of the Study

Today, buildings act as communication terminals, data manufacturing centers, life support systems and so on. Thus, facility management (FM) concept is gaining a new importance as all facilities are becoming quite complex. FM is more than the management of a building and the related services. Instead, FM necessitates an interactive road-map which is driven between corporate organization objectives and occupants when the occupant management, resource planning and asset management, and all others, are the be considered.

Strategic FM concept is merely beyond the typical building and asset management practices. Yet, the facility services impact internal and external stakeholders' interests with the issues of operational sustainability, energy usage, safety, wellbeing, comfort and the others [1]. Indeed, FM leaders are usually aware of the fact that an occupant-oriented strategy may enhance human productivity. National Research Council (1998) has confirmed the largest investments in the facilities are human resources, so that, "any improvement in productivity of the occupants is the most important performance characteristic for the facility" [2]. Thus, an occupant-oriented strategy supports core business in the long-term and needs to be studied in a transdisciplinary fashion [3].

All these developments have motivated the industry to search for new concepts that bring forward the "circular buildings" [4]. Beyond the explicit description of "circular buildings", which implies obvious objectives such as reducing energy consumption, recycling or reusing, recently human behavior has emerged as a key factor for circular model in built environment. "Circular operation" (CO) concept is derived from "circular building" idea to make the actual users more engaged in FM. The latter also advocates economic considerations for core businesses along with the occupancy comfort and wellbeing [5]. Hence, transdisciplinary innovation challenges are required for the next generation FM practices in order to achieve human comfort, well-being and productivity in seamless manner by encouraging maximum user engagement with the help of new technologies. Current digital technologies can help modeling human behavior by using cutting-edge devices which convey specific data directly to a sophisticated management system [6]. It is also possible to let occupants communicate with the FM leaders by a mobile application or web tool. In this process, the most critical element is the data management. The incoming data from the users need to be sorted out efficiently. Then, they need to be transferred to the FM to be handled effectively for the benefit of users.

There is an emerging agreement in circular model and sustainability challenges necessitate a new way of systematic collaboration of various actors and knowledge production [7]. The concept of transdisciplinary approach was proposed by Max-Neef [8], which can be appropriate approach for the requirements of new generation of FM strategy. Transdisciplinarity in facility management requires efficient coordination between various disciplines and effective knowledge transfer among the hierercial order. Figure 1 is interpreted by hierarcial order of Max-Neef concept. It is important to realize that transdisciplinary idea of operation is different from the multidisciplinary or interdisciplinary studies. In transdisciplinary, an unknown human element emerges as a need and a solution is possible only by coupling technological and social aspects with the behavior one.

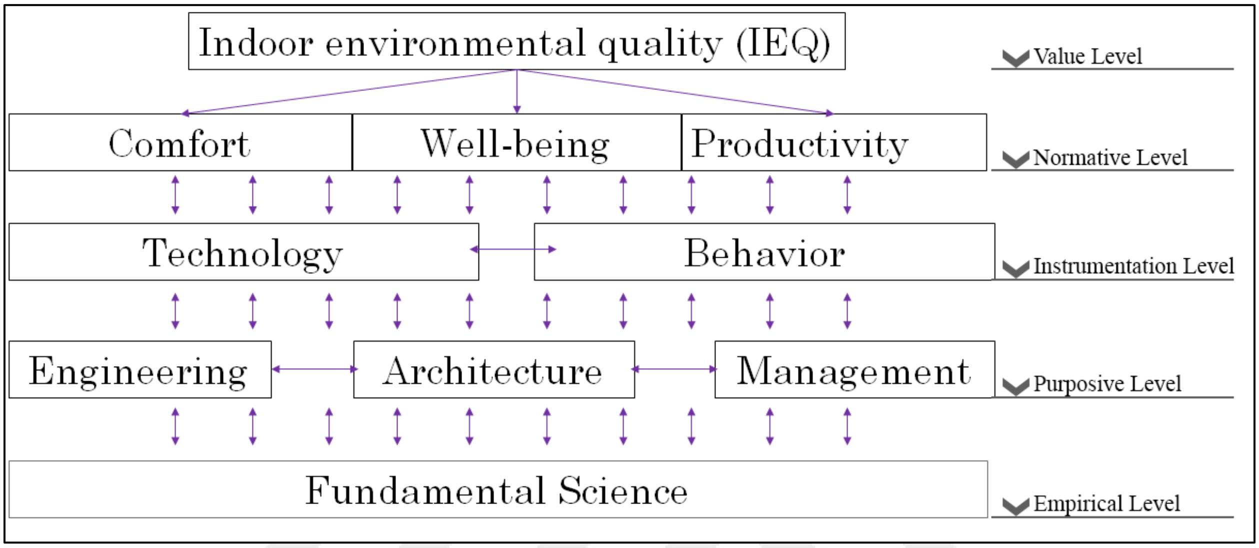


Figure 1: Required levels of transdisciplinarity for the new generation FM strategy. This schematic is adapted to optimize the indoor environmental quality of

For achieving the highiest possible indoor environmental quality, three important human factors, comfort, well-being and productivity, need to be considered. These three factor emerges in building science and requires applicability of technological solutions and the behavior models. Three integrated disciplines (engineering, architecture and management) of building science need to be coupled with fundamental science like physics, mathematic, psychology and others. This coupling results in transdisciplinary. Figure 1 shows how layers are interrelated each other in transdisciplinary approach. Still, Figure 1 is discussed in detail in Chapter III.

Towards this goal, this thesis seeks a creative methodology to construct an applicable CO distinctively from the other studies to increase user comfort, well-being and productivity corresponding to a good level of indoor environment quality (IEQ).

1.2 Problem Definition

Regarding advance requirements of human factor and the transdisciplinary approach, a series of problems arises for efficient FM strategy. The three important problems are identified as below;

1- Most of the studies in FM strategies are financial based.

With the advances in technology, buildings have turned into extremely expensive facilities that must be managed systematically and efficiently. The cost of operational and maintenance in a facility is predicted to be between 60 and 80 percent of the total ownership cost for whole life cycle of the building [9]. Also, it is reported that about %70-80 of total operational of a building cost is influenced by decisions of the design and construction stages [10]. For that reason, traditional FM strategies are designed by the engineers and aims to have the optimum operational strategy from financial point of view.

2- Most of the studies do not address the gap between the occupants' desires and the FM strategy.

There are many studies in the literature which show how important the indoor environment quality (IEQ) for the occupants of a building for their comfort, well-being and productivity [11]. However, the examples of coupling human factor with FM strategy is lacking in the literature reviews even though there are studies emphasize the trade-off between the facility management and energy efficiency in operational phase.

A recent literature search using the most relevant keywords shows how limited the cross-disciplinary studies, as seen in Appendix 1. Many of these studies are summarized in the eBids database developed by Carnegie Mellon University, Center for Building Performance and Diagnostics [12]. In constructing Appendix 1, the relevant keywords are searched in a systematic way. "Building management" is searched first as an alternative key word to "facility management" even if there are systematic differences between the terms. It is obvious that there are only a few studies about "facility management" coupled with other factors. Also, there is no study coupling "facility management", "user engagement" and "IoT". The emphasis only on the building management or facility management, with little emphasis on energy efficiency, or human comfort or sensor network clearly indicates the sector needs a more cross-, multi-, and trans-disciplinary studies. Such studies should focus on new methodologies to quantify benefits and productivity of the occupant centered environmental control strategies [13].

On the other hand, there are other studies reported on strategic FM and cost effective FM services through the core business profitability [14].

3- Lack of transferring experiential knowledge to the early phases may cause uncomfortable indoor environments and increase in operational cost.

While owners typically focus on architectural design and construction (D&C) phases and the corresponding costs, planning for facilities operation in early phases is usually not done [15]. Lack of contribution of experience in early phases to predict the prospective problems for future of a building may cause uncomfortable indoor environments for occupants as well as the increased renovation, repair and operational costs. On the other hand, the lost user information and inadequate attention to the use of BIM tools in D&C cause inefficient operational decisions [16]. This problem may be solved by developing an integrated, transdisciplinary "*future vision*" in the early phases of the D&C process. Designing a methodology for such "future *vision*" for facility management concept is expected to be the product of this thesis. "*Future vision"* for CO is used as a statement to represent FM knowledge transfer from previous operational phases to next buildings' early phases. This approach is to be built on the behavior data from the previous operation experiences to the next D&C experience for high performance buildings.

1.3 Research Objectives

The main objective of the study is to re-structure FM services and their interactive relationship with the occupants. By doing so, their contribution to the benefit stakeholders, who pay for a building beyond the technical repair and maintenance, is also expected to be significant. The study intends to introduce such a new FM strategy with an interactive user feedback tool that enables to community engagement into the process. Such a facility operation and maintenance process are expected to make the entire building operation cost effective in the long-term.

To develop the next generation FM service, in this thesis a series of qualitative research studies are conducted by integrating various dependent parties to find out the relations among them. These parties include the key stakeholders in life cycle of the building, particularly, the users. The key approach is to find out how to manage this relationship efficiently. Therefore, the following steps are suggested:

1. Investigate the wishes and the perceptions of the occupants from FM services
2. Analyze the problems with the traditional FM process between the occupants of the building and the managers.
3. Develop an interactive, digital-library based user feedback tool to enable maximum user engagement into the process.
4. Develop a circular operational approach for continuous improvement of FM services with the relative data gathered from actual users
5. Identify a methodology for adapting circular operation approach from the corporate perspective to achieve increase in profitability in the long term.
6. Document the key performance indicators (KPIs) regarding human factor of the process details from the stakeholders who are responsible for operation as well as design and construction of the building.
7. Develop a data management algorithm to contribute "*future vision*" of the FM leaders in the next projects to achieve more efficient buildings.

These general steps are discussed in the thesis in more details during the rest of this thesis.

1.4 Scope of the Present Research

A FM methodology which accounts for the occupants' engagement necessitates a number of transdisciplinary innovation challenges. The major focus of the research is to develop a collaborative win-win strategy for the users, service providers and the owner in the operation and maintenance process without tampering the D&C phase. The subsidiary impact of the thesis is about how the "*future vision*" for FM based on the operational experiences may be beneficial in D&C phase of a building.

The study will conduct a qualitative research including the users as well as the other stakeholders during the operational phase of the building. At the end of the study, a methodology is produced to match users' needs and demands with the operational strategy. A gap analysis is conducted among these actors; occupants, FM professionals and the building itself. The gap needs to be overcome to achieve an effective occupant – oriented circular FM model. The methodology comes up with interactive user feedback tool regarding a series of data taken by the actual users of the building.

1.5 The Statement of the Thesis

The research objectives of the thesis will be outlined after a critical literature survey, which is given in the next section. The discussion below comprises the typical FM practices in the sector, the role of FM during the whole life cycle of a building (WLCB), human factor in buildings, and the details of a transdisciplinary approach that need to be identified for built environment. These steps are expected to answer the sustainability concerns for a FM phase and applicability of the CO approach for building. These ideas are reviewed to clarify several research questions and to identify ineffective and inefficient FM styles.

One of the negative factors that significantly influences the efficiency of a traditional FM strategy is its myopic approach, that it is based on only the financial aspects and neglecting the human wishes, comfort and behavior. For this reason, a conceptual framework must be developed to study the impact of occupant engagement in buildings. In order to test and apply this framework, a number of case studies need to be conducted by qualitative analysis based on individual responses. These specific studies help us to determine the gaps between the occupants' desires and the managers' solution strategies. The gap analysis is produced to figure out the correlation between the users' responses and the FM leaders' thoughts. To overcome the gap and generate an applicable circular strategy, an interactive user feedback mechanism is developed.

The conceptual framework presents the CO model which stands on three pillars. The three pillars of CO model are detailed in Chapter V. The requirements and the relations are identified for an interactive user feedback mechanism. The feedback mechanism is transformed an applicable interface tool for mobiles to enable collecting meaningful behavior data and managing them.

CHAPTER II

LITERATURE REVIEW

This Chapter is to introduce the research context of the thesis based on a broad literature review, which includes short introduction to FM and fundamental concepts surrounding it. The concepts refer to the role of facility managers and the typical strategies. In the literature, human factor is sought as a major parameter to achieve full sustainable and the "circular operation" strategy by engaging transdisciplinary ideas. Human factor as a missing block in the building operation is discussed. Comfort, well-being, the productivity of the occupants, and their benefits to the core business are introduced as a core concepts and the ultimate objectives of the thesis.

1.2 An Introduction to Facility Management Concept

Buildings are complex systems. With the advantage in technology, they turned into extremely expensive facilities that must be managed systematically and efficiently. The facility management phase has become just as crucial as its D&C phase. In Figure 2, the relative decrease in the performance of buildings has been shown in relation to time. It is shown that a poor FM strategy drastically decreases the performance of a building and increases the associated cost to the stakeholders and the occupants during the service life of a building [17]. In the figure, the red arrow shows how the life of a building can be extended with an effective FM implementation.

On the average, the total cost of a building ownership is calculated to be about 40 years for non-residential buildings, including the operational cost which may be as high as 70% of the total. Operational costs include maintenance, repairs, renovations, utilities, janitorial services, capital reserves, and so on. D&C phases and the other costs of the building can be only around 30% of the total expenses [18]. Interestingly, most stakeholders of the buildings pay attention to only the design and construction phases. Therefore, even small improvements in design phase have greater positive impacts on further stages like construction cost reduction, operational cost reduction, and also societal impact as long-running but very significantly [19]. For that reasons, facility management should be considered as a part of the actual business, particularly for mid-sized and large-sized companies settled in large office buildings and for academic buildings, where facility services are directly associated with occupants' behavior. This means that both the operation cost and the attention to human comfort should be paramount for them.

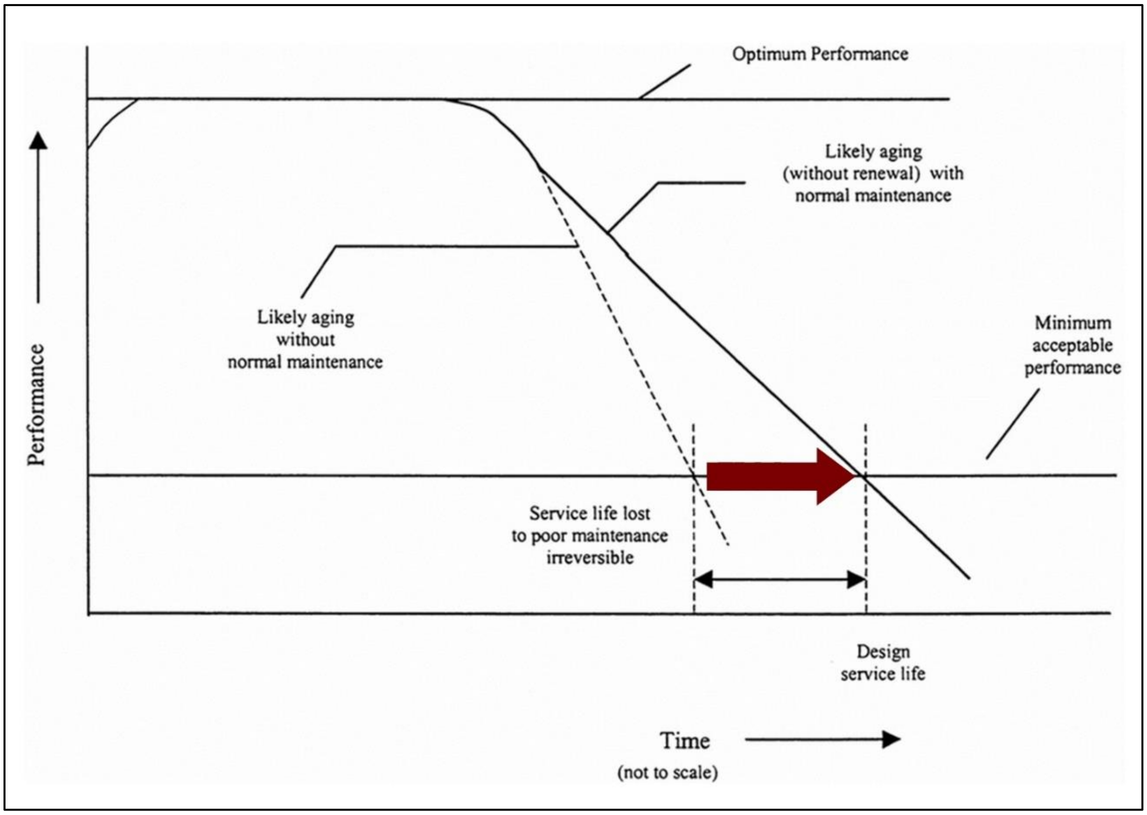


Figure 2: Effect of adequate and timely maintenance and repairs on the service life of a building. (NRC, 1993) [17].

In this figure, the red arrow shows how the life of a building can be extended with an effective FM implementation.

Traditional management models in the industry lacks the consideration for sustainability practices and occupancy concerns. That causes uncomfortable working spaces and results significant cost of operation and maintenance budgets. For these reasons, new strategic management model of facility services based on occupants is needed.

2.1 What Is Facility Management? Why Is It Important?

FM is a term which differs from the general term of building management. The definition of facility management includes long term strategic planning and focus on the users of a building in addition to the daily tasks of building operations [20]. On the other hand, building management may be defined as a technical work process in order to sustain existence and value of a building by keeping, restoring and improving its services and standards.

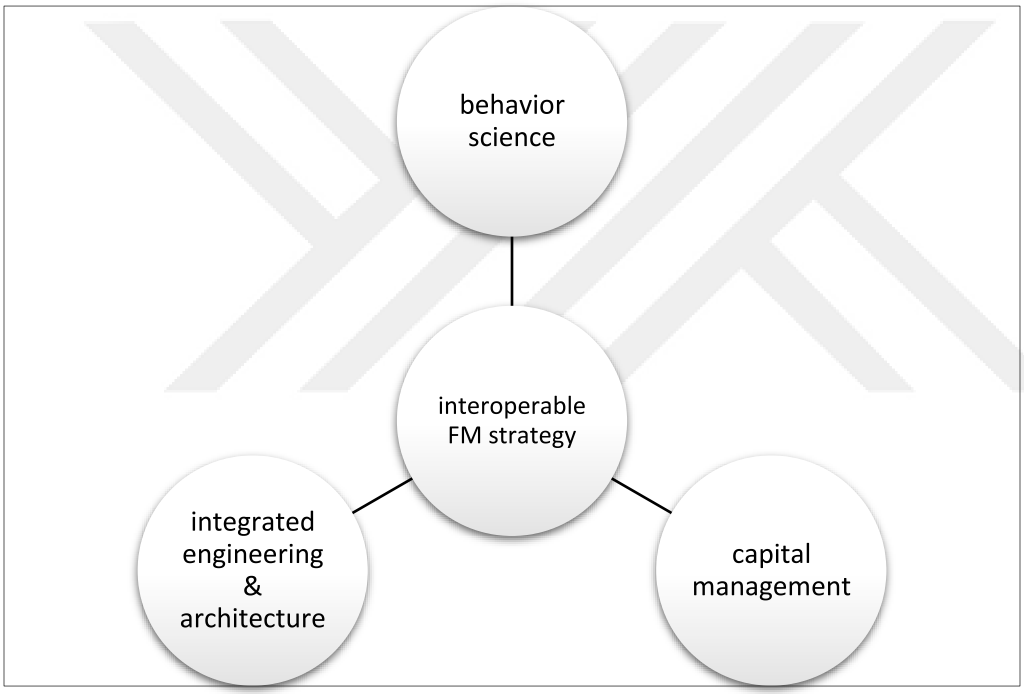


Figure 3: Three significant interconnected area for sustainable facility management strategy (STN EN 15221 Facility Management, 2008) [21].

International Facility Management Association (IFMA) defines the scope of facility management as '*a profession that incorporates multiple disciplines to ensure functionality of the built environment by integrating people, places, processes, and technologies.*' In broader aspect, The US Legal Dictionary states that '*the coordination of the physical workplace with the people and the work of an organization. It is the integration of business administration, architecture, and behavioral and engineering sciences. In the most basic terms, facility management encompasses* *all activities related to keeping a complex operation.*'. Furthermore, facility manager is '*to create an environment that encourages productivity, is safe and pleasing to clients and customers, meets government mandates, and is efficient.*'[22].

Facility management is an effort of cost effective service business that supports core business activities and allow them to optimize them by reducing the operational cost and increasing employee productivity within sustainability concerns, thus, this approach contributes to the profitability of the enterprise. Strategic facility management (FM) requires integration and alignment of non-core services to operate and maintain the core business's objectives.

According to this definition, facility management is an interdisciplinary enterprise, following the three core areas shown in Figure 3. They are related to: 1) human behavior with respect to social sciences and the occupancy management, 2) cost effective operational management to support the core business profitability, 3) work environment that is related to advanced engineering and architectural solutions, incorporating the sustainability concerns, along with health and safety [21]. In corporate and education settings, these three key aspects can be handled by human resources (HR), finance (CFO), building managers (technical, health and safety services), respectively.

2.2.1 Facility Managers' Role in The Building Life Cycle Phases

In general, the entire construction phase of a building needs to be considered in four steps [23]: design, preconstruction, construction and owner occupancy, as shown in Figure 4 [24]. The WLCB starts with the raw materials used all the way to the building deconstruction and recycling. If the energy performance or influence on environment of the entire project is to be assessed, then a life cycle assessment (LCA) should be conducted [25]. Most of the times, stakeholders are more likely to focus on developing productivity-enhancing strategies in construction phase because it is considered to be the most complex and time-consuming period in the whole life cycle of a project. In an ideal case, facility managers should also be engaged in the preparatory phases in order to foresee the potential risks of operations. This way, unexpected and undesirable conditions related to user at the post-construction phases can be avoided by early decisions.

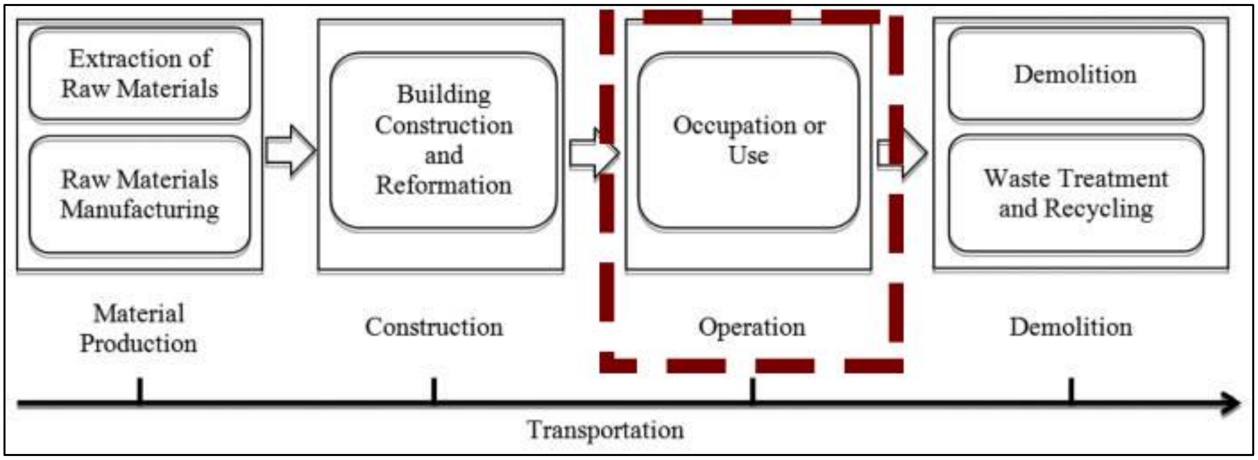


Figure 4: The life cycle phases of a building, W. Wu et al. (2014) [22].
The dashed area is the focus of this thesis.

After commissioning of a facility, facility managers appear actively on the stage to proceed a strategic alliance of internal management. Their priority is to constitute productive supply service of running real estate with assets/equities and an acceptable cost towards the most quality support for all individuals within the enterprise. In case that outsourcing of FM services which means the service is provided by external staff; internal managers become responsible for management policy, strategic administration of the management, determination and the measurement of key performance indicators (KPIs). While doing these all, they intents to collaborate with other departments such as sales to select the external suppliers, quality controls, financial planning, sustainability services and the all users of the building. However, to design with a strategic road map to increase productivity of the facility services, a process should be embraced entirely, regardless of which items of work are outsourced or internally managed. Such a strategy structure is likely to guide the managers in aspect of user behavior, financial matters and the technical solutions in order to achieve more productive business model [26].

2.2.2 Typical Building Management Strategies

Building operation and maintenance is one of the major activities in WLCB. For example, the statistical data of construction output in Great Britain the monthly volume of repair and maintenance market is around £4,500 million that means it is annually about £54 billion [27]. This is approximately one third of total volume of construction work in Great Britain. Accordingly, any improvement in building maintenance phase means visible impact on a national economy. The typical approach on building management is to seek a strategy to cut back on maintenance and operational cost, or the easiest way as a matter of fact is to cut off doing maintenance and operation. However, in the long-term this strategy will be costlier. Generally, there are three common strategy is available in operating the building, those are corrective, preventive and condition-based strategy.

Corrective Strategy is based on failure condition and unplanned maintenance. This is usually conducted depending on user requests or breakdowns. Corrective strategy may be perceived as the cheapest way of maintaining, yet, the failure of one item may cause larger returns of consequential damages. Additionally, this failure may occur at inconvenient time for users and operational authority that makes the condition extremely difficult.

Another strategy is *preventive strategy* in other words time-based maintenance. It requires performing maintenance task at regular fixed intervals in order to overcome the disadvantages of corrective strategy. Nevertheless, this requires plenty of unnecessary works which means waste of money and time because of performing irrespective of the conditions of the work items.

The third one, *condition-based strategy* is defined as carrying out the maintenance in case of any change in the unit condition or performance of the monitored parameters [28]. To apply condition-based strategy, each item should be monitored to notice any evidence of change. However, the initial investment of a monitoring system is to be taken account for this strategy.

It is also possible to reach an optimum building management strategy combining all three strategies [29]. The determined strategies, integrated by the three, are most likely to acquire the lowest cost strategy by considering only the significant items that are related to human health and safety or utilities of the building as urgent, and, this new strategy enables to decide which one of them should be used for each item depending on whether its cost of failure is higher than the any maintenance response. However, any sudden failure conditions may be unfavorable even though it is neither a significant item nor so much costly, it may cause negative impact on core business like decreasing productivity of employees because of uncomfortable environment or reasoning poor customer experience. For all reasons, it is important to understand that the low-cost based strategy is not always the cost-effective strategy.

2.3 Strategy Formulation and Implementation in FM

FM service context requires extensive understanding of external factor affecting the support services, also, it should have flexibility to create or apply new solutions. FM service need continuous communication with either internal or external stakeholders to meet their requirements and constant improvement. Certain features of successful FM service context are based on by RICS Guidance note (2018), which is summarized as;

- Flexible and fast responsive for alterations
- Focused on desires of the occupants
- Constant and continuous development
- Multifunctional as well as cross functional
- Setting and meeting long term goals as well as short term ones

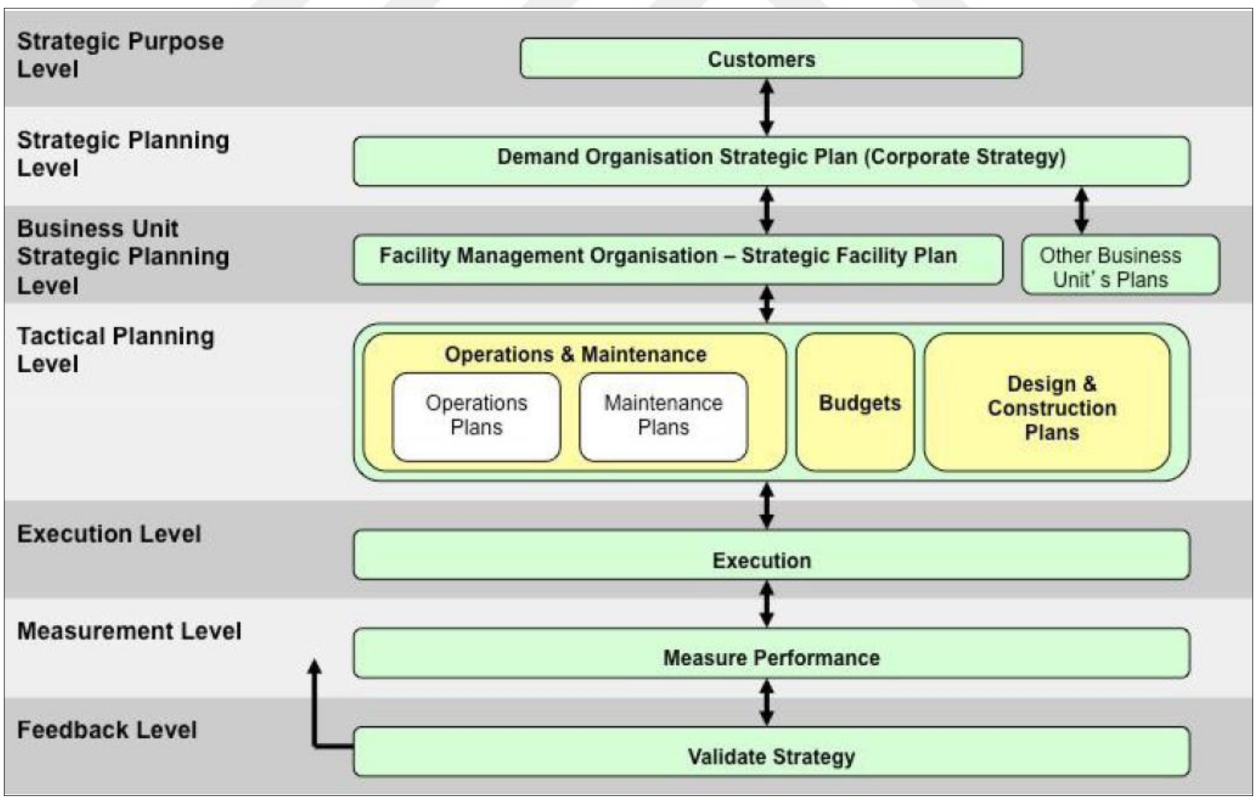


Figure 5: Leadership and Strategy Course Facility Management Professional (FMP), Edition 2015, Version 3.1.

FM strategy should achieve reliability (timeliness) and consistency (quality). Overall cost effectiveness is also key factor in management process.

The distinct the relationship between the corporate enterprise and the FM service, at organization level, is based on ISO 41001 standards (management system standard for facility management) to robust to create a management system for FM. Figure 5 illustrates the iterative process of deriving the FM strategy from the corporate level strategy.

According to the reviews, corporate level strategy interests the overall company plan takes actions in which diversified business units in addition to aiming to create shareholder value in a different way. In that sense the corporate strategy needs to identify businesses should be entered and how the top organization should manage these business units.

Facility Management strategy, either by outsourcing or performed by internal management, is formulated depending on corporate level strategy of a corporation. Michael Porter says that "Diversified companies do not compete; only their business units do"[30] . Facility Management strategy is a business unit for a demand organization and should reinforce competitive advantage to lead a value for owners who pay for the building [31]. Human factor is the value which may make a difference in the FM service in competitive environment.

2.5 Human Factor in Buildings

2.5.1 Human Comfort, Well-being and Productivity

"Comfort theory" is developed as a nursing theory in 1990s by Kathrine Kolcaba. She defined "comfort" in four contexts which are physical, psychospiritual, sociocultural and environmental. "Environmental comfort" is described for health seeking behaviors (HSBs), regarding to the external background of human behavior experience (temperature, light, odor, color, sound, furniture, landscape and others.) [32]. The theory may be enhanced in built environment, associatively function of space as well as physical environment, which is particularly associated with users' perceptions and feelings. In buildings, the challenge is not only elimination of the problems, but also creating pleasurable and healthy environments.

Subjective well-being (SWB) is defined in 2009 by Diener as an umbrella term which is the personal outcomes from subjective evaluations of their experiences [33]. Comfort and well-being have become invaluable denominators in recent years not only because they are measure of quality of human experience and satisfaction but also because they are the achievement of caring across disciplines [34].

A variety of building design, construction and operational decisions influences the IEQ which refers to the measurable values of thermal, luminous, acoustic and olfactory environment [35]. The IEQ, in return, affects the human response factors in comfort and well-being. Although, comfort and the well-being are invisible at any time, they might have negative or positive financial implications in long term. It is possible to correlate human comfort and well-being by productivity to make them observable. Therefore, i.e. in commercial buildings, productivity may be quantifiable by its financial implications and employee work performance [36]. In general, the primary challenge is a conflict between the decision makers’ intention of less cost and the comfort level, i.e. energy consumption and the comfort trade-off. An embedded strategy that allows intelligent multi-objective optimization may be the best solution for the users and the owners [37].

2.5.2 Technology and Behavior

Although the last attempts to figure out the potential of behavior programs for energy saving, behavioral evolution is currently proceeded in fields other than energy efficiency such as health, well-being and comfort. American Council for An Energy-Efficient Economy (ACEEE) estimates the potential of behavior programs as 30% whereas the pilot studies efforts routinely 5-15% reduction in energy use [38]. According to this information, behavioral modelling may help the decision makers in building operation about how people react and response to any change in condition or uncomfortable situation. Common behavior programs are enabled by interacted technologies such as online interfaces, smart phone application, and two-way communication devices. The technology infrastructure enables the utilities to receive real-time feedback data and sometimes control. The behavior programs as real-time feedback mechanism may be implemented for effective FM strategy in commercial sector. The current researches have shown that real-time feedback is not delivery primary component in the program, instead, it is bundled with additional information and recommendations as a part of diagnostics program or bundled with in-person reaction like trainings, commitment, follow-through etc. as a part of continues improvement program [39].

2.5.3 Quantifying productivity

Whether or not climate issues and energy concerns dictate the decisions in design, construction and even operation phases of the building. These decisions influence occupant experience regarding indoor environmental quality as well as total cost of ownership. Strategies such as daylighting, heating, ventilating and air Conditioning (HVAC), acoustic, healthy materials and air quality not only improve IEQ, but also increase occupancy productivity and contribute core business objectives [35].

There are various methods to quantify productivity and contribution of human comfort and well-being. Commonly, in sector, human comfort and well-being is measured by their economic profits associated with noticeable increase in employee productivity in office environment. According to researches e.g. in only benefits of human centric lighting, the research outputs show that in average + 1.15% productivity increase due to increased alertness and energizing effect which means extra output worth 2 hours per month. This corresponds to decrease of -1% sick days due to better well-being worth 1 more year duration of employees staying [40].

There are another metrics but financial outcomes that engage productivity are used for measuring the impact of human comfort and wellbeing. These are defined in Figure 6 as key metrics which are perceptions of the workforce, physical features of the office itself and financial outcomes [41].

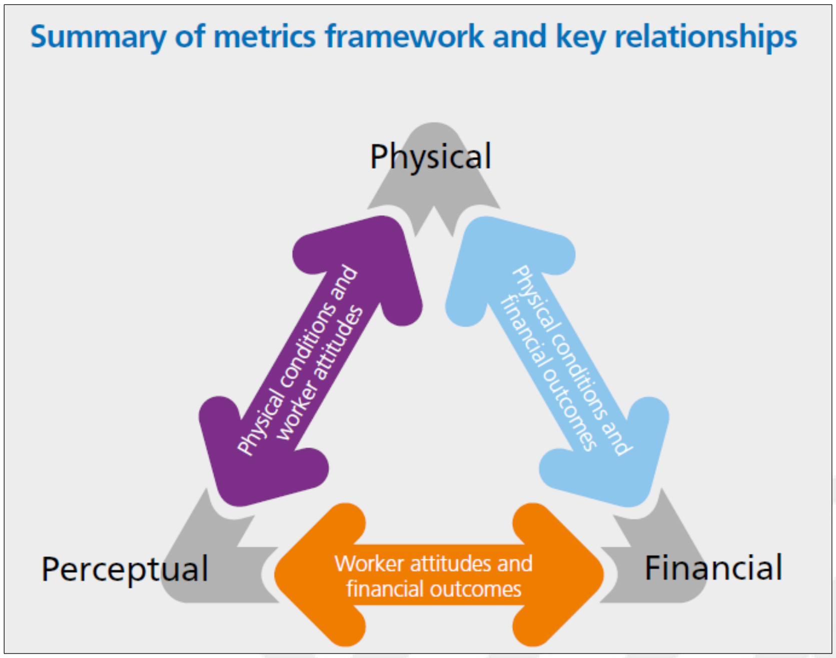


Figure 6: Key metrics framework and relationship to measure impact of health and well-being, WGBC (2014) [41].

2.4 Sustainability Concerns

It is quite significant to take into account whole life cycle assessment of the building because the building sector is responsible for 35-40% of the total global energy demand and 30% of energy-related greenhouse gas emissions although the percentages are varying region to region. Heating and cooling are together counts for 60% of the total energy consumption of the buildings [42], [43]. If no action taken, the buildings will be demanding approximately 50% of total energy consumption in the world in 2050 [44].

The energy consumption of a building is majorly influenced by the advance engineering and architectural solutions that are decided in pre-investment and the construction phases. All stakeholders would agree on designing and constructing sustainable buildings that provide desirable outcomes of mitigating energy uses and cost of operating. Yet, the life after construction should also be considered for the ultimate comfort of the people who will reside or live in a building.

The definition of sustainability should be clearly specified in this context as *'the ability to be maintained at a certain rate or level'* in US Oxford Dictionary. In building sector, National

Institute of Building Science (NIBS) defines the sustainable building design approach as *'to reduce, or completely avoid, depletion of critical resources like energy, water, land, and raw materials; prevent environmental degradation caused by facilities and infrastructure throughout their life cycle; and create built environments that are livable, comfortable, safe, and productive'*. This means that there is one more parameter which is influenced from the implementations of pre-use phases besides of energy that is occupants' comfort and well-being. Therefore, it is essential to include the facility managers into the earlier phases to predict the future of the building in terms of energy, occupants' comfort and well-being, and cost effectiveness. This necessitates to look all phases in big picture, calculate in terms of total cost of ownership to correlate sustainability and the cost.

2.5 Circular Operation Model in Building Systems

Circular operation (CO) model in buildings is principally referred by "Circular Economy (CE)" in literature. CO model includes only the facility management phase in buildings after the construction is completed. The concept aims to achieve a close loop during the operational phase of the building by transdisciplinary innovations.

Apart from the dozen explicit definitions of CE, there are many attempts to define it in a coherent and cohesive definition fashion. It was defined conceptually by Charonis (2012), in line with The Ellen Macarthur Foundation vision (2012), as "a system that is designed to be restorative and regenerative." [45]. Accordingly, CO model in building is a close loop system which is actively engaging its users in the FM process based on business model replacing end-of-life concept with the linear frames, increasing energy efficiency; in other words, it must also be designed to be restorative and regenerative.

CE principles can be applicable in diversified fields and levels. At microscale, the term of "circular buildings" is developed to present the loop as "built, operated, maintained, and deconstructed" in a manner consistent with CE principles. On the other hand, it should be admitted the idea of "circular buildings" presents a huge leap forward from existing research on Life Cycle Assessment (LCA) perspective. Similarly, it is beyond the concepts just dependent on the total cost of building life cycle, reused/recycling materials or saving resources.

In this thesis, CO concept is derived from “circular building” idea to make the actual users more engaged in FM. Focusing only on the resource consumption and energy efficiency as well as reusable/recycled materials might be insufficient for the CO concept. In fact, this attitude may evolve financial based approach and neglect the human involves. Yet, recently human behavior has emerged as a key factor for circular model in built environment.

The meta-analysis of the sustainability literature is quite limited and mono-dimensional which is focusing on three important pillars which are environment, economy and society. However, the CO approach at any level requires transdisciplinary studies.

Figure 7 presents the idea of ‘six pillars’ framework developed by Pomponi and Moncaster (2016) is based on the transdisciplinary engagements combining various disciplines to meet the requirements of sustainability and circular economy [5].

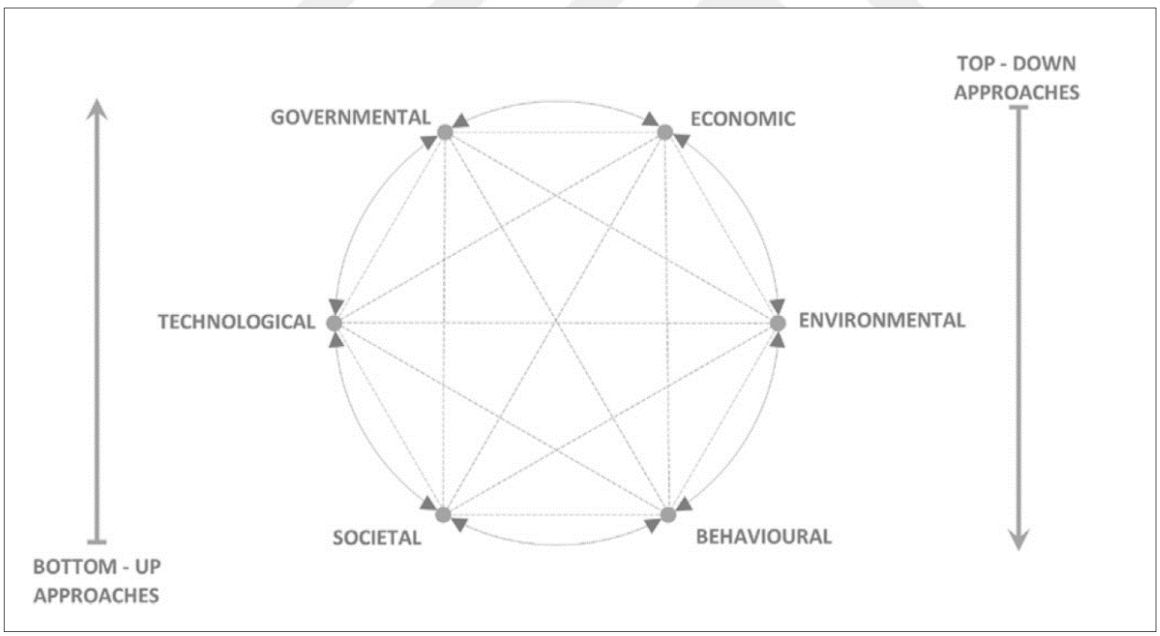


Figure 7: Frame of six pillars in a circular economy by Pomponi and Moncaster (2016) [7].

2.6 Transdisciplinary Approach

The journey towards green buildings concept is first started in 1970s due to OPEC crisis. It stimulated sustainable building concepts that drive energy efficiency concerns implementing advance architectural solutions in conjunction with engineering technologies. It is realized later that it is not sufficient to talk about only the building itself based on its economic, environmental and energy impacts. There is also needed to emphasize the built environment that includes their users, which are the most significant mass in the complexity. Thus, the new generation of challenges necessitate designating the human as a priority. Now, human factor is compelled inseparable from the challenge of circular operation.

The new challenges create more cross questionings and intersected fields, and, require many specialties in the sector. There is an emerging agreement in circular operation and sustainability challenges necessitate a new way of systematic collaboration of various actors and knowledge production [7]. Hence, circular operation necessitates the transdisciplinary approach in the industry.

The concept of transdisciplinary proposed was by Max-Neef [8] and it can be appropriate approach for designing the requirements of the new generation FM strategies. Max-Neef's transdisciplinarity concept advocates the systematic coordination between the hierarchical levels instead of considering only the same level. The levels refer to, from bottom to top, as 1) empirical level, 2) purposive level, 3) normative level and 4) value level.

The concept starts with the question of "what exists", which can be answered by the fundamental sciences such as physics, mathematics, thermodynamics and so on. One upper level asks that "what are we capable of doing with those?". The answer comes up with "engineering, architecture, commerce and so on". The third level brings the question "what we want to do" and results in design, planning, operation, politics, among others. The last level question is the "what we must do", or rather, "how to do what we want to do" and the answer to it introduces the ultimate value.

Figure 1 is our interpretation of building science using the hierarcial order of Max-Neef transdisciplinarity concept. It is important to realize that transdisciplinary idea of operation is different from the multidisciplinary or interdisciplinary studies. In transdisciplinary studies, an unknown human element emerges as a need and as a solution. A transdisciplinary approach is possible only by coupling technological and social aspects of a problem with the behavioral aspects, which are sometimes unquantifiable.

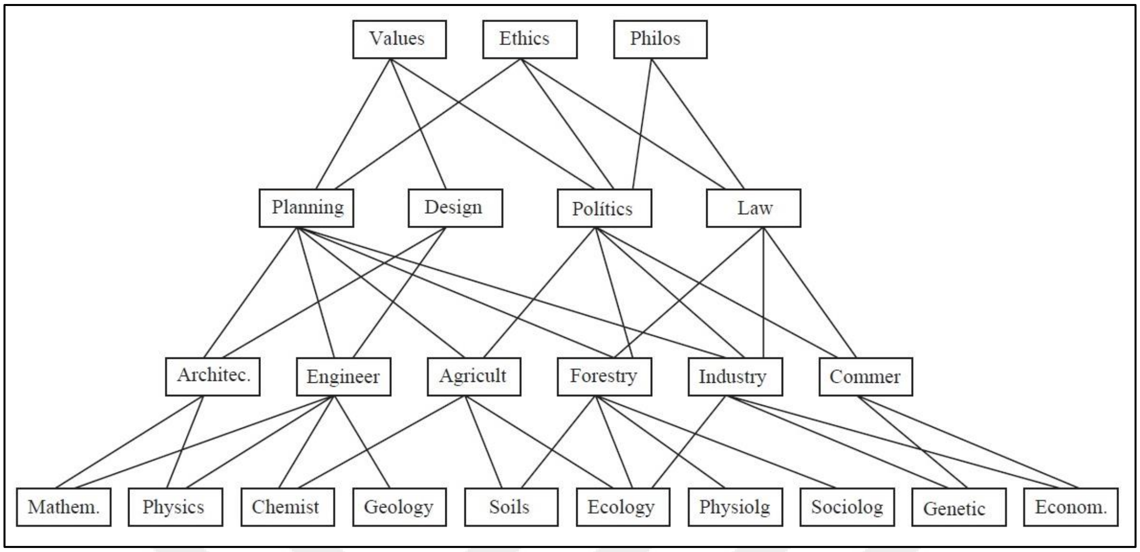


Figure 8: Max-Neef's transdisciplinarity concept. Coordination between different hierarchical levels (2005) [10].

Max-Neef's concept will be enhanced to study in CO strategy in next Chapter. For CO, required state of the art studies in fundamental science are identified such as economy, physics, mathematics, psychology, sociology and so on. Later than, the requirement of integrated engineering, architecture and management disciplines is discussed with an additional layer includes cutting-edge technologies and behavior. What we want to do in this CO strategy is identified such as comfort, well-being and productivity to create value in IEQ.

2.7 Results and Discussion

Facility management concept of a building is quite important and should be considered as a part of actual business since the buildings are more complex centers. The strategy for facility management should be formulated by prioritizing corporate and owner's objectives as well as considering the users as the key determinant in the process.

The human decisions are the key influencer after commissioning of the building when all the stakeholders who built the building leave. A building cannot be imagined apart from its end users. If we discuss the sustainability and the circular operation of a building, apart from the financial based strategies, the users should be engaged into the process actively and support continues improvement of the facility. In this way, it is possible to achieve "occupant-oriented circular facility management strategy". This model is only understandable with three interoperable fields:

1) capital management refers more operational and administrative loads, 2) integrated engineering and architecture which includes the building technologies and services, 3) users and behavior models.

The behavior models mean that the users will have comfort, well-being and productivity, regarding to the IEQ. If the behavior models are quantified and converted to meaningful data by the help of today's technologies, the data may lead the facility management strategy and continues improvement.

Such a challenge in building operation as CO, necessitate the transdisciplinary innovations for systematic collaboration of various actors and state of the art knowledge production. For all that, next Chapter will seek a methodology by emerging transdisciplinary approach to engage behavior data actively in the CO strategy.

CHAPTER III

RESEARCH DESIGN AND METHODOLOGY

Current chapter discusses the research approaches and techniques used to further explore in occupant – oriented facility management strategy by adapting CO model in the process. The research approach challenges with new dimensions regarding transdisciplinary framework of the field. Below, we will discuss a coherent and step-by-step methodology, which is structured based on the transdisciplinary concept summarized in Figure 1. This methodology, alongside the aspects of the conceptual framework in Figure 10 to recommend a CO approach in occupant-oriented facility management model. Regarding this framework, qualitative research approach has been adopted with multiple case studies and non-case specific interviews to map the gaps throughout the progress. According to the collected data, "occupant – oriented circular facility management strategy" framework has been developed at result. The resulted model has supported to suggest an interactive user feedback tool to engage the occupants into the process actively.

3.1 Transdisciplinary Approach for Circular Operation

Our research shows that the buildings should be considered with transdisciplinary studies over following six concerns: environment, energy, economy, socio-culture, government and behavior. Figure 9 is interpreted from the frame of six pillars in a circular economy by Pomponi and Moncaster (2016) presented in Figure 7. Here, it is shown that experiential increase in the effectiveness of circular operation for building can be possible with interrelated layers, and particularly with transdisciplinary chart.

Environment dimension is stressed by the lower environmental impact and the carbon footprint that steered the world to reuse or recycle the materials. Environmental aspect is one of the initial concerns of green buildings in history accelerated technological developments in energy efficiency in buildings. *Energy concerns* also spread the world after OPEC crisis and realizing the fact that the building sector demands the 35-40% of total produced energy; thus, the world tended towards renewable energy resources and high-tech applications in buildings to achieve the maximal energy efficiency. *Economic constraints* evenly have crucial recently because sustainable buildings can only be possible if financial sustainability is achieved. The economic aspects encouraged more collaborative business models and promoted quick feed forward mechanisms to contribute profitability. *Socio-cultural structure of the community and the body of current regulations* may be considered necessary for sustainability. Socio-cultural dimension determines the routines and folklores of the society and matches with the construction practices; therefore, it is generally advocated by tales from the past. Governmental dimension also determines the capabilities, gaps and opportunities and draws boundaries of the flexibility to succeed continuous sustainability as well as the desire to move forward. *Human behavior* has emerged as a key factor for sustainability of built environment and full circular economy. It should be admitted users are the only decision makers after commissioning the buildings; though human needs and demands, their comfort and well-being, and their active communication and engagement through the process are essential for circular operation.

This human aspect is the key to the variable for transdisciplinary studies, and likely to cause a major shift in the industry. Respecting the impact layers of transdisciplinary research, there should be interrelated disciplines to create value in circular operation. The transdisciplinary concept depicted in Figure 1 should be considered as a bottom-top approach starting from the fundamental sciences such as psychology, physics, mathematics, thermodynamics, sociology, economy and others; this first level is called *empirical* level. Second level is integrated "engineering", "architecture" and "management" disciplines, and called as *purposive* layer. The purposive layer interrelated with another layer, based on instruments, such as "technology" and "behavior", which are capable of producing sensible norms. This integration with the instruments is what we propose and beyond the original model given by Max-Neef. In the case of next generation buildings, new technologies will be capable of learning and influencing the behavior of those involved in buildings. FM concept will benefit from the new developed *instrumentation* layer based on the integration of technology and behavior. This integration will impact the one upper layer, which are the norms that described as "comfort", "well-being" and "productivity". This is the *normative* layer, as described by Max-Neef. At the top of the concept is the *value* layer; in the specific case of building operation, it impacts the indoor environmental quality (IEQ) with the new FM strategy. This is the ultimate objective of the FM strategy proposed here, which is based on the new *instrumentation* layer, and likely to impact the value and the sustainability of the next generation buildings.

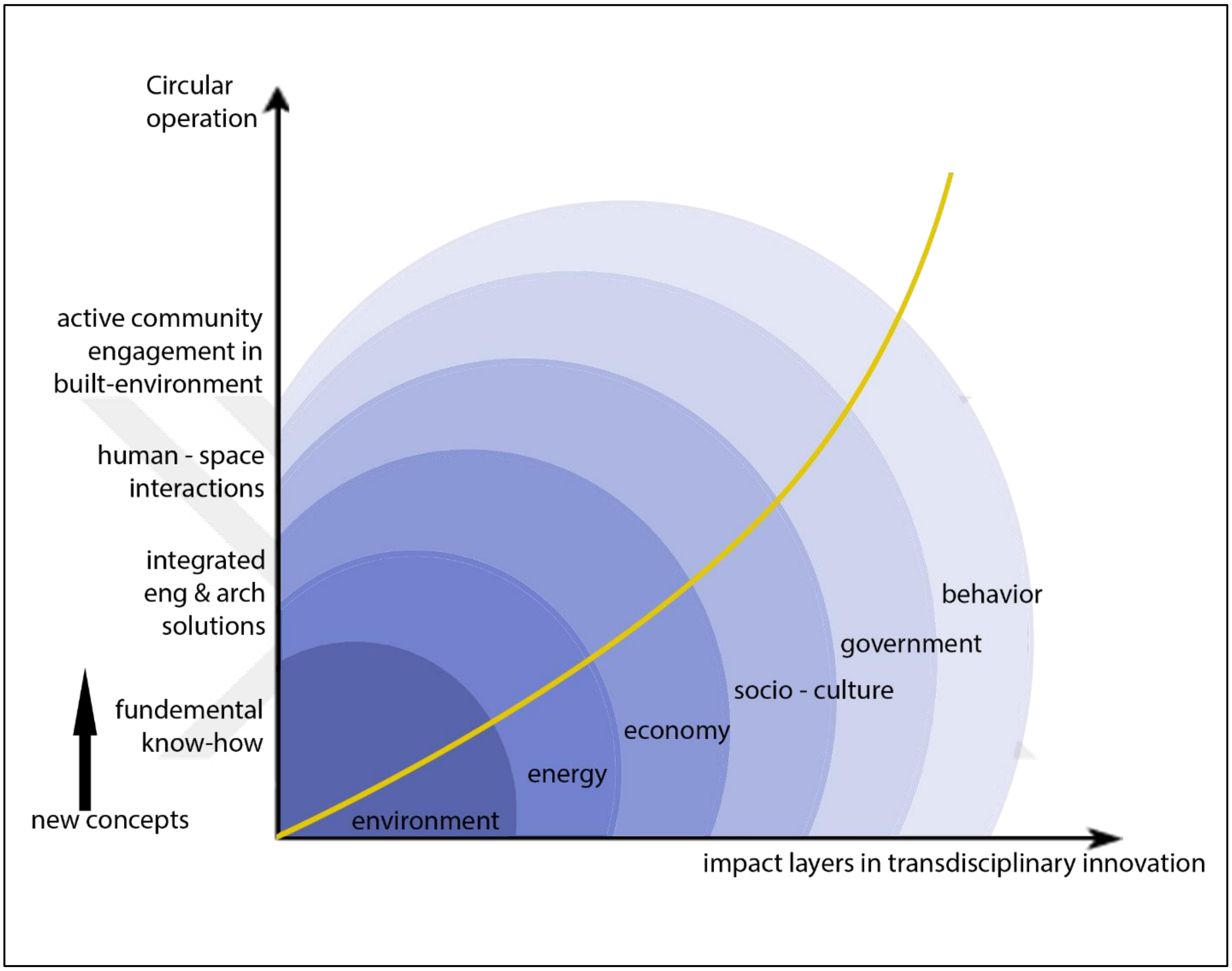


Figure 9: Transdisciplinary approach and respected dimensions for circular operation

3.2 User Engagement into Facility Management Through Core Business

Human centered business model in FM services may be applicable only if the business objectives intend to improve long term FM strategies. In the long term, achieving circular operation by active occupant engagement into FM processes will support the core business even if FM is aligned or integrated to non-core services.

FM service will have impact on the performance in turn, which are any potential changes on total cost ownership and/or core business outcomes. The strategy must be built on continuous improvement principle and should evolve to achieve the peak productivity of operation. Majority of the studies focus on tangible financial indicators in benchmarking of FM processes; however, FM is a service business based on performance rather than products where the issue of ‘intangibility’ should be discussed [46]. McDougall and Hinks recorded the user satisfaction emphasis in FM as a key determinant in benchmarking, suggesting that shifts from cost oriented to occupant performance [47]. Hence, the occupant-oriented management strategy in FM services will enable to develop continuous circular model through building economics and will support the core business activities.

3.2.1 Towards A Conceptual Framework

Based on the literature review and observations from the experience gained at CEEE a conceptual framework has been developed to study occupant engagement into buildings for circular model in the building economics. In general, the concept demonstrated in Figure 10, which represents how the information flow as well as cycling in diverse levels. It is desirable to divide to Figure 10 smaller pieces, as shown in Figure 11, Figure 12 and Figure 13 to disclose the processes in detail and of smaller scales. These focused concepts are used to analyze the case studies.

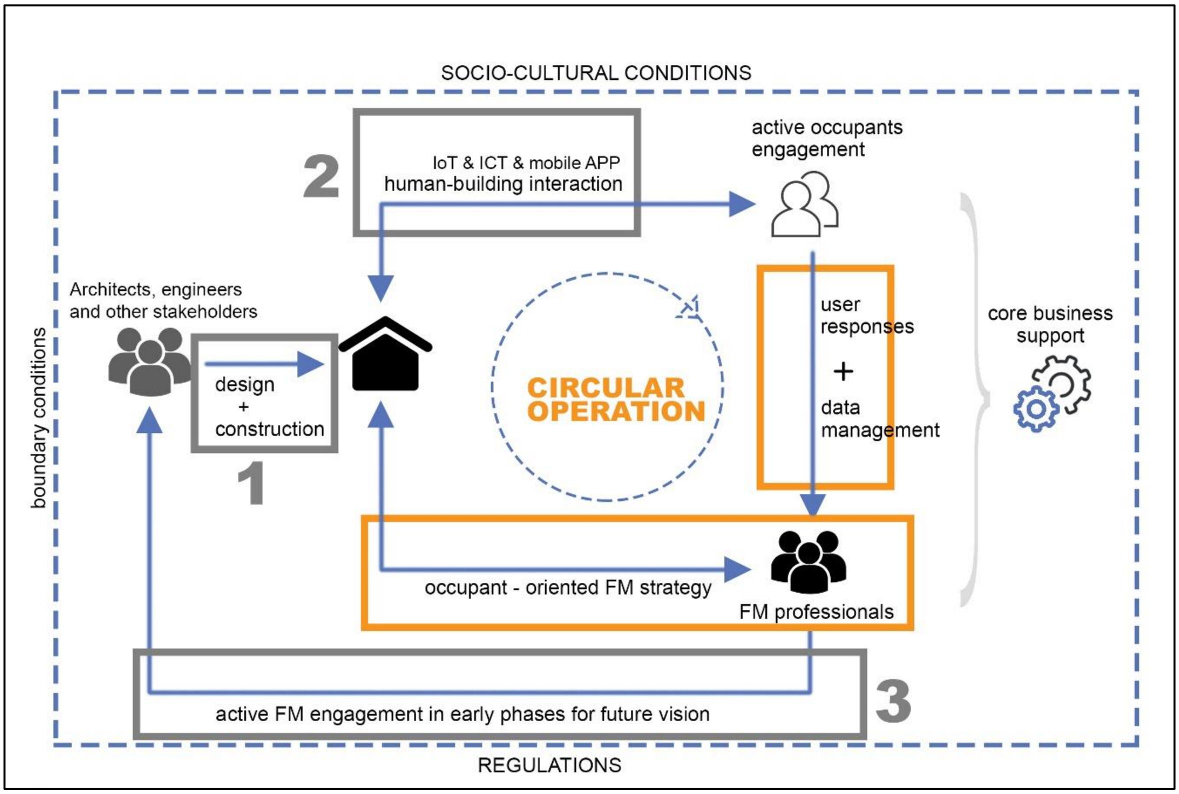


Figure 10: General conceptual framework of design, construction and operation a building

The conceptual framework as an integrated picture of whole process is referred by distinct but joint multiple studies conducted by CEEE researches for different buildings over the years. Each section (Number 1, 2, and 3) of the framework represents a research project and a demonstrated building. Therefore, the framework proves that the whole life-cycle and the whole practice may be achievable only with a continues loop. The loop can be completed by “Circular FM strategy” which is the main objective of this thesis. While developing a new management model for FM practice, this framework is considered.

Figure 10 outlines the entire life cycle of a building, from the Design and Construction (D&C) phase, to operation phase. CEEE researchers have contributed to this cycle in a sensible way with the help of several project. EU FP-7 NEED4B project allowed us to be involved at D&C phase of a sustainable building in the campus, which is a high performance, energy efficient and comfortable building. This SCOLA building is shown as Number 1 in Figure 10. It is a product of an efficient D&C effort led by engineers, architects, owner and other stakeholders. There are plenty of key partners in this stage in decision making, and the CEEE researchers were involved in its design since the beginning. However, all these partners, but the owner, leave the facility after commissioning, when the users are settled, although the CEEE researchers and campus facility managers have been discussing some of the problematic issues about the building periodically. The building shown as AB1 (Academic Building) is Number 2 in Figure 10. It is the flagship building in the campus, Yet, it is not as energy efficient as SCOLA. To circumvent this problem, CEEE has worked with a group of researchers in a Horizon 2020 project, called TRIBE, to make the building more energy efficient and comfortable. To this end, sensor networks have been installed in the building and mobile game application was developed by Swedish partners [48]. The details of these efforts will be outlined in a PhD thesis by Cem Keskin soon [49].

The buildings are designed and constructed by a large number of stakeholders within senior level collaboration. In an early stage, visions of stakeholders draw an image of a possible future with coordination among heterogeneous actor groups, and provide orientation for joint action through collective goals [50]. At the end of the construction, the building is commissioned by the facility managers and the occupants, where the significant gap arises. The lack of experiential knowledge of occupancy comfort results costly operational and maintenance activities. Therefore, the outputs of active user engagement in operational phase helps to improve the building before arising the gaps if the FM leaders contribute in D&C phases. This is why future visions are important for transition of knowledge in “Circular Operation” when the design starts. “Future vision” for circular operation is used as a statement in this thesis to represent FM contribution to early phases which is shown as Number 3.

The conceptual framework intents to produce a close loop by an active user engagement methodology. This methodology requires to process user responses data and data management which lead the “circular FM strategy”. In this way, the conceptual framework shows that how this human focused circular FM strategy supports core business profitability in the long term.

3.2.2 Information Flow for Future Vision

One other objective of the thesis is the definition of vision and actor learning based on circular flow of information in early stages throughout the process which defines one of the end goal: *future vision.* Future vision is to put forward by the experienced FM leaders in the design and construction (D&C) phase to predict potential failures in future operational phase of the building. Some studies show us the quality of information conveyed through the stakeholders who charged to manage the building after handover. Poor quality information causes financial losses, reducing performance of the building and occupancy satisfaction [51]. Because of that, early phase contribution of the experienced FM leaders may increase the performance of the building in the whole life cycle.

The thesis defines the macro level as whole life cycle of the buildings including planning, designing, construction, and operation and maintenance. FM professionals may contribute positively to the total ownership model when they participate the early phases where the grey box of the cycle in this thesis, because their learnings and visions for the future experienced where the building is operated and maintened are valuable in early stages. Facility managers who experieced users’ habits and behaviors with their impact for the operational sustainability can forsee the potential risks and the opportunities in future. If the 80% of total operational cost is caused by the decisions in D&C, the “future vision” concept may have significant contribution for FM process. The benefit of the concept may be observable by the increase of human comfort, well-being and productivity as well as the positive financial impacts. The conceptal approach is presented in Figure 11.

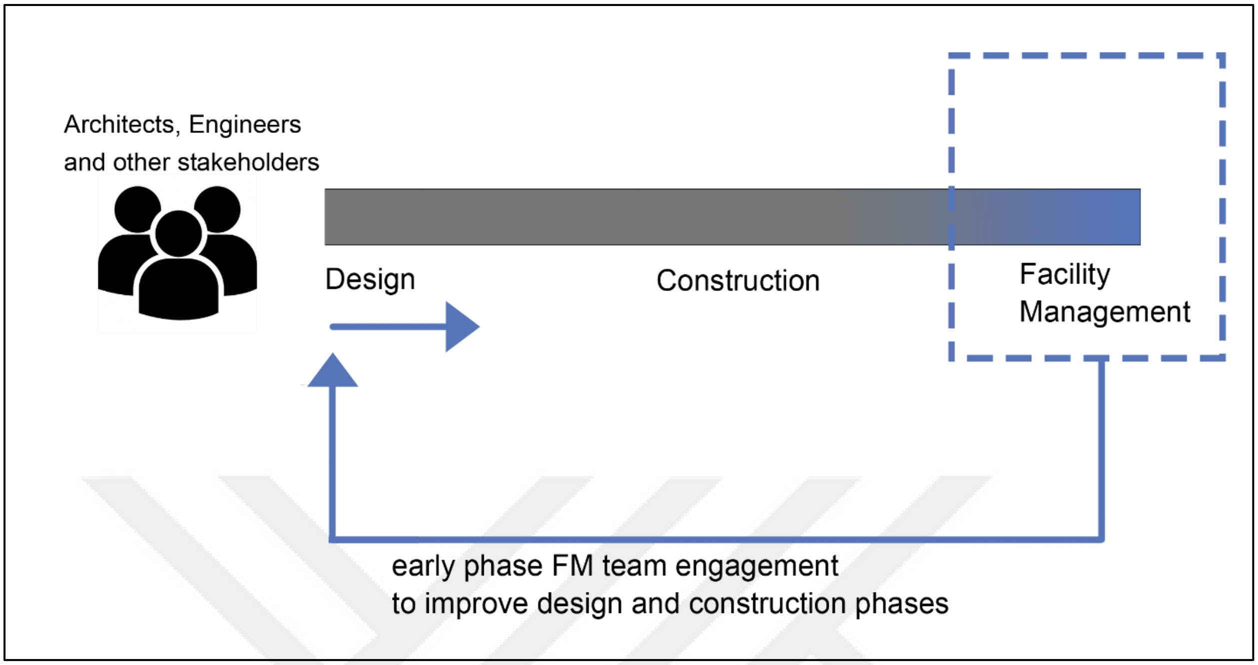


Figure 11: Circular flow of information at macro level (The 1st focus of the overall process)

3.2.2 Human – Building Interaction

The building technologies in general emphisize the building itself, apart from their occupants whereas they are actual data centers and support systems for human life. HVAC systems, lighting solutions or other embedded technologies are evaluated for endurance and energy efficiency concerns of a building. However, any systematic solution cannot be imagined separate from its users. Indeed, human behavior dynamics, their responses with respect to their comfort, and their health and safety should be interacted with the building for transdisciplinary level of innovation. Recent studies on benchmanking for correlation of human comfort and satisfaction prove that perceived comfort level by the occupants is highly correlated with productivity, particularly in office environments [52]. In non-residential buildings, performance optimization scenarios and control mechanisms by building automation systems (BAS) and energy management and control systems (EMCS) are embedded to manage the link between the occupants and the buildings [53]. This interaction is managed by the decision makers about building operation that conforms to the specific policies and needs of the building owners and operators. Such decisions are based on with respect to the codes and standards like these published by ASHRAE [54]. On the other hand, recent studies on human factor is focussed on the development of demand-based, individual and localized comfort solutions instead of accepting common and generalized comfort indexes [55].

In fact, recent developments on information and communication technology (ICT) including internet of things (IoT) and sensor technologies enable to measure instantenous desires and map the human behaviour, which play key role in improving the performance of the building [56]. With this, ICT and its derivatives may be adopted as a bridge between the occupants and the building (Figure 12). The data collected by the sensor networks can draw occupant behaviour map to create an action plan for decision makers, furthermore, the future vision is that the map may be conveyed to smart data sorting system, then, converted to a computational algorthm to be used for the learning building automation system (BAS) and energy management and control systems (EMCS). In this thesis, the embedded technologies which allow human – building interaction are considered in different cases. Human - building interaction technologies enable to a new way of communication channels. *Occupant and facility managers communication* is studied as the most significant gap to be solved in the methodology.

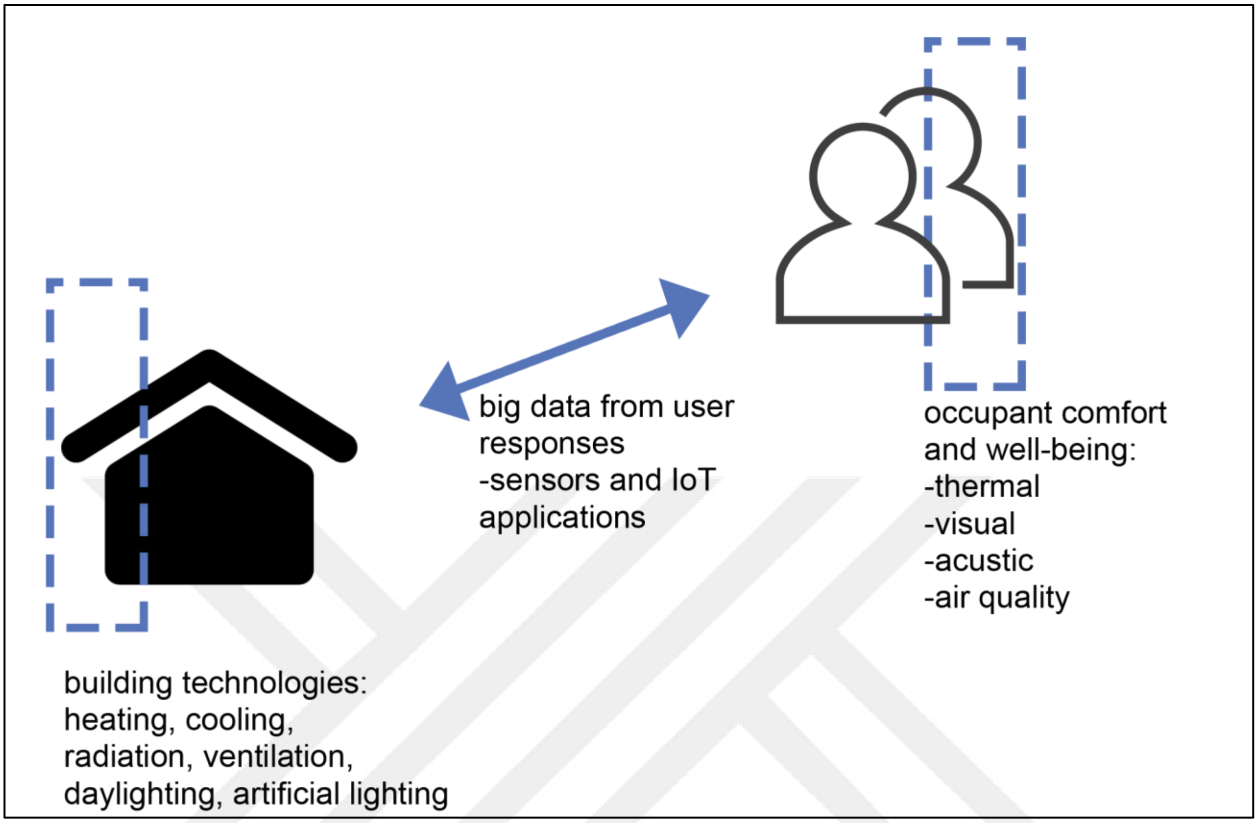


Figure 12: Human Building Interaction Scope (The 2^{nd} focus of the overall process)

3.2.3 Circular Operation Model of a Building

The circular model in building operation may only be possible with the active *occupant engagement* into the process (Figure 13). Complex results collected by the way of human-building interaction defined in Figure 12 is sorted and processed by the facility managers to convert the best solution. FM leaders must be sure about preventing the leakage of information flow between them and the occupants. According to the conceptual framework, the processed data is used to shape overall building management strategy for improving the built environment prioritizing users' desires. In fact, the strategy intends to achieve continuous occupant-oriented management, aiming for increasing user productivity and cost-effective service, not the low-cost strategy. The loop of CO starts from the building itself apart from the occupant. Its maintenance needs then continues with a communication technology that enables human – building interaction that supports to measure users' experience, and transfers the responses to the facility leaders. The managers finalize the loop a management and prioritizing strategy by enhancing users' satisfaction as well as corrective maintaining the building. The overall process emerges a conceptual operation circle to ease for quantifying the contribution of the occupant-oriented FM strategy to the core business. After all, FM leaders who have pursued the occupant-oriented FM strategy and experienced occupant behavior paradigms may feed the design phases to put the future vision for the business.

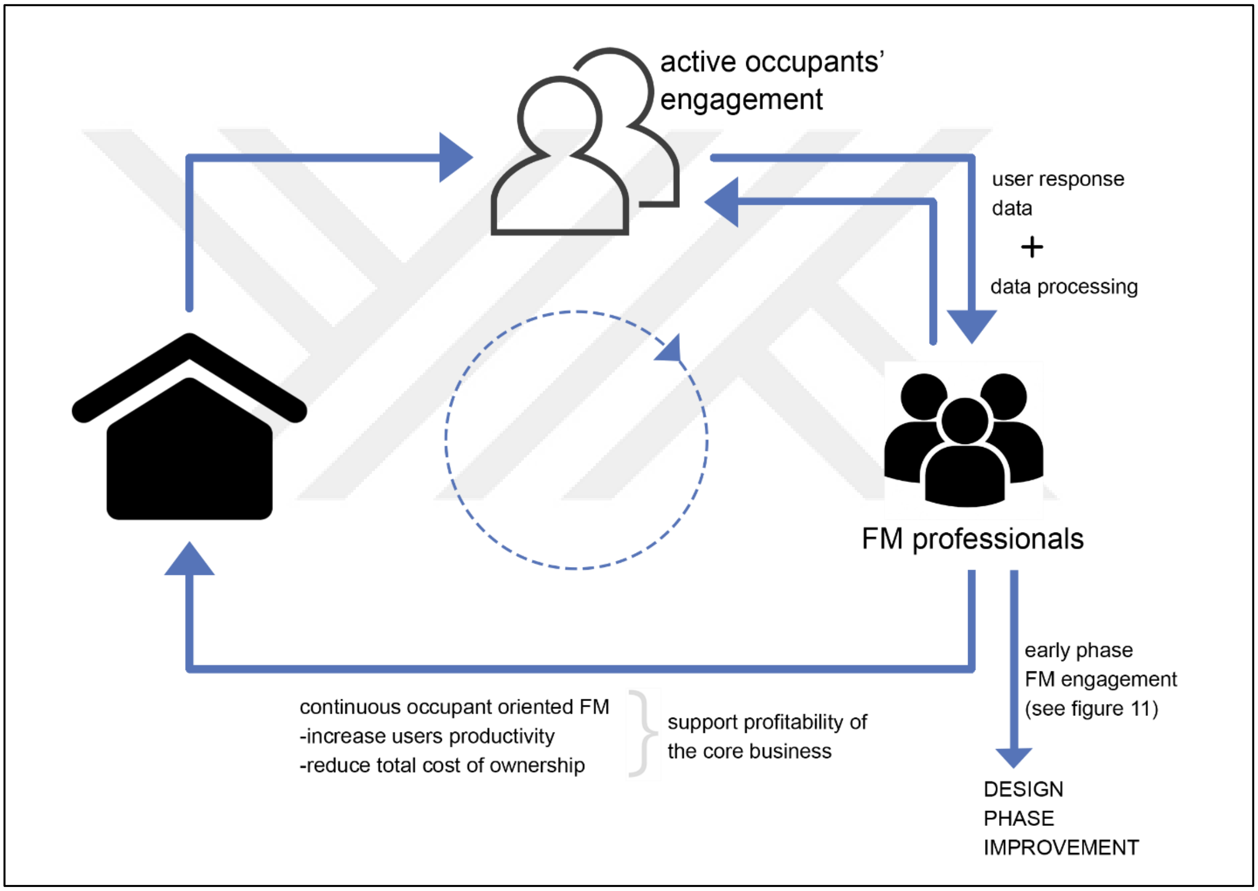


Figure 13: Circular model in Operational Phase of the Building (The 3rd focus of the overall process, which is the main objective of this thesis)

3.3 Case Studies

Three academic buildings which are School of Foreign Languages (SCOLA), Academic Building 1 (AB1) and Academic Building 4 (AB4) at Özyeğin University campus were selected as cases based on their innovative characters. All three buildings were studied by Center for Energy, Environment and Economy (CEEE) and funded by EU. The key characteristics of the buildings were represented in Table 1.

The cases were analyzed with the documents gathered from the research documents of the projects as well as from new qualitative tests. Qualitative tests were conducted by multiple choice surveys on the actual users of the buildings. They were collected from students, academic faculty members and administrative staff. The questionnaire was prepared based on critical issues in the FM process. Tucker and Pitt (2008) showed that in accordance with the user responses, technical engineering services like mechanical and electrical (M&E), and the interests of occupants' health and safety are the most critical matters in facilities. These primary issues concerns the human behaviors, habits, health and comfort, their satisfaction and productivity as well as enhancing building performance in terms of energy, endurance and sustainability. The study also gathers information from the technical activities, and the health, safety and environment (HSE) issues are the priority in FM activities. Then the study is introduced to re-consider these services as occupant centered. The survey was designed to measure satisfaction of actual users and, in relation with to control devices and the managers. During the same period, the interviews were conducted as non-case specific way with the present leaders responsible for health and safety (HSE), technical service engineering in the campus, general operations and the IT infrastructure. In this way, a gap analysis was initiated between the occupants, managers, sector leaders and the operation people.

3.3.1 Outline of the Cases by Documentation

The collected documents initially processed as a background for each case studied. Selected three case buildings have been consulted by CEEE which a research center at Özyeğin University as part of funded projects. The documents are majorly provided by CEEE based on its previous studies and the official websites of the projects. Technical specifications, budget information, energy consumption results, administrative data and so on were achieved by CEEE as a part of EU project requirements.

The key characteristics of the cases were analyzed by documentation represented Table 1. There were seven parameters in documentation.

- *Size* of the building which is the gross area to be used in calculating per sqm for each user.

- *Program* that represents which facilities is offered in the building, how many offices, auditorium, parking areas, how many meeting areas and…so on.
- *Occupants profile* shows us how many students and employees are living in each space
- *Energy performance* of the building shows the total energy consumption of the building annually and what the major energy consumption factors are considered.
- *Status* of the building is shows in which year the building is opened to use and which specific actions has been taken for consideration.
- *FM strategy* introduces current management approach taken by related people

CASE	Size (gross)	Program	Occupants Profile	Energy Performance	Status	FM Strategy
SCOLA	17.000 m²	offices, classes, meeting areas, café, roof-top PV panels, basement parking	142 employees, 930 students	Electricity demand measured as 50 kWh/m²/yr consumption. This is 48% of total energy demand. 62% HVAC, 20% Lighting, 18% Appliances. 200.000 USD/year saving corresponding to the AB1.	building in use: delivered in 2014; still real-time monitoring	Solution Center allows occupant to convey their demands and needs. The center allocates the tasks to the respective department
AB1	26.000 m²	offices, classes, meeting areas, café, auditorium, labs, green roofs, roof-top PV panels	164 employees, 1540 students	Electricity demand is measured as 98 kWh/m²/yr electricity consumption average, LEED Gold score, expected to generate 30% energy saving with TRIBE Project.	building in use: delivered in 2011	
AB4	under planning	under planning	under planning	under planning	building in planning phase; expected to complete in 2019	

Table 1: Overview of key specifications of the selected cases

3.3.2 The Structure of Questionnaire

The case studies analyzed with the help of a well-organized surveys delivered online to actual users of buildings. The users are defined as students, administrative stuff and academic members. The major aim of the surveys is to collect the feedback from occupants regarding their experiences, comfort levels and the communication quality between them and the FM professionals. With these surveys, the study aims to generate a preliminary user behavior models to be used in a FM strategy.

The survey is organized for two operated buildings; AB1 and SCOLA (see Appendix 4). The third case, which is under construction, this study is only studied to measure how future vision can benefit from the current building operation strategy. Therefore, the third building is only measured by interviews not included in occupant survey.

The questionnaire is organized and evaluated in five sections as shown in Figure 14.

1- Participants personal information includes their age, occupancy, sex.
2- Participants experiences regarding IEQ; This part focusses on four important factor which are air quality, temperature, lighting and noise. This aims to measure the comfort level of the participants, the impact of their comfort level on their working performance and their self-control devices on those four factors.
3- The survey also searches their energy consumption and motivation on energy efficiency in building.
4- One of the most important part of the survey is to find out the quality of communication between the users and the FM leaders. Thus, some questions were asked to evaluate communication tools and their effectiveness.
5- Lastly, the participants were asked to choose their preferences on the control method for the IEQ and energy efficiency.

The questions are prepared as multiple choice and matrix rating scale and the checkboxes. Some multiple-choice questions are asked to rate the performance between “1 to 7”, excluding the option “4”. This is because “4” is considered as the dead mean and has no weight. Therefore, the participants should choose one options from “1 to 3” which indicates the negative answers whereas “5 to 7” indicating the positive answers.

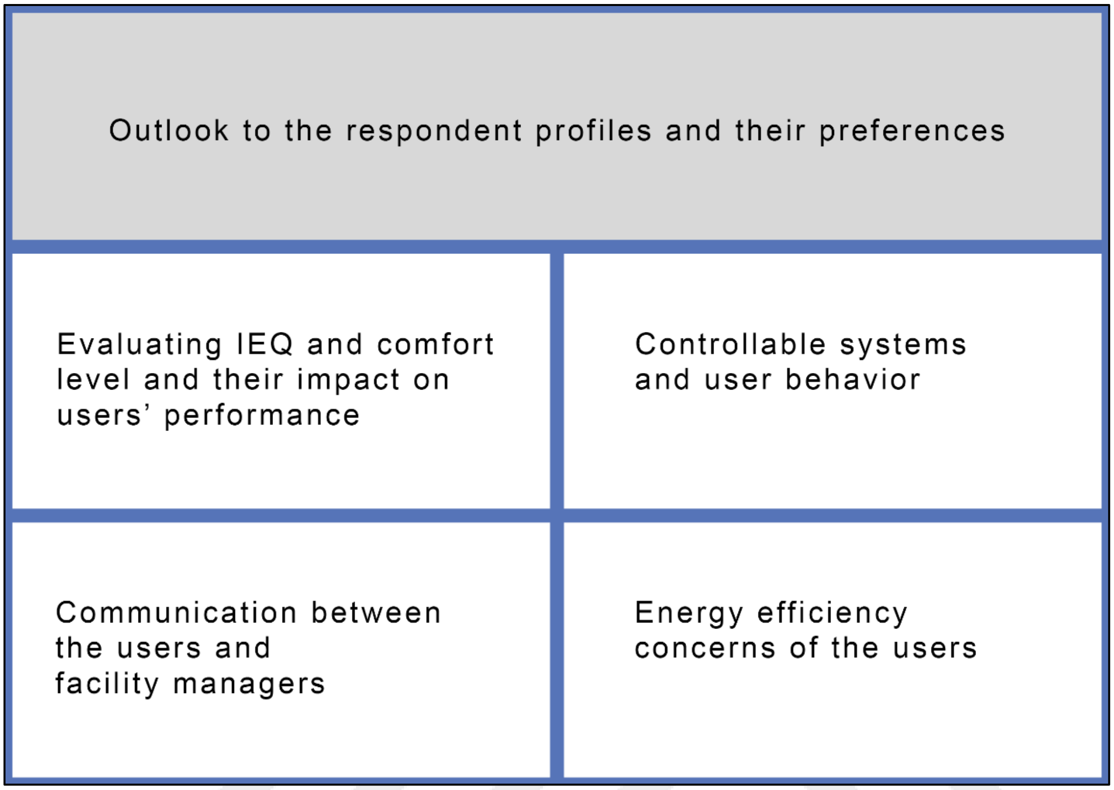


Figure 14: Response evaluation criteria of the surveys

The individual responses were compounded with documentary results and analyzed to associate with the interview responses.

3.4 Interviews

As a part of qualitative research, a number of interviews are recommended with the intension of understanding current practices, define potential issues and the missing information in the documents. Interviews enabled us to learn about different viewpoints and experiences in depth to be used further when necessary.

For this study, two in depth semi-structured interviews were conducted. Compared to structured interviews, semi-structured interviews were more likely in-depth discussion and their intents to discover potential unanticipated issues [57]. Prior to the interview, the questions were prepared based on literature review (See Appendix 2 & 3) and, consisted of closed and open-ended questions.

The participants were selected based on their positions and the areas of responsibility. The overview of the key actors for the interviews can be found on Table 2.

Since there is no overseeing facility manager at the campus of Özyeğin University, the potential managers were found in accordance with the key critical activities of FM. The first interviewee was the Director of Technical Services who leads many engineers, technicians and workers. The directorship is responsible for all building technical maintenance and repair and, their operational strategy. The second interviewee was the Director of Health, Safety and Environment (HSE) who is responsible for environmental sustainability and waste management. HSE is in continuous communication with the occupants due to their responsibility to avoid any trouble that may occur. These interviewees were very critical leaders to act on occupants' comfort. Both directors were asked to reply the specific questions related to their responsibility for all campus, not focusing on any specific case buildings.

The questions are designed to evaluate six significant parameters for each professional as shown in Table 3. Those are general approach of FM services based on their experiences, their special business unit strategies, their communication tools and strategies with their collaborative departments. Also, the questions were related to the users of the campus, cost of operations, scale up from business level strategy to corporate level strategy issue, and the directors' future vision to contribute the new building construction in order to develop effective FM strategy at macro level. These parameters were constructed on three pillars as referred three-series-interviews logic of Seidman (2006) [58]. The first parameter which was to obtain general insights about the FM is based on their professional background. Second, third and the forth parameters (their special business unit strategies, their communication tools and strategies with their collaborative departments and the users of the campus, and cost of operations) include questions which search the experience in detail during the process. The last two parameters (scale up from business level strategy to corporate level strategy issue and their future vision) were also asked to seek the meaning of their profession in a complex system, with respect to their professional expectations and visions.

	Position	**Profession**	**Responsibility Area**
Interview 1:	Director of Technical Services	Building maintenance and repair	All campus
Interview 2:	Director of Health, Safety and Environment	Occupancy health, safety, and environment	All campus

Table 2: Overview of two key actors considered for interviews

3.5 Developing Occupant-Oriented Circular Facility Management Strategy

Based on the case analysis, interviews and the documents of CEEE projects, a conceptual occupant oriented circular facility management strategy was developed to provide a guideline to the key actors for facility management. The drafted model which is discussed in Section 3.2.3 was aimed to success circular operation of a building by emerging individual responses taken from its actual users while managing the entire facility. While developing an applicable model, this thesis is to develop a road map and, it introduces the logic for an interactive user feedback tool to maximize the comfort level in a facility. Eventually, the study can be expanded to a mobile/web application, after it establishes a foundation for an applicable model. The feedback tool collects the individual responses as 1-0 data and converts them meaningful analytics to utilize for the automation and learning system of a building. The tool aims to accumulate the data to be used as future vision as well. The strategy based on mapping the demands and feelings of the actual occupants in a facility to achieve maximum productivity, comfort and well-being by engaging the into the operation. The tool is designed as appealing as possible, user friendly and desirable. otherwise, a series of questions to be answered by the participants corresponding to the experienced conditions can be considered boring and not engaging. Gamification may also be based on this approach for this interactive tool.

3.6 Results and Discussion

Transdisciplinary approach in circular operation discusses six-important dimensions while defining the human factor as an only decision maker in operation and maintenance of the building. The full circular model can be only achievable by activating user feedback tool within a circular operation strategy. Human engagement is the key idea in designing this study. The goal is based on the literature reviews and previous studies funded by EU projects.

The conceptual framework which presents a circular operation model (Figure 13) initialized by the D&C phases has been developed to support core business objectives and profitability. The framework remarks the relations between different key actors, but most importantly, it suggests the circular operational model between three actors: the building, facility managers and the users.

The occupant-oriented facility management strategy which is founded on the conceptual framework of this model studies the relations of occupants' responses with the interview results. It studies by conducting three case studies and non-case specific interviews.

The case studies have been analyzed by questionnaire asked to the actual users at Özyeğin University campus and the documentations. The results have been compared to the non-case-specific interview results which is conducted by the key actors in facility management service in Table 2. Based on the results, one occupant-oriented circular facility management strategy which activating interactive user feedback mechanism has been developed Section 5.2.

CHAPTER IV

ANALYSES OF CASE STUDIES

In this Chapter, three different case studies are discussed based on results documented and responses received from individuals. At the same time, non-case specific interview results are analyzed, then, the cross-case comparison are presented by applying conceptual framework in all cases. As a result of documentations, interviews and the surveys, a gap analysis framework produced to determine how to figure out the major problem which is the “communication”. The major findings of the applied methodology are summarized in section 4.7 Research Outcomes.

4.1 SCOLA Building and NEED4B Project

4.1.1 Documented Results

The first building chosen for a case study is SCOLA, which is the building of School of Foreign Languages at Özyeğin University. It is a demonstration product based on a funded EU-FP7 collaborative project called as NEED4B. SCOLA is one of the series of pilots located in different European partner countries (Italy, Sweden, Belgium and Spain) that demonstrated cost-effective and energy efficient technologies and methods for the design, construction and operation of very low energy new buildings. NEED4B methodology, published at the end of the project, intended to support to consultancy service provided by a dedicated group of specialized professionals which is called “energy efficiency team (EET)” [59]. Figure 15 demonstrates EET professionals’ involvement at different phases of the project. The professionals have been selected among the main stakeholders with specific expertise to reinforce integrated innovative approach, those are engineers, architects, surveyors and others. The findings from the project shows us the efficiency of the collaborative team work beginning of the delivery process. These findings are interpreted in this thesis as the “*future vision*” that support the requirement of consultancy facility managers in early phases to meet prospective user requirements as well as owners.

Figure 15: Energy Efficiency Team (EET) involvement, NEED4B Final Guidelines (2018) [59]

The methodology instruments an optimization and prioritazation mechanism implemented by the EET. The mechanism functions a procurement strategy for overall works during construction delivery process. The strategy includes the tips based on the findings from the project for three stages - those are design, construction and operation – and measures impact rating depend on user requirements in cost effectiveness, energy performance, quality, time of delivery and environmental impact [60]. However, the adaptibility and flexibility of the methodology (see Figure 16) can be simplified and made more user friendly. Therefore, CEEE members currently work on a simplified tool which enable to make the methodology replicable in the industry.

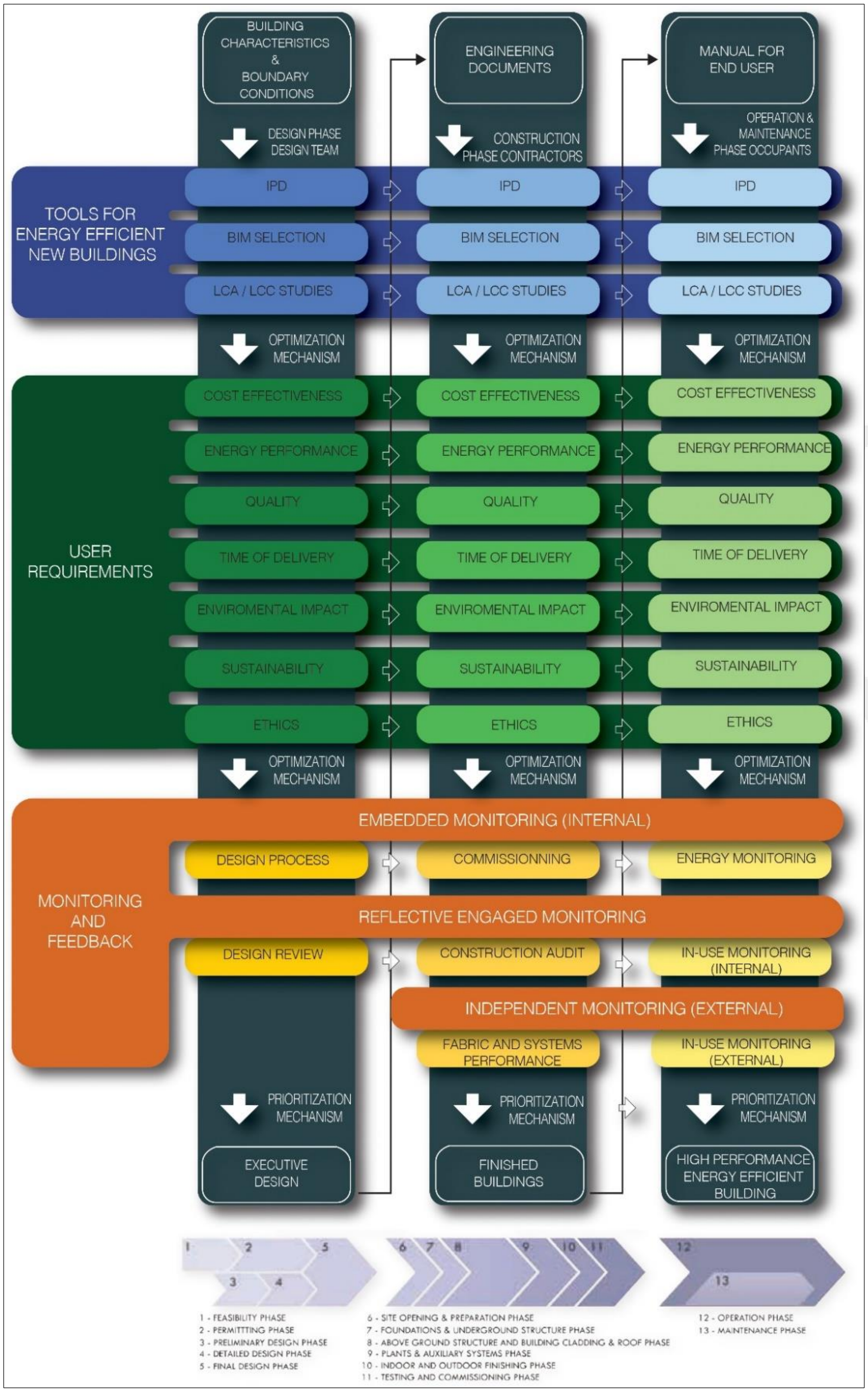


Figure 16: Procurement strategy of a methodology to comeout with energy efficient building, NEED4B Handbook 2018 [60].

Although the NEED4B methodology is studied on energy efficiency applications for three stages, its third stage which is the operation and maintenance of the building is only focused on real-time monitoring of the energy values during the five-year of the project [60]. The project applied 6 – dimensional building information model (BIM). 3D architectural, M&E and structural models were produced in detail to be used in budgeting and planning in 5D of BIM. In 6D, SCOLA building was operated and real-time monitored. An energy management applications were embedded to follow and improve the energy efficiency of the building in operational phase. The operational strategy intended to plan preventive maintenance activities depending on BIM life cycle documents in addition to the corrective maintenance activities. The main concern is to control energy consumtion amounts trading off daily tasks. An energy dashboard was projected for energy management activities controlled by the technical service team at the university.

To increase awereness and reduce occupancy consumption in energy, a number of workshops were organized to communicate with the users. In this project, the workshops are the only communication channel with the actual users of the building and the objective is tohoroughly energy, not their comfort and well-being. Therefore we can say that the methodology is developed in linear logic starting from the building reaches to the occupants. There is not any systematic feedback system regarding their needs and desires to make the procedure circular. The missing instalment of the project was an active and sustainable commucation mechanism between the managers and the occupants for achieve continues improvement in occupancy comfort, well-being and productivity.

The simplification and applicability of the NEED4B methodology in the industry is possible. Later in Section 5.2, thesis will be recommending a simplified tool as a management model for facility managers to be attachable for the NEED4B project by refferig the missing aspects and the complexity of the methodology. The conceptual framework as a base for the new management model is a pruduct of the deep study and the observations of the operation and maintenance stage in the methodology with combination of TRIBE project which conducted in AB1 building as second case [61]. The second case will announce a communication methodology between the occupants and the building where enables the ICT applications and gamification strategy for active enagement.

4.1.3 Questionnaire Results

The questionnaire was delivered online and attended by 36 participants. A total of 49 questions were asked and the estimated time for the complete survey was 12 minutes. The questions contained multiple choice, matrix/rating and checkboxes. The questions which rate the answers out of 7. The rating 4 was ruled out to avoid of useless rates.
At the end, the five evaluation criteria have been considered. Their demographics are given below:

The general outlook the responses

1. 81% of participants are women, 19% total is men is seen according to the results of the survey.
2. 100% of the participants are administrative and academic staff. There is not any student participant for this survey.
3. 17% of the participants are in the age between 20-30-year-old, the majority is between the age of 30-40 with 67%, and 17% is above 40.
4. During daytime, 44% of the participants, which equals to 16 users, spend more than 5 h in their offices whereas the 33% of the total participants spend 3-5 h in their offices. 64% of total respondents spend 3-5 h of their daytime in classes, while only 22% of them spend more than 5 h in classes. Also, 31% of participants spend their total daily life in meeting rooms. The answers indicate about 1 h of lost were neglected time. According to the data of occupants' spending hours in which spaces of SCOLA concentrated offices/study rooms, classes and the meeting rooms of the building during the daytime. (see Figure 17)
5. There is no significant number of users spend their time at the school during the nights, therefore the responses are neglected.
6. These analyses show us the major responses of the survey is related to the three distinctive spaces: offices/study rooms, classes and the meeting rooms.

Evaluating Indoor Environmental Quality (IEQ) and its impact on users' performance

1. It is assumed that there are four IEQ factors which may influence performance of the people during the day where they spend their time at most (see Figure 19).

2. The indoor environmental quality (IEQ) in offices/study rooms was rated by majority as negative (See Figure 18). About 6% of the responses consider it as very bad, 19% was quite bad, 36% was bad rated as “3” out of 7. Just 28% of the total responses were a little bit positive about IEQ that rated only “5” out of 7. The rating of the classes was similar. 36% of the responses rated the classes just as “3” out of 7, which can be considered bad. 30% of the total responses rated “5” out of 7 although 11% of the participants is a little bit satisfied from the IEQ point of view (“6” out of 7). Therefore, majority of the responses are varying around the average while still some of them says bad. This means the IEQ of SCOLA should be improved.
3. According to the user responses, the most impactful factor is the temperature levels as shown in Figure 19. More than 88% of the users agreed with the thermal comfort is very significant for their working performance and productivity. About 58% of respondents rated as this is very significantly impactful. According to the survey results, only 33% of total respondents think the temperature level is ideally comfortable in winters while majority of those think it is quite hot. On the other hand, 75% of total respondents think that the temperature of the summers is not the ideal for the users. About 16% of respondents decided that the indoor environment is hot than desired although it is rated as “3” out of 7 which is quite converging to the ideal. Also, 40% of the people think that indoor environment is quite cold in summer. Still, 25% converges to the average while 11% feels extremely cold.

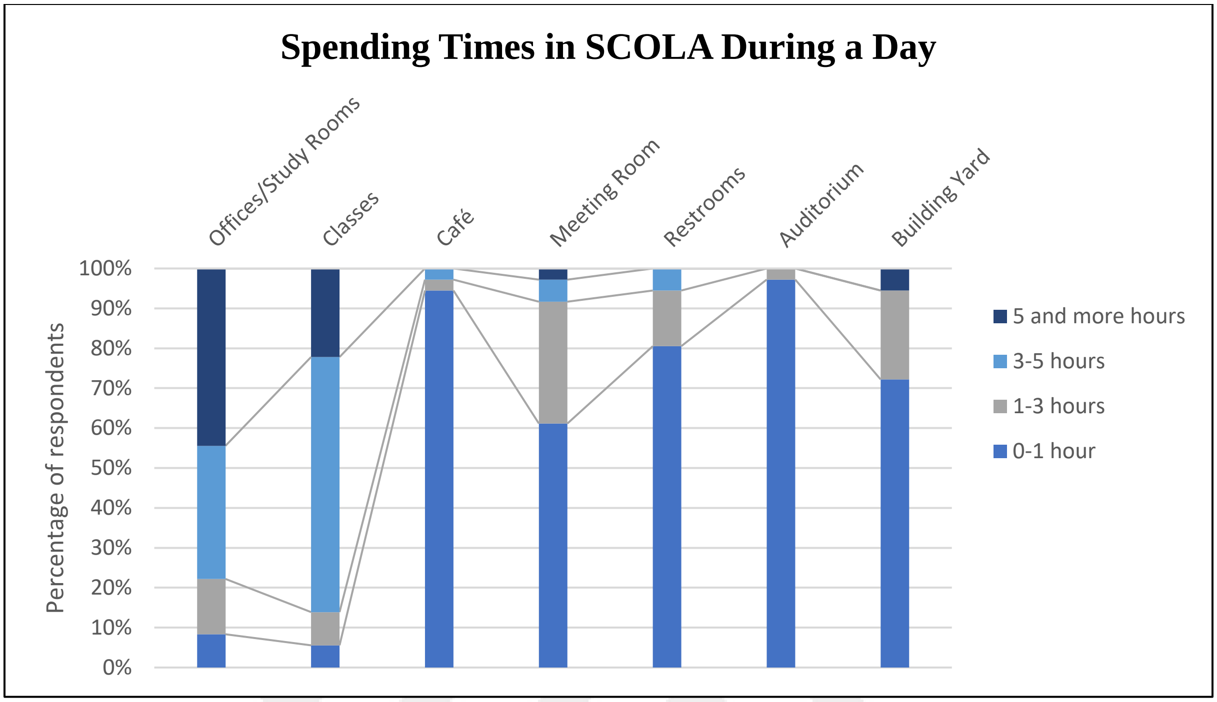


Figure 17: Occupation periods of different quarters of daytime in SCOLA

4. In winter, desired range for temperature of the indoor environment is 19-25°C according to the 72% of the total respondents. On the other hand, in summer, most of the participants which is 67% still specify 19-25°C their preferences whereas the 28% of them prefer the range between 14-19°C.
5. Another impactful factor on performance is air quality. 50% of the survey participants decided that air quality has very significant impact on their performance while 40% says also quite significant. In working hours, the respondents indicated that freshness of air reducing over the day time until 6 pm. The humidity was evaluated majorly in ideal level; however, the smell could be said as increased after the noon during the day. 80% of total users specified that the air circulation is not good enough. These data indicate the ventilation rate may not be sufficient and; air quality is associated with the temperature increase as well.
6. The third important comfort factor that influence working performance is visual comfort. 47% of total answers said that lighting level has a very significant impact on their performance while the other 39% said it has significantly affect their performance. 54% of ratings is negative about daylighting level. Yet, 28% of total answers is ideal as “4” out of

7 and 14% of total answers rated “3” out of 7 which converges ideal but still it is negative. 17% of total responses converges very inadequate. The glare discomfort depending on daylight has no significant effect on the occupants. Majority of discomfort may be related with the daylight level. The artificial light level seems also quite problem. 41% of the users decided the artificial light level is not good enough. However, glare-based discomfort is not the point again.

7. The last important factor which influences IEQ is the noise that less important than the other three factors on user’ performance. Only 28% of total respondents think that noise has very significant effect on their performance while working. Also, most of the users rated as there is no significant distraction from the noise inside or outside of the building.
8. These all factors are analyzed and demonstrated in Figure 20 to show how user responses condense in which ranges.

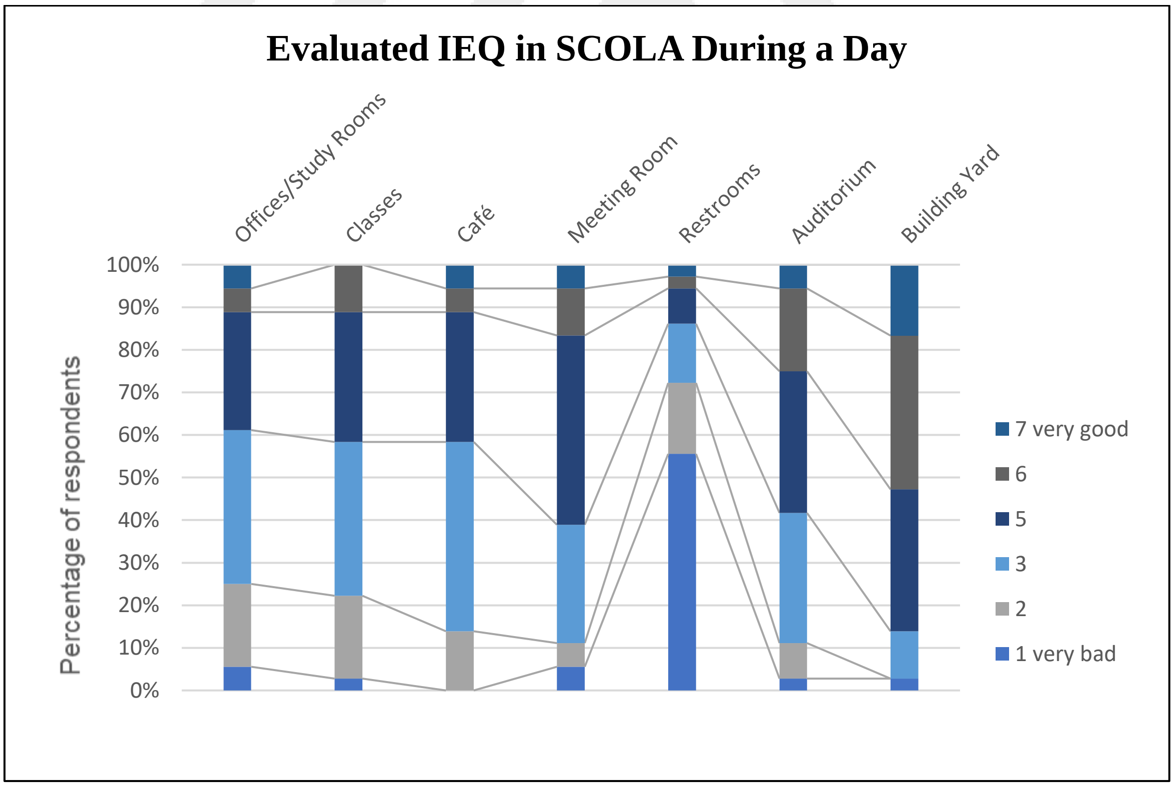


Figure 18: Evaluated indoor environment quality during a day in SCOLA

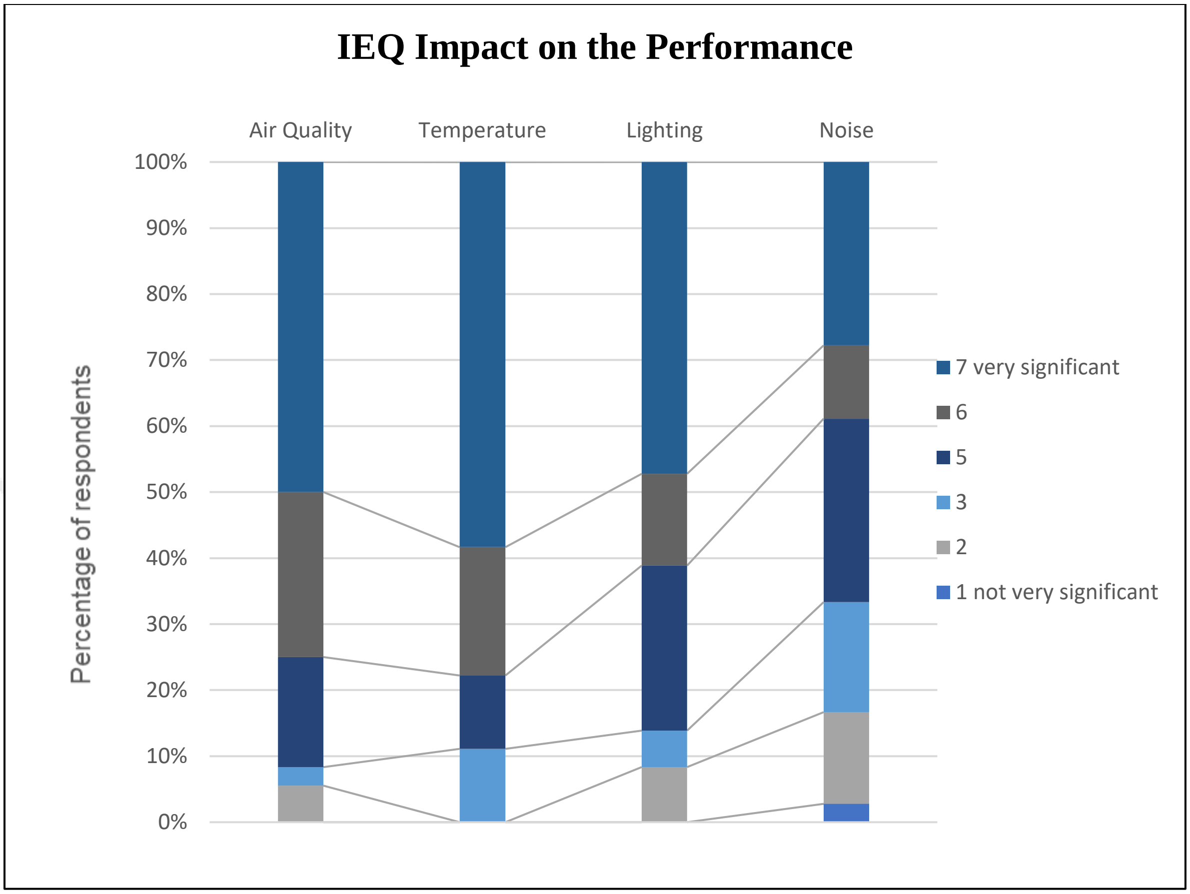


Figure 19: IEQ impact on users' performance in SCOLA.

The graph shows us which parameter is more critical for human comfort, well-being and productivity.

9. In Figure 20, each coloumn specifies the critical parameters which affect the users' comfort in a building. The critical parameters derived from the four specific and measurable characteristics of a space: temperature, lighting, air quality and noise. Temperature performance of the building is evaluated for two different season as summer and winter. Lighting is also evaluated as daylight and artificial separately. Thus, it is possible to predict more accurately the reason of the dissatisfaction. The percentages specifies the number of respondents who participated the survey. Temperature is the most critical parameter which influences the human performance according to Figure 19. Second is air quality, third is lighting and noise is the least significant. The size of the circle visualizes the percentages to make it more observable the satisfaction rates.

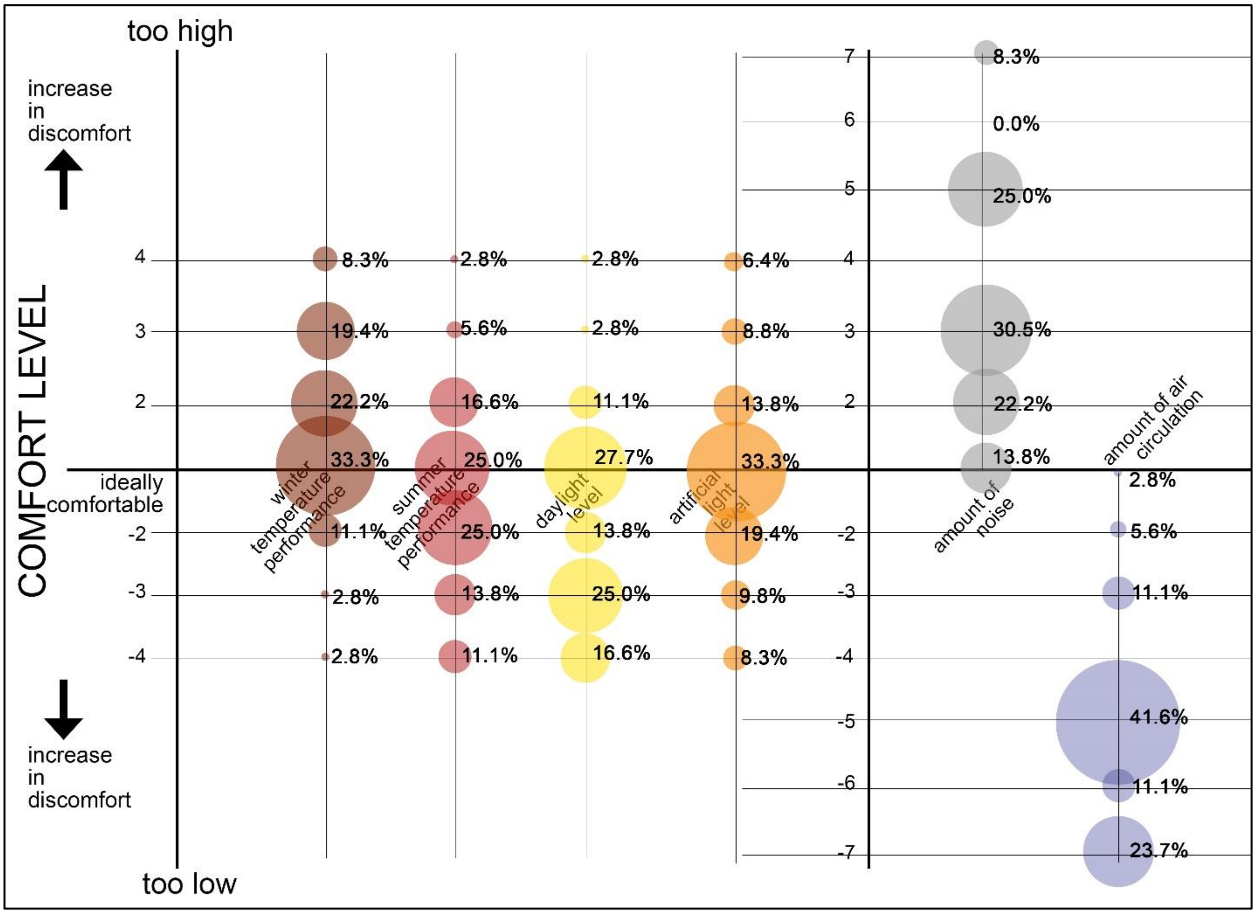


Figure 20: Measured comfort levels for important factors in SCOLA
The percentages specifies the number of respondents who participated the survey. And, the size of the circle visualizes the percentages to make it more observable the satisfaction rates.

Controllable systems and user behavior

1. 33% of the users are not able to control the ventilation to change the indoor conditions while just 6% of the total users have full control opportunity in their spaces. The rest has partial control on the units. The same can be said for temperature and lighting as well. Only %6 of the total users can control the temperature level while 31% of them do not have any control unit. In lighting, only 22% have access to control even in artificial lighting. Those probably are the on/off lighting control because the rest specifies they do not have full control on lighting conditions.

2. The most adjustable elements in the buildings are very fundamental: doors, blinds and openable windows. Most of thermostats, ventilation equipments, shading devices or blowers are not allowed to be controlled. The adjustable lighting fixtures are majorly on/off switches and blinds (shown in Figure 21).
3. Building occupants some special touches particularly on temperature, lighting and ventilation because they do not have full control on those services. Almost all of them prefer at least room specific adjustable system instead of building centered.

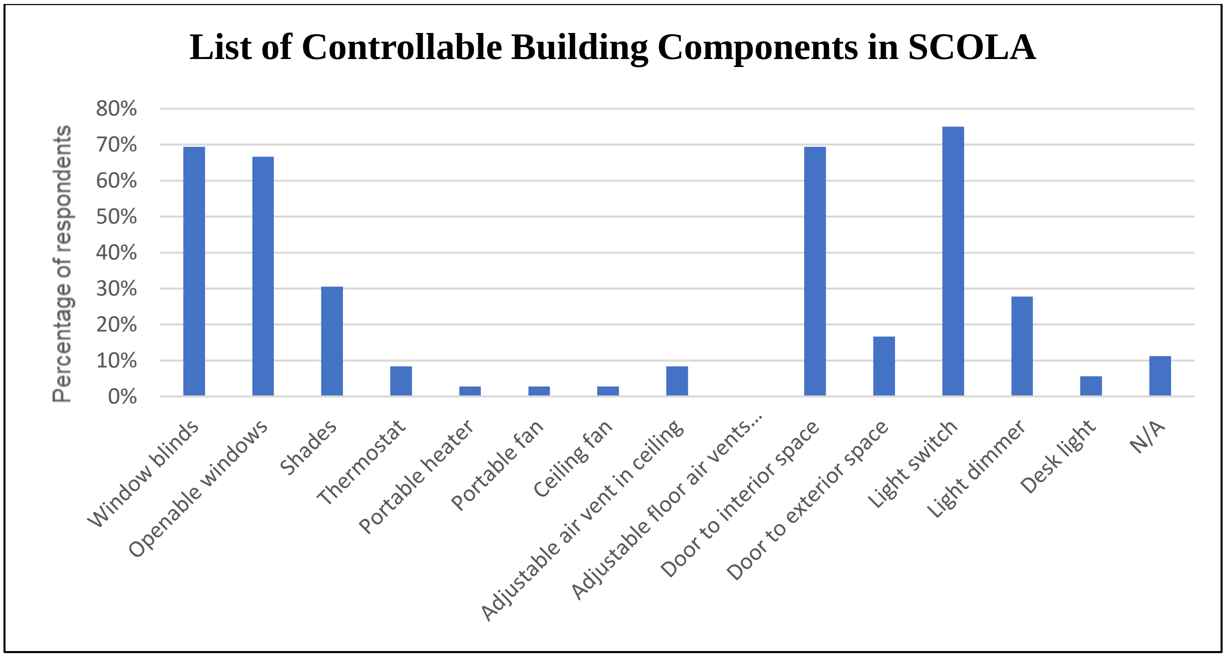


Figure 21: List of controllable building components in SCOLA

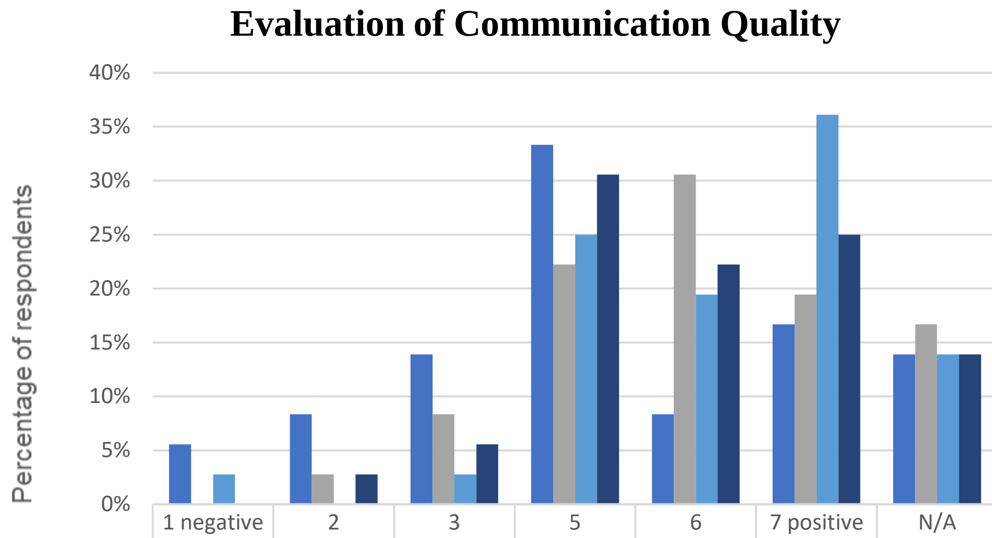
The controllable items are very significant because they allow people to adjust their spaces as they want. The respondents were asked to find out how many of them can control those components in their own spaces.

Communication between the users and facility managers

1. One of the most important issue for effective facility management services is to overcome the gap between the users and the service providers. 80% of SCOLA users contact with the service providers when they experience uncomfortable environmental condition (in Figure 22). 14% of them do nothing and yield to the inefficient work environments where only

6% may adjust their desired indoor environmental conditions. People who do nothing and who are able to control their units represented as N/A.

2. Almost two third of total people who contact with the service providers (58% of total respondents) evaluated the quality of service as above the average. 14% of total respondents do not evaluated quality of service, it may be because they do not contact the FM specialists, or they are able to adjust their own environment. 6% of total respondents are very strict about the low quality of service where 14% are evaluates converging the average as “3” out of 7. Only 17% of people are very satisfied with the quality of service.
3. The similar pattern is seen on the speed of service. Majority of the respondents evaluates the speed of service as average converging positive. None of the respondents think that the speed of service is too long. 19% of the evaluators are very satisfied with the speed of service. 17% skip as N/A.
4. Most of the users evaluates the easiness of the communication as above the average while 36% of total says they can reach the service providers very easily. Only 3% of total evaluates as very difficult to recognize and communicate with the service providers.
5. Most of the users evaluate quality comprehension as above the average. None of the respondents say that there is an understanding gap between service providers and them. 36% of total evaluated in average while 25% believes the service providers can understand their needs and demands very well.
6. According to the survey, the most desired channel to communicate with the service providers is e-mail with 50%. Calling method is chosen with 28% behind the e-mail. Mobile app is only 19%.



	1 negative	2	3	5	6	7 positive	N/A
Quality of service	5.6%	8.3%	13.9%	33.3%	8.3%	16.7%	13.9%
Speed of service	0.0%	2.8%	8.3%	22.2%	30.6%	19.4%	16.7%
Easiness of communication	2.8%	0.0%	2.8%	25.0%	19.4%	36.1%	13.9%
Quality of communication	0.0%	2.8%	5.6%	30.6%	22.2%	25.0%	13.9%

Figure 22: Measuring efficiency of communication between the FM leaders and the occupants at the campus in SCOLA.

Facility management authorities can be considered as technical services, HSE services, IT people, security and so on. The occupants are the students, academic staff and administrative staff.

Energy concerns of the users

1. More than half of the users do not control their own energy bills. Around 53% of the respondents which is the percentage of people who take their own bills usually prefer to use paper bills and e-mail. Only 8% of the respondents prefer mobile interfaces.
2. When we ask how often they would prefer to control their energy consumption, the responses concentrated on weekly check with 50%. 31% of the respondents would prefer to see their daily energy habits as well.
3. People also majorly prefer to see energy consumption/specific space and their share on the climate change or the number of trees cut to perceive building energy performance.

4.2 AB1 Building and TRIBE Project

4.2.1 Documentation Results

The second case is another faculty building at the same campus, which is called as Academic Building 1 (AB1). The building has been affirmed green building and accredited with LEED Gold certificate, however, the certificate does not rate the operational efficiency or user satisfaction. AB1 has been studied with another EU Horizon 2020 (H2020) project which is named as TRIBE conducted at CEEE. CEEE researchers have planned a framework where a mobile game could be used to measure and enhance energy habits of the users. The energy consumption of AB1 has real time monitoring, and it was built before SCOLA. However, the main purpose of this monitoring at AB1 if different than that of SCOLA. The monitored energy consumption is correlated with respect to the occupants' behavior models. The behavior models were determined by the sensor network. The correlations are used to quantify user energy impact on building [62]. The amount of impact is reflected to a mobile game which is a serious game to increase awareness of energy efficiency among the users.

The project directly aims to improve users' habits to enable their active engagement of energy efficiency in building operation. However, the intelligent implementations do not consist of any systematic feedback mechanism which activates communication tool between the facility managers and the users.

According to conceptual framework of circular operation, this case meets the human-building interaction using ICT technologies and creates human behavior data to be used by facility managers. Even if the behavior models which are patterned by ICT refer to users' comfort, the data does not represent their satisfaction rate, productivity or any feedback. It just calculates their existence and the impact of their attitude in the case. Still, the method developed in this TRIBE project to map the behavioral data can be used for quantifying comfort and the satisfaction, as this thesis do. In this way, the thesis will develop an active occupancy engagement tool to maximize comfort and satisfaction to improve productivity.

4.2.3 Questionnaire Results

The questionnaire about AB1 was delivered online and answered by 164 participants. A total of 49 questions were asked and the estimated time to complete survey was 12 minutes. The questions and rating system used in the survey are same as that used for SCOLA building.
Similar five evaluation criteria have been applied to the responses. They are outlined below.

The general outlook the responses

1. 43% of participants are women, 57% total is men.
2. 80% of the participants are students and the rest are administrative and academic staff
3. 75% of the participants are in the age between 20-30-year-old, the other majority is 30-40, very few people above 40 and below 20-year-old.
4. In daytime, 31% of the participants which equals to 51 users spend their more than 5 h in their offices or study rooms whereas the 36% of the total participants spend their 3-5 h in classes. Also, 42% of participants spend their total daily life outside of the building in yard. The answers indicate 0-1 h in any location were neglected. According to the data of occupants' spending hours in which spaces of AB1 concentrated offices/study rooms, classes and the outside/yard of the building during the daytime (see Figure 23).
5. In the nights, there is no significant number of users spend their time at school, however, still a few of people spend 3-5 or more than 5 hours. There may be some academic staff (the range between 18% - 12%) remain at the campus until the late nights.
6. Those analysis show us the major responses of the survey is related to the three distinctive spaces: offices/study rooms, classes and the school yard. School yard is also very interesting study field because it is outdoor spaces includes different comfort parameters [63].

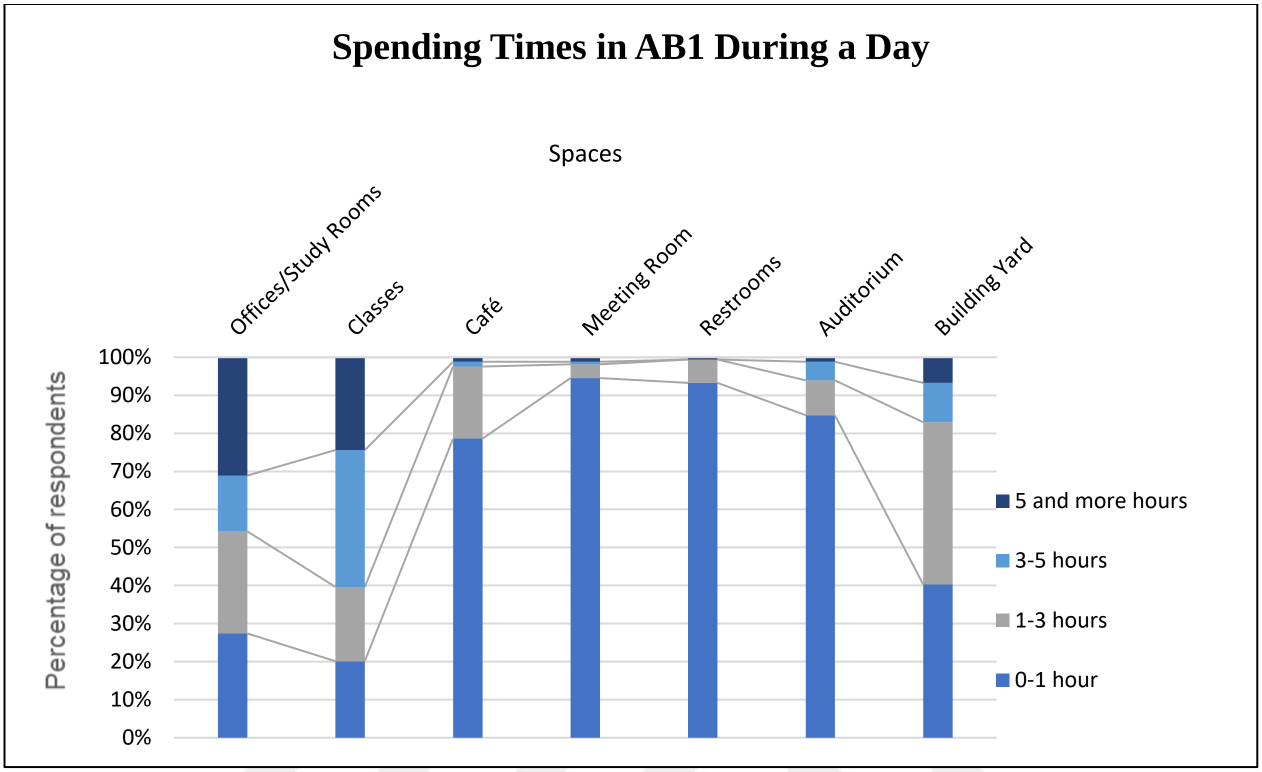


Figure 23: Occupation periods of different quarters of daytime in AB1

Evaluating Indoor Environmental Quality (IEQ) and its impact on users' performance

1. The indoor environmental quality (IEQ) in offices/study rooms was rated majorly in negative. About 11% of the responses was very bad, 20% was quite bad, 32% was bad rated as "3" out of 7, just 27% of the total responses was a little bit positive about IEQ that rated only "5" out of 7. The classes were rated quite better. 27% of the responses rated just as "3" out of 7 which can be considered only bad, 37% of the total responses rated "5" out of 7 that we may say better than offices/study rooms as presented in Figure 24. Therefore, majority of the responses are varying around the average, some converging to good while some to bad. This means the IEQ should still be improved. It is assumed that there are four IEQ factors which may influence performance of the people during the day where they spend their time at most.
2. According to the user responses, the most impactful factor is the temperature (Figure 25). More than 90% of the users agreed with the thermal comfort is very significant on their working performance and productivity. About 55% of respondents rated as this is

significantly impactful. According to the survey results, about 53% of total respondents do not think the temperature level is not comfortable in winters while majority of those think it is quite cold. On the other hand, 70% of total respondents think that the temperature of the summers is not the ideal for the users. About 44% of respondents decided that the indoor environment is hot than desired.

3. In winter time, the desired range for temperature of the indoor environment is 19-25°C according to the 73% of respondents. On the other hand, in summer times, almost half of the participants specify 14-19°C as desirable, whereas the other half of them still prefer the range between 19-25°C.
4. Another impactful factor on performance is air quality. 44% of the survey participants decided that air quality has very significant impact on their performance while 40% says also quite significant. In working hours, the respondents indicated that freshness of air reducing over the day time until 6 pm. The humidity was evaluated majorly in ideal level; however, the smell could be said as increased after the noon during the day. 65% of total users specified that the air circulation is not good enough. These data indicate the ventilation rate may not be sufficient and; air quality is associated with the temperature increase as well.
5. The third important comfort factor that influence working performance is visual comfort. 42% of total answers said that lighting level has a very significant impact on their performance while the other 42% said it has significantly affect their performance. 45% of ratings is negative about daylighting level. Yet, 38% of total answers is ideal as “4” out of 7 and 26% of total answers rated “3” out of 7 which converges ideal but still it is negative. 20% of total responses converges very inadequate. The glare discomfort depending on daylight has no significant effect on the occupants. Majority of discomfort may be related with the daylight level. The artificial light level seems also quite problem. 40% of the users decided the artificial light level is not good enough. However, glare-based discomfort is not the point again.
6. The last important factor which influences IEQ is the noise that less important than the other three factors on user’ performance. Only 34% of total respondents think that noise has very significant effect on their performance while working. Also, most of the users rated as there is no significant distraction from the noise inside or outside of the building.

7. As in SCOLA case, these all factors are analyzed and demonstrated in Figure 26 to show how user responses condense in which ranges.
8. In Figure 26, each coloumn specifies the critical parameters which affect the users' comfort in a building. The critical parameters derived from the four specific and measurable characteristics of a space: temperature, lighting, air quality and noise. Temperature performance of the building is evaluated for two different season as summer and winter. Lighting is also evaluated as daylight and artificial separately. Thus, it is possible to predict more accurately the reason of the dissatisfaction. The percentages specifies the number of respondents who participated the survey. Temperature is the most critical parameter which influences the human performance according to Figure 25. Second is air quality, third is lighting and noise is the least significant. The size of the circle visualizes the percentages to make it more observable the satisfaction rates.

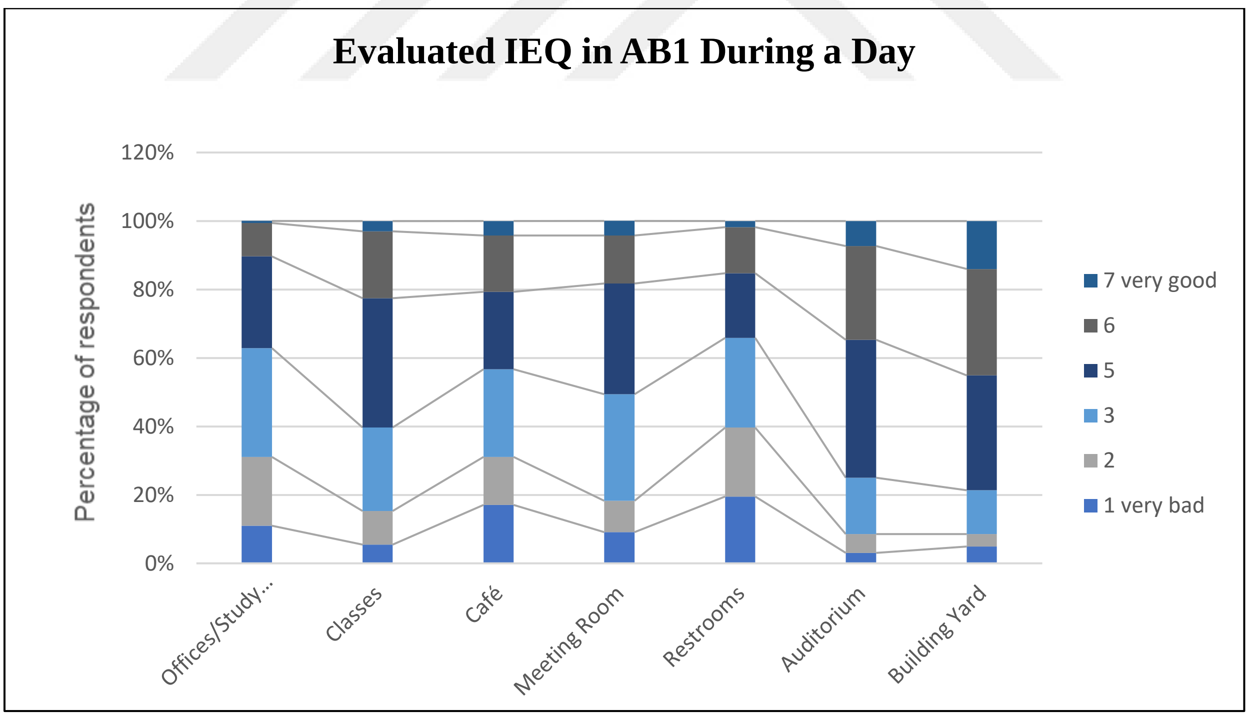


Figure 24: Evaluated indoor environment quality for AB1 during a day in AB1

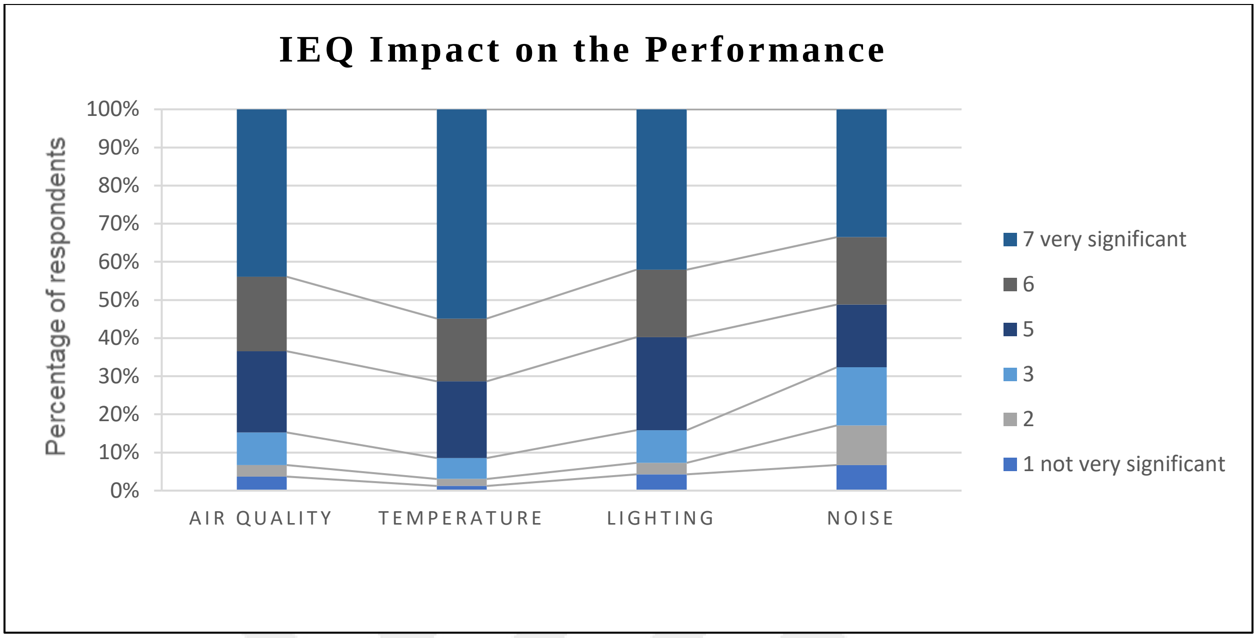


Figure 25: IEQ impact on users' performance in AB1

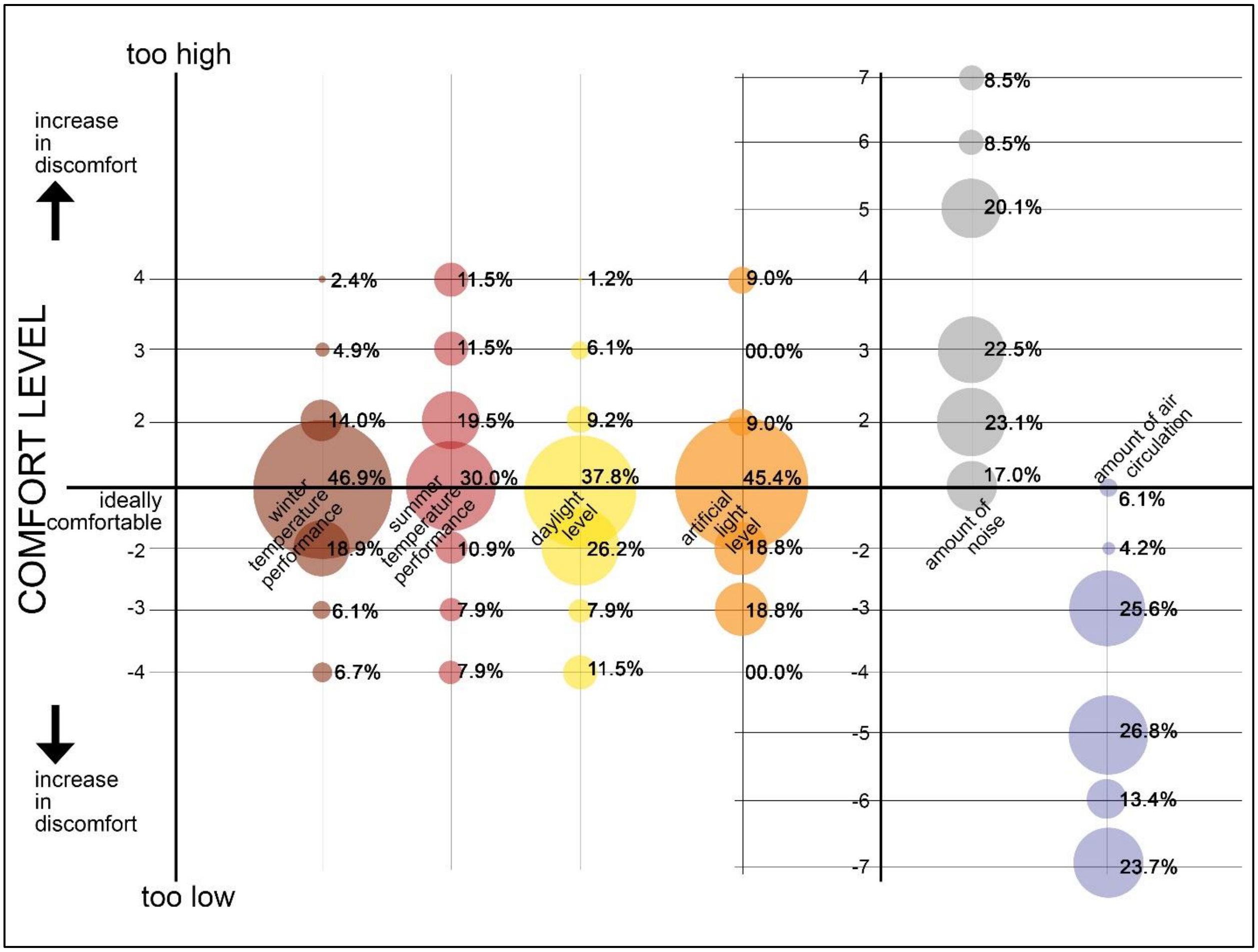


Figure 26: Measured comfort levels for important factors in AB1

The percentages specifies the number of respondents who participated the survey. And, the size of the circle visualizes the percentages to make it more observable the satisfaction rates.

Controllable systems and user behavior

1. For ventilation units, 56% of the users are not able to control the indoor conditions while just 2% of the total users have full control opportunity in their spaces. The rest has partially control on the units. The same picture may be seen on temperature and lighting as well. Only %2 of the total users can control the temperature level while 57% of them do not have any control unit. In lighting, only 23% have access to control even in artificial lighting. Those probably are the on/off lighting control because the rest specifies they do not have full control on lighting conditions.

2. The most adjustable elements in the buildings are very fundamental: doors, blinds and openable windows. Most of thermostats, ventilation equipments, shading devices or blowers are not allowed to be controlled. The adjustable lighting fixtures are majorly on/off switches and blinds (Figure 27).
3. Building occupants some special touches particularly on temperature, lighting and ventilation because they do not have full control on those services. Most of them prefer at least room specific adjustable system instead of building centered.

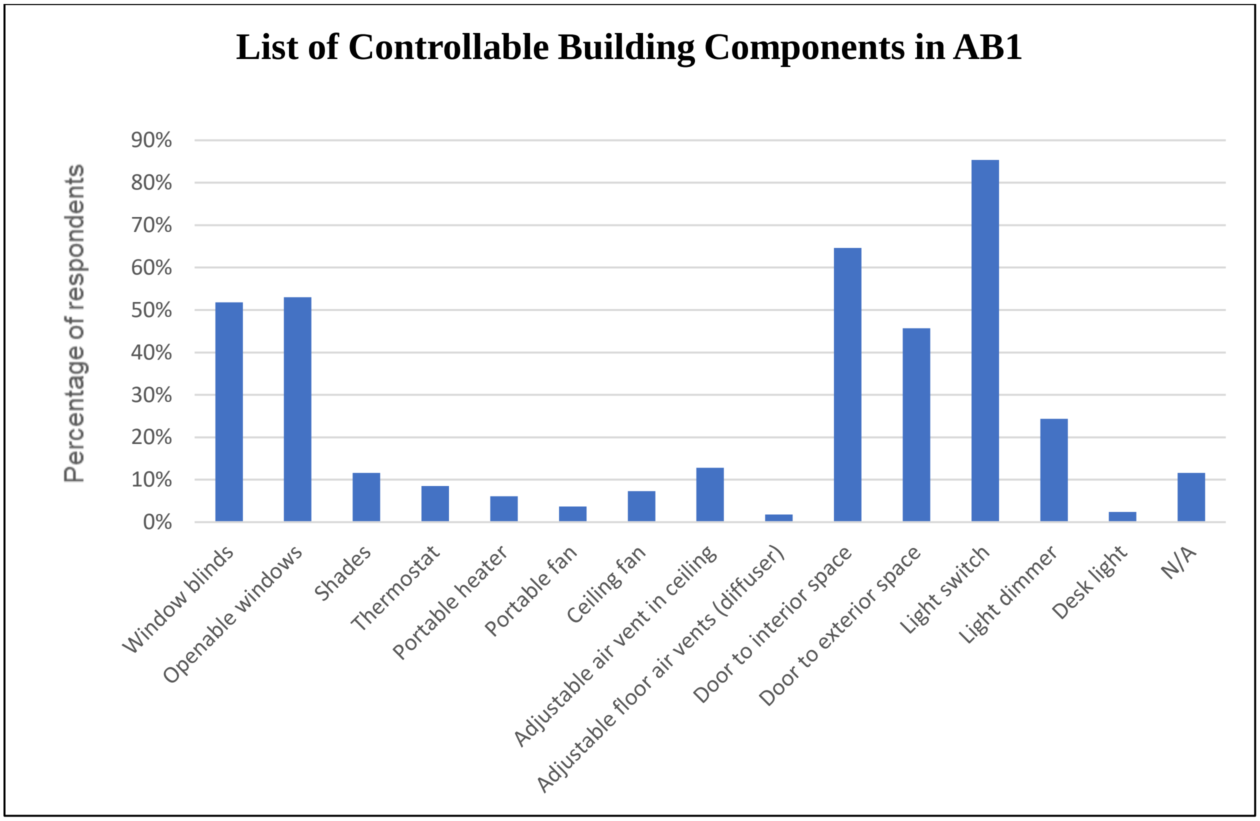
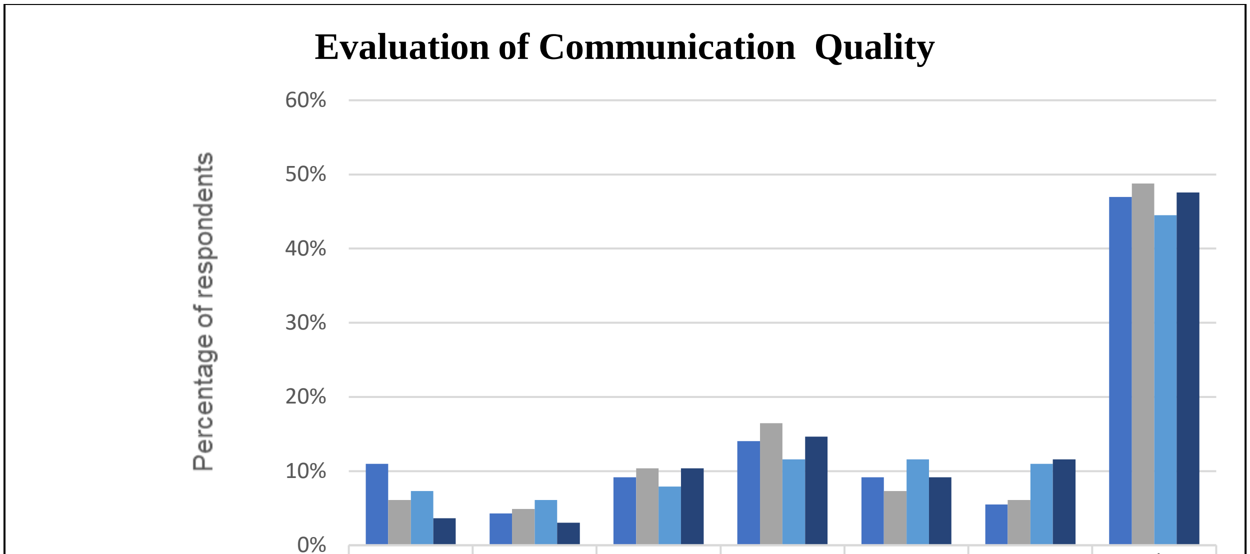


Figure 27: List of controllable building components in AB1

The controllable items are very significant because they allow people to adjust their spaces as they want. The respondents were asked to find out how many of them can control those components in their own spaces.

Communication between the users and facility managers

1. One of the most important issue for effective facility management services is to overcome the gap between the users and the service providers. 48% of AB1 users contact with the service providers when they experience uncomfortable environmental condition as summarized in Figure 28. 38% of them do nothing and continue with the inefficient work environments where only 18% may adjust their desired indoor environmental conditions.
2. Almost 50% of total people who contact to the service providers (28% of total respondents) evaluate the quality of service as above average. 47% of total respondents do not evaluate quality of service, probably, because they do not contact the FM specialists, or they are able to adjust their own environment. 11% of total respondents are very strict about the low quality of service where 23% are evaluates it as average. Only 5% of people are very satisfied with the quality of service.
3. The similar pattern is seen on the speed of service. Majority of the respondents evaluates the speed of service as average. Only 11% of the total respondents agree on the speed of service is long. 6% of the evaluators are very satisfied with the speed of service.
4. Most of the users evaluates the easiness of the communication as above the average while 11% of total says they can reach the service providers very easily. Only 7% of total evaluates as very difficult to recognize and communicate with the service providers.
5. Most of the users evaluate quality of communication as above the average. Only 4% of the respondents say that there is an understanding gap between service providers and them. 25% of total evaluated in average while 12% believes the service providers can understand their needs and demands very well.
6. According to the survey, the most desired channel to communicate with the service providers is mobile app with 37%. E-mail method is chosen with 34% behind the app.



	1 negative	2	3	5	6	7 positive	N/A
Quality of service	11.0%	4.3%	9.2%	14.0%	9.2%	5.5%	47.0%
Speed of service	6.1%	4.9%	10.4%	16.5%	7.3%	6.1%	48.8%
Easiness of communication	7.3%	6.1%	7.9%	11.6%	11.6%	11.0%	44.5%
Quality of communication	3.7%	3.1%	10.4%	14.6%	9.2%	11.6%	47.6%

Figure 28: Measuring efficiency of communication between the FM leaders and the occupants at the campus in AB1

Energy concerns of the users

1. More than half of the users do not control their own energy bills. Around 41% of the respondents which is the percentage of people who take their own bills usually prefer to use paper bills. Only 23% of the respondents prefer digital bills like e-mail, mobile or website.
2. When we ask how often they would prefer to control their energy consumption, the responses concentrated on weekly check with 47%. 30% of the respondents would prefer to see their daily energy habits as well.
3. People also majorly prefer to see energy consumption/person and their share on the climate change to perceive building energy performance.

4.3 AB4 As A New Building

4.3.1 Documentation Results

The third case considered in this thesis is a New Building which is called Academic Building 4 (AB4). It is still in progress of planning and design and will be used to analyze the contribution of FM leaders in early phases to develop an integrated and visionary management model. Currently, the technical details of the project are not sharable, however, the impact of early contribution of FM leaders may be measurable by the interviews.

4.4 Interview Results

The interview results are analyzed according to six important requirements shown in Table 3. The interviews are conducted with two important actors in FM: The director of technical services and The Director of HSE. The main objective of these interviews is to discuss the requirements for integrated FM strategy from the perspective of service providers.

The first requirement is effective collaboration. The interview results show several teams should be involved into the process to be managed effectively. Survey results prove that the solutions necessitate to have collaborative work.

The second requirement is the business unit strategy. HSE or any other teams have their own strategic goals and ways of working. They follow different standards even if there have same objectives. Yet, these strategies should intersect in the line of corporate strategy.

Corporate strategy always emphasizes the productivity of their employers and its profitability. At business level, optimization of occupant satisfaction and cost is one of the major goals for each unit.

	Director of Technical Services	Director of HSE
Most collaborated departments	Purchasing, Financial Affairs, HSE and Administrative Affairs, CEEE	Administrative operations, purchasing, technical services and information technology team (IT).
Business unit strategy	Proactive, always in the site, preventive, corrective and monitoring by automation	Follow the certificates ISO 14001 and OHSAS 18001 procedures and requirements. Always in the site, preventive and corrective.
Strategy from business to corporate	Increase in user satisfaction turns it back as prestige. Increase in quality of students selected from university entrance exam.	Operational efficiency contributes the quality. HSE is a loss prevention unit. It contributes to cost reducing.
Communication	**With users:** Solution Center No systematic feedback collection **Internally:** WhatsApp and face to face	**With users:** Solution Center and face to face No systematic feedback collection **Internally:** WhatsApp and face to face
Cost management	Heating / cooling and electricity consumption	Mobility and cleaning because of the high number of staffs.
Future vision	If the owner and the operation are the same sources, the total cost of whole building cycle is managed more effective. Giving feedback to D&C based on experienced some users' habits.	Risk analysis is conducted, and feedback is given to avoid risks.

Table 3: Summary of interviews based on six important factors

The forth important requirement is the quality of communications. Participants of the communication network may be categorized in two different groups; users and other stakeholders. Other stakeholders may include their own team members or other teams. In the case studies located at Özyeğin University, "Solution Center" is the only channel to communicate with the users. This channel is used to collect their demands and solve them. Then, the users can rate the quality of service. The web tool may be useful to benchmark user desires and assess the quality of service as well as measuring the performance of the service providers. However, it is just used for corrective strategy. Also, the researches show that there is a serious communication gap between the users and the service providers as presented in Section 4.6. This thesis aims to figure out a new way of communication and managing data for users desires to achieve continuous operational loop. For this reason, we focus on communication factor and response measuring model in text Chapter to achieve occupant oriented circular operational model.

Another important requirement is the cost management. Electricity consumption is major costly item. Therefore, the energy consumption should also be optimized while considering the occupants.

The last important requirement is the "future vision". If the user behavior models are patterned and experienced by the service providers, the knowledge may be transferred to the D&C phases to reduce operational cost and user complaints in future.

The cumulative outputs based on surveys, interviews and the documents will be displayed in under the division 4.8 Research Outcomes and applied to a new model in next Chapter.

4.5 Cross Case Comparison and Application of Conceptual Framework

The cases conducted in this study are compared in Figure 29 based on observations from the cumulative professional experience gained at CEEE, case documentations and based on the literature review.

The case studies are applied to the conceptual framework to generate a clear gap analysis. The studies show us the building operation is proceeded in linear pattern for all three cases. Even if these cases involve user feedbacks, it is still combination of corrective and preventive maintenance. The majority of the works are to increase energy performance of the buildings and the campus. According to the case comparison results, the conceptual framework represented in

Chapter III (in Figure 10) was implemented into case studies to reveal the gaps and recommend an integrated approach involves the whole life cycle process. The implementation of case studies to the framework is shown in Figure 30.

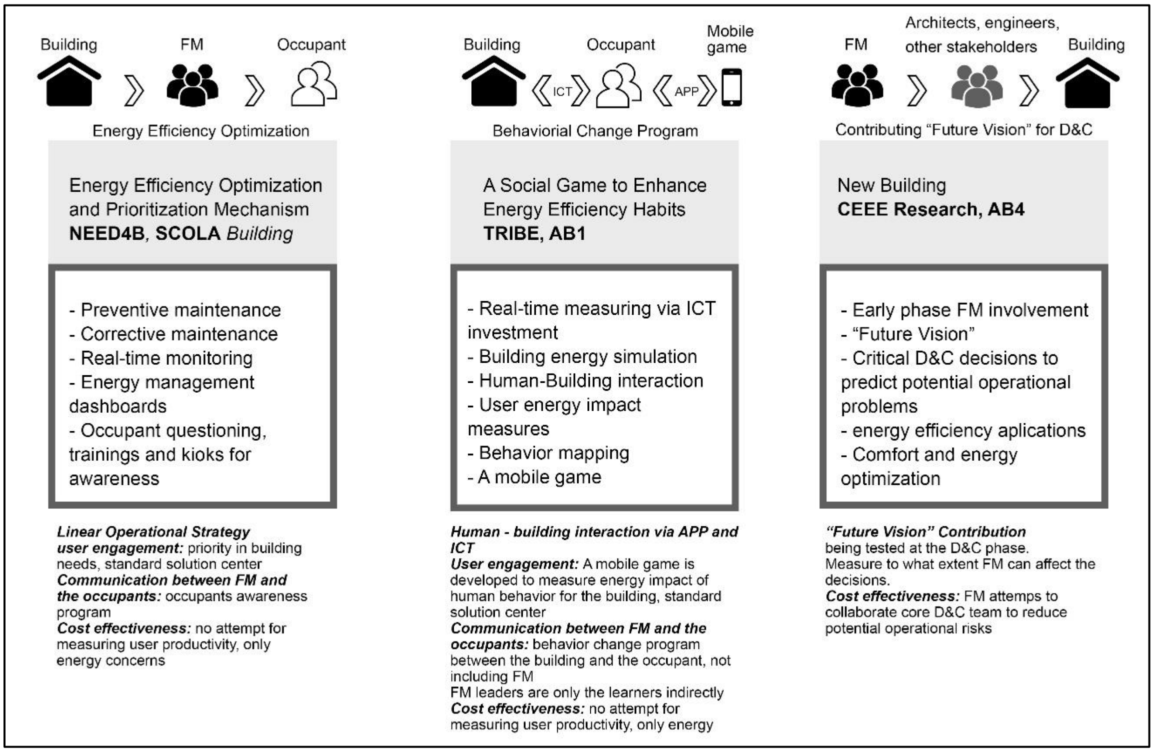


Figure 29: Summary of cross case comparison of there buildings, SCOLA, AB1 and AB4.

The first case building, SCOLA with NEED4B Project, majorly focus on integrated and collaborative handover process with effective prioritization and optimization strategy. The major aim is to quantify the quality of innovative design and construction strategy by real-time energy monitoring system and a dashboard to follow up the energy performance of the building. There are diverse applications like interactive workshops, periodic questionings and kiosks to increase occupant engagement into the process, however, the intent is only to create energy efficiency awareness. The linearity of the operation is an expected strategy whereas the lack of active user engagement.

In AB1, the LEED certified building, a mobile game project is applied to measure user behaviors and habits for energy concern. Still there is not any effective user engagement into facility operation even if activating this mobile game. The game enables to detect user decisions corresponding to the energy and environmental conditions in their spaces. At the end, users may realize their energy impact in that building and compare their friends. Yet, the project is not designed to create communication channel between the users and the service providers even though the project helps to recognize the users' attitudes. It still just concerns to improve the building energy performance by engaging occupants into the process. The project only contributes to FM leaders to understand user responses better in energy efficiency.

The third case, AB4, is selected because it can validate FM contribution in early phases to increase comfort level and well-being while decreasing operational costs in future. The interviews with the FM specialist prove that either technical services or health-safety-environment teams actively engaging to the design and construction phases. The director of technical services says *"I, personally involved in construction process of this all campus. I experienced many operational faults coming from the D&C decisions. Now, we involved in the new building D&C process working with CEEE to work on energy as well as comfort. We also collaborate current academic staff. For example, research members majorly demand heating/cooling system for out of administrative working hours. Then we plan room based controllable heating/cooling equipment as initial investment for their spaces and collaborated architects/engineers. Thus, our operational cost will be decreasing. We experienced some users' interventions during the years; i.e. opening the windows even if the indoor air quality at normal level. So, we recommend all the windows of the offices openable. In conclusion, I believe that if the owner and the operation are the same sources, the total cost of whole building cycle is managed more effective".* (Director of Technical Services)

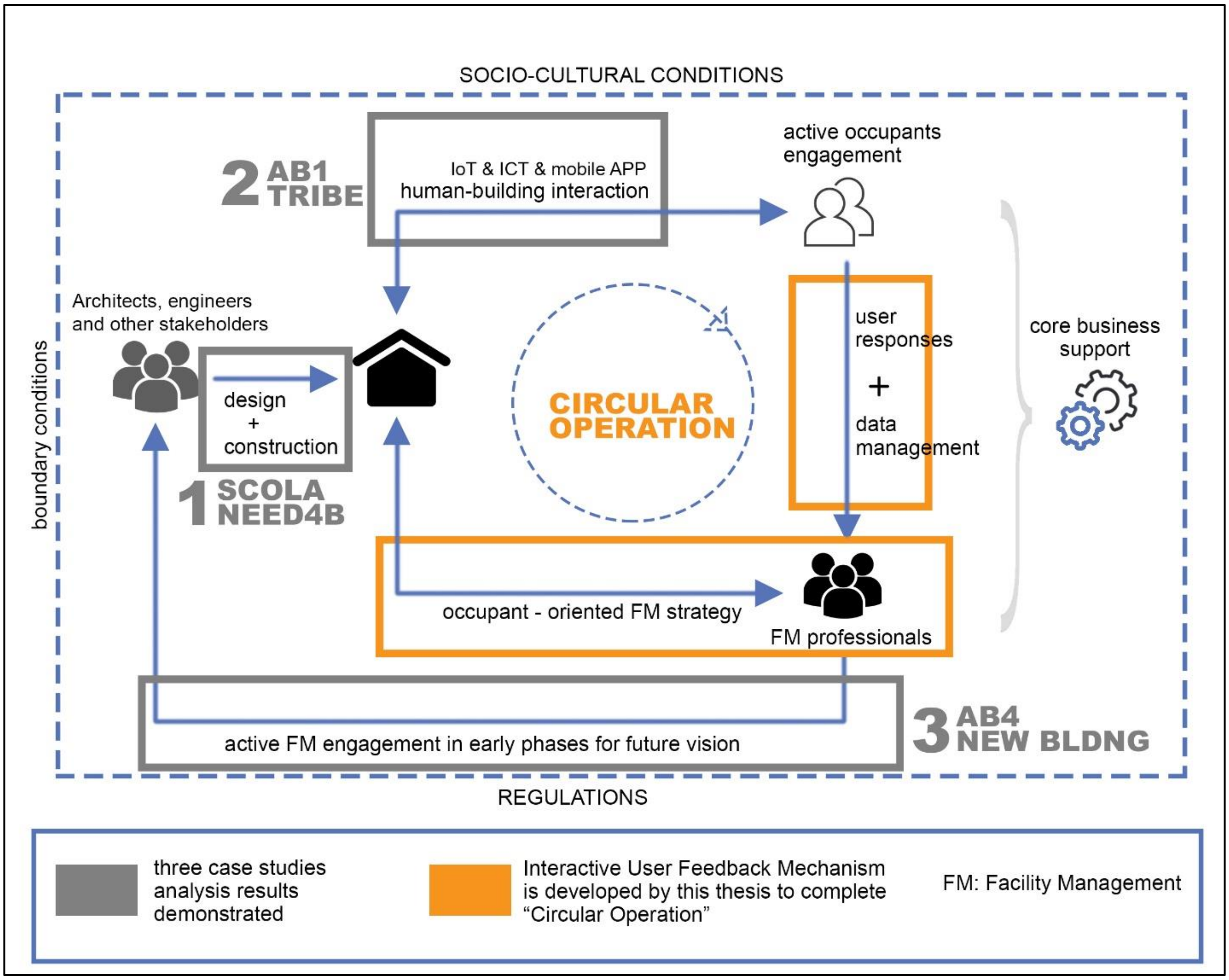


Figure 30: Applied conceptual framework for three cases and complete circular model

To complete circular operation in a facility an active user engagement model with transdisciplinary approach must be coupled. A user demand response program to implement into whole life cycle of the building is developed here. It is detailed in Chapter V as "Interactive User Feedback Mechanism". This mechanism intends a systematic data collection from the users and to convert them into meaningful analytics. Those analytics will be implemented into the FM strategy to achieve cost effective and occupant-oriented model which supports core business profitability with increase in occupant productivity. The scope of the work is presented by orange rectangular frames on conceptual framework in Figure 30.

4.6 Gap Analysis

Gap analysis is generated as a result of combining interviews, individual surveys and the documentation. Gap analysis is used for diagnostics to figure out the way of solution in user engagement model (see in Figure 31).

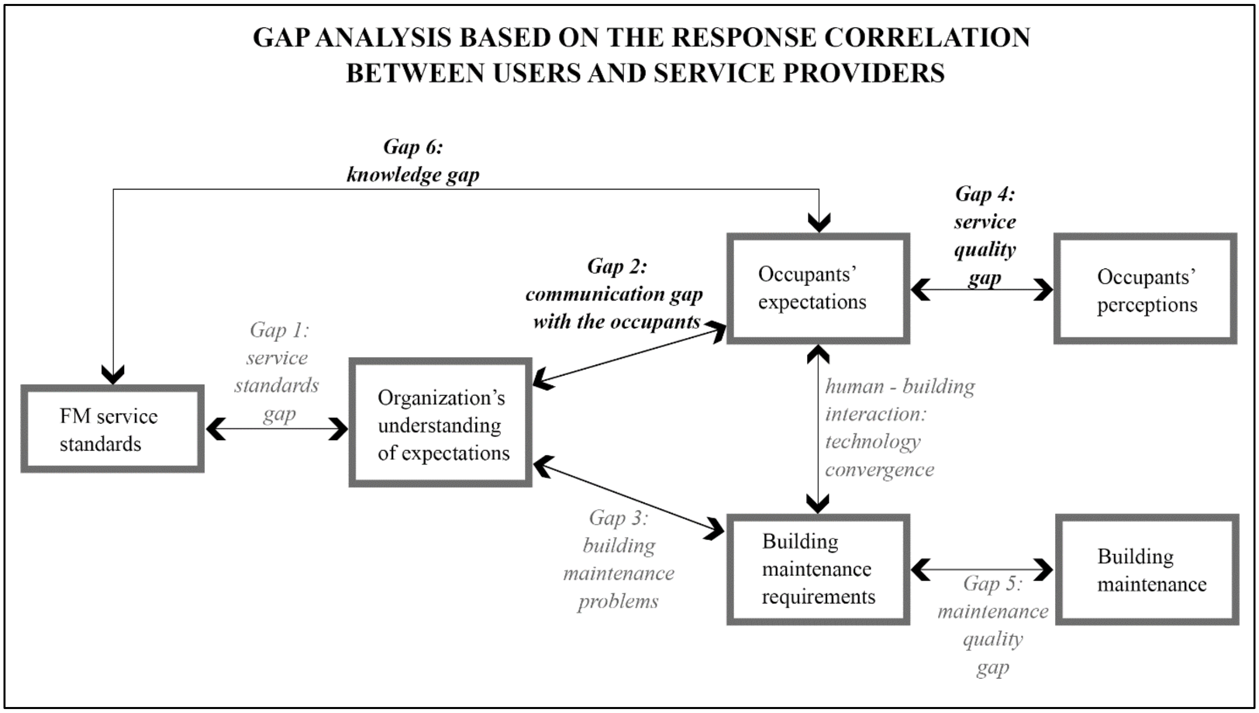


Figure 31: Gap analysis based on interviews, surveys and the documentations

Universal codes and standards usually determine the service standards of organization and user demands, yet, the codes do not truly represent user expectations. The campus operation, including both cases SCOLA and AB1, is certified with ISO 14001 and OHSAS 18001, and respects the ASHRAE standards for high occupancy comfort. AB1 has also LEED Gold certificate to prove its energy efficiency. However, the expectations are completely different from the codes and standards. This is the reason of "service standards gap" which is called *Gap 1*.

Gap 2 defines the difference between the expectations and the understanding of expectations. This is called "communication gap" with the users because the gap arises from lack of active feedback mechanism for users. The gap between occupants' expectations and the service providers' understanding of expectations is the most crucial one. This gap can be only explained by behavior models. If user behavior models are quantified by service providers, the understanding level raises, and gap can be overcome. Insufficient communication techniques with the users in a building lead low service quality and dissatisfaction. *Gap 2* also causes the absence of knowledge of high quality operation to transfer D&C phase. For this reason, the priority of this thesis to suggest a solution to overcome communication gap between the users and the service providers.

The forth gap (*Gap 4*) is between the users' expectations and perception which may be called service quality gap. The reason of this gap is a series of shortfalls within the service provider organization [64]. The service providers may ignore the actual needs and demands of the users because of low cost strategy and any prioritization strategy different from the occupants. Improving the quality of service can only be possible by correcting "communication gap".

On the other hand, there is a difference between understanding of service providers and the requirements of maintenance of a building. This may cause building maintenance problems *(Gap 3)* because of shortfalls of the organization. These may be about the service providers cannot predict the potential failures, or they have planning problems. Another issue that the maintenance requirements of a building are not sometimes satisfied by the service providers (*Gap 5*). The reason may be the low-cost strategy or technological problems.

Sometimes, building maintenance requirements and the occupants' expectations converges under low IEQ. Thus, the Gap 2 and Gap 3 sometimes show parallel trends. In recent years, well optimized and expanded automation systems can detect the any change of a building condition and low quality to be interfered by the service providers. IoT and ICT applications enable to measure and monitor real-time values of a space. These new technologies narrow the gap down for building and help for human interaction with the building.

There are deficiencies between the occupants' expectations and the determined standards and thresholds for their comfort in a space. It is called as "Knowledge Gap" (*Gap 6*). The gap is narrowed down by reforming "communication gap" and transferring experienced knowledge to D&C phases. "*Future Vision*" is studied in this thesis to overcome the knowledge gap for efficient building operation. This progress also improves the standards, thresholds and certifications.

As a result, as shown at the bottom of Figure 31, “communication gap”, “service quality gap” and “knowledge gap” (Gap 2, Gap 4 and Gap 6) are the essential points of the circular operation flow. If the users’ behaviors are modeled and used effectively in operational phase, this information can be utilized to dissolve “communication gap”. To the extent that, “service quality gap” and “knowledge gap” are dissolved. Hence, this thesis introduces an interactive user feedback tool in next Chapter to collect systematically human demand responses and data management as a preliminary approach for quantifying behavior.

4.7 Discussions and Results

The multiple cases are analyzed to measure user perception and satisfaction while non-case specific interviews are conducted by the service providers to measure the quality of operation from the perspective of FM contributors. The cases are evaluated and compared based on the records and archives. Then, the individual responses and the interviews are conducted. The outcome is presented as “gap analysis” regarding the correlation of interviews, the case studies and surveys. Gap analysis explains what the major reason of the low quality of FM service is and why we need to quantify users’ behavior. Gap analysis are produced as a reason of circular operational strategy and interactive user feedback tool (See Chapter V).

Based on the study, the general outcomes can be summarized as;

1. One major outcome is that the general FM strategy in case studies are linear and there is not any systematic feedback mechanism that helps to observe users’ behavior.
2. The major concern in the strategy is trading-off between energy efficiency and comfort. User satisfaction should be optimized with the energy efficiency solutions in the cases.
3. For example, there is a south oriented room, and occupants complains about the high temperatures because of full transparent façade. Solution is to increase the power of the air conditioning and cool the place down, however, this will increase the energy consumption. Instead, an optimizer may calculate the cost and benefit of a shading device to reduce the energy consumption and increase the comfort. The only solution may not be the air conditioner.

4. Even though small technical differences and same operational strategy in the case buildings, the user responses are quite different in comfort and IEQ. Figure 20 and Figure 26 show the difference in user comfort in their case buildings. We may say the comfort level differences may be caused because of the design principles as well as demographic structure.
5. In both cases, the users agree on the room specific controllable systems instead of centered adjustable systems. However, in AB1 building, almost %50 of the respondents ignore to communicate with the service providers. We can say there is a significant communication gap. In SCOLA, the communication gap is less than AB1. The participants of the SCOLA survey are 100% staff. However, in AB1, 80% of them are student, that proves the gap between the students and the FM leaders. Thus, we can say that we need to find a solution to encourage the student to communicate with the service providers in efficient way. Gamification may be an attractive strategy for the students.
6. The interviews are conducted non-case specific. As a result, they believe that facility management is a collaborative work including information technologies (IT), health-safety and environment (HSE), technical services, human resources (HR), finance and operation manager.
7. The interviewees agree on their impact on D&C phase to improve operational service quality. The both interviewees are engaging and contributing the third case building (AB4) based on their experiences.
8. The case studies prove that most of the attempts are beneficial for user awareness, increase energy efficiency and reduce the cost.

In next Chapter, the research establishes an interactive user-friendly tool which enable to collect user behavior data. This data is converted to meaningful analytics to be executed by facility managers as well as owners. Not the code but the logic behind the tool has been developed by collecting meaningful data from the users. In this way, it is possible to achieve maximum comfort index based on the continuous responses corresponding to the specific indoor environmental conditions in a specific area.

CHAPTER V

AN INTERACTIVE FEEDBACK MECHANISM FOR CIRCULAR FACILITY MANAGEMENT STRATEGY

This Chapter introduces an iterative approach for a systematic user feedback mechanism to achieve a “Occupant-oriented Circular Facility Management Strategy” based on the measures of user expectations and perceptions for specific case buildings, and understandings of service providers in all the campus. This strategy will shift the decision making to the actual users where the service providers are only the executives and control authority.

The main objective of the strategy is to solve communication problem between the students and the FM people. For that reason, the strategy requires an interactive feedback tool and a mobile interface to collect the behavioral data systematically. As a preliminary approach for visualize the behavior models with an interactive feedback mechanism intends to achieve a circular operation initiating by the actual users, data transferring to the FM leaders and improving the building. Then, the loop continues with the users’ feedback consistently.

In this Chapter, first we will discuss what the three pillars of Circular FM Strategy. The relation of the FM providers, occupants and building are depicted in Figure 32 and discussed in Section 5.1.

Later in Figure 33, we will discuss a new interactive feedback tool of the Circular Facility Management Strategy as came out of this thesis. The details of the tool are summarized once more in Section 5.2. And then, we show an example case in Figure 34 for one of the buildings at Özyeğin University.

5.1 Towards Circular Operation

In buildings, focusing circular operation and the maintenance of the building is a new challenge for its users who seek comfortable environment as well as owners who pay the building.

The objective of the circular movement is to develop an occupant – oriented FM strategy. The conceptual three pillars circular model presented in Figure 32. According to the conceptual framework, occupants follow typical behavior models in the building and give systematic feedbacks. The feedbacks may be used by the service providers to execute the desired environmental conditions in the building. If the feedbacks are converted to meaningful data analytics and managed effectively by the service providers, the embedded technologies can easily control the building. This is a continuous loop based on interactive user feedback mechanism which is expected to converge 100% comfort index in time.

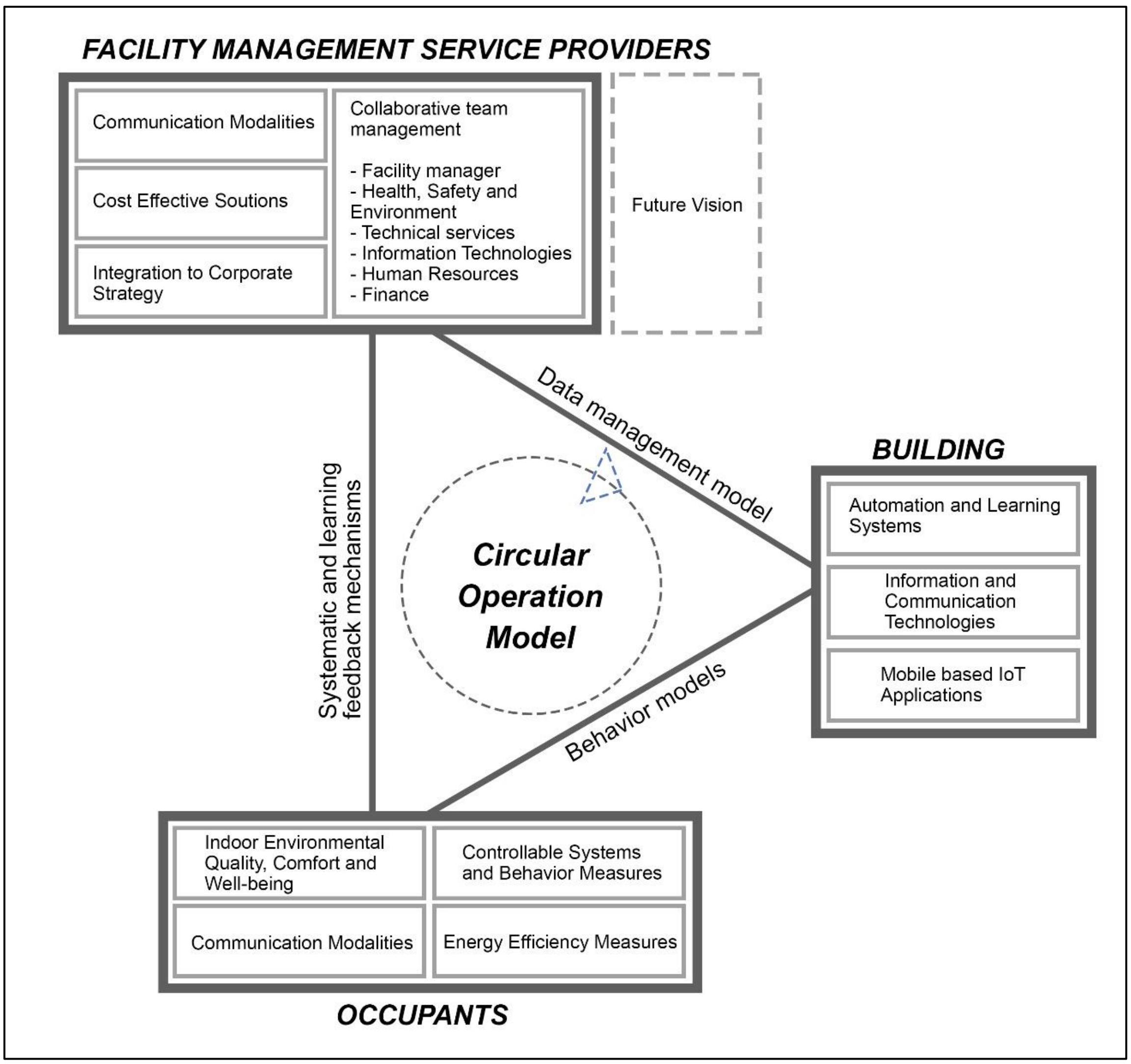


Figure 32: Three pillars of circular operation in buildings required for continous loop.

The circular model is constructed between three pillars with their specific requirements; 1) service providers, 2) occupants and 3) the building. The requirements are identified based on the previous studies which are literature reviews, surveys, interviews and the archives.

1- *Facility Management Service Providers:* The new model describes the FM service providers as the executives who are responsible for sustaining environmentally comfortable conditions for users.

   There are five critical requirements for an effective FM strategy from the perspective of service providers. These are;

   a. Facility management service requires a collaborative team working with quite different departments which are Health, Safety and Environment, technical services, Information technologies, human resources and finance. Facility manager is responsible for coordinating through entire departments.

   b. Communication modality is another critical factor among the collaborative team members. Internal communication network among the teams entirely affect the quality of service.

   c. Cost is one of the most critical issue for the FM team as well as the owner. The demands and needs always should be cost optimized to foresee the alternative solutions and the benefits.

   d. The FM strategy in business level as a part of the corporate strategy which will support the profitability of the core business. The occupant oriented circular operation strategy influences the corporate objectives and profitability by loss prevention.

   e. Future Vision is the last parameter which influence operational quality of the building depending on the D&C decisions. If the previous user data is managed effectively by the FM leaders and transferred to the next projects, occupant-oriented circular strategy may be applied starting from the ideation phase of the project. Therefore, the operational costs may be minimized by the user centered building design.

2- *Building:* for the success of the circular operational strategy, building should be studied in detail with its environment where the users spend most of their times during the day. The new generation of buildings are different from the past. They are donated with many high-tech devices allowing them to understand the demands and feelings of the occupants. Also, they are controllable and learning involvements in our habits.

The three significant requirements from a building in the circular strategy may be determined as;

a. In recent years, automation system became essential in the complex buildings because of the necessity of the monitoring, remote control and corrective maintenance of the costly devices. The energy efficiency concerns also became highly priority in recent years. Automation is a cost-effective way to control energy consumption in accordance with the space requirements. The learning systems are quire new and rarely seen. To run a learning system linking to the automation, a logic and vision should be designed beyond the computational coding and algorithm. In buildings, a utilizable learning system can only be applicable with a user behavior models behand it. The data collected by mobile applications or sensors can only be converted to meaningful analytics by correlating behavior measures.
b. Information and communication technologies (ICT) enable the users to interact with the building via sensors, network infrastructure, measurement devices, thermostats…etc. ICT as a data collector is a must for automation and learning systems.
c. Mobile based IoT applications are the new generation communication tools between the users and the devices. Now, IoT applications can understand your feelings, collect your demands and convey to the data center. Therefore, IoT applications are key elements to measure behavior models.

3- *Occupants:* They are the most important factor in the context. In the circular system, occupants are the most weighted decision makers. User behavior patterns regarding to the building conditions are transferred to control center as meaningful data and executed by the FM professionals.

There are four important occupant factors;

a. Occupants productivity in an office environment is mostly associated with their comfort and well-being regarding to the indoor environmental quality. Comfort and well-being is directly influence the occupants' motivation and productivity, at the result, it influences entire profitability.

b. Comfort and well-being demands are mostly trade-off with the energy efficiency decisions. Yet, owner who pay the building and the facility managers concern the financial losses and should optimize the energy consumption and the comfort. In the circular operation strategy, the tool aims to gain energy awareness and change habits while adjusting their comfort standards.

c. Communication is the challenge for the occupants when they want to convey their problems to the service providers. The major obstacle is the difference between the user expectations and the understanding of the facility managers. The circular operation strategy which puts the occupant to the center suggests a simple modality to transfer the user demands to the FM leaders. The modality is based on yes/no cross-questionings to transfer the data into the 1-0 data. The data can be utilized by the facility managers and the automation and learning systems (Section 5.2 and Figure 34).

d. The last important factor is the controllable devices and the behavior models. These are the part of the building ICT implementations and used for defining human behavior patterns. User behaviors and their impact can be recorded and measured by the controlled devices and transferred to the screen.

5.2 Interactive User Feedback Tool

The objective of the tool is to converge maximum comfort index depending on the user responses. The tool which is a product runs the three joint lines interconnect the three pillars represented in Figure 32. The tool is expected to lead a disruptive business model in FM and operation sector by transforming the business more transparent and bringing it closer to the actual customers.

The comfort index which is used by this tool is defined as the relation between the total of comfort for a specific space and number of respondents. The index changes statically regarding number of responses which are given as "comfortable" or "not comfortable". The total comfort can be defined as sum of the responses.

The idea behind the tool runs with a simple logic. An integrated technology which is embedded in the building enable to measure the users desires directly, convert them into the meaningful analytics and make the building response. On the other hand, the data is statistically stored to achieve a learning system in buildings. Those statistical data can be installed in future in another building.

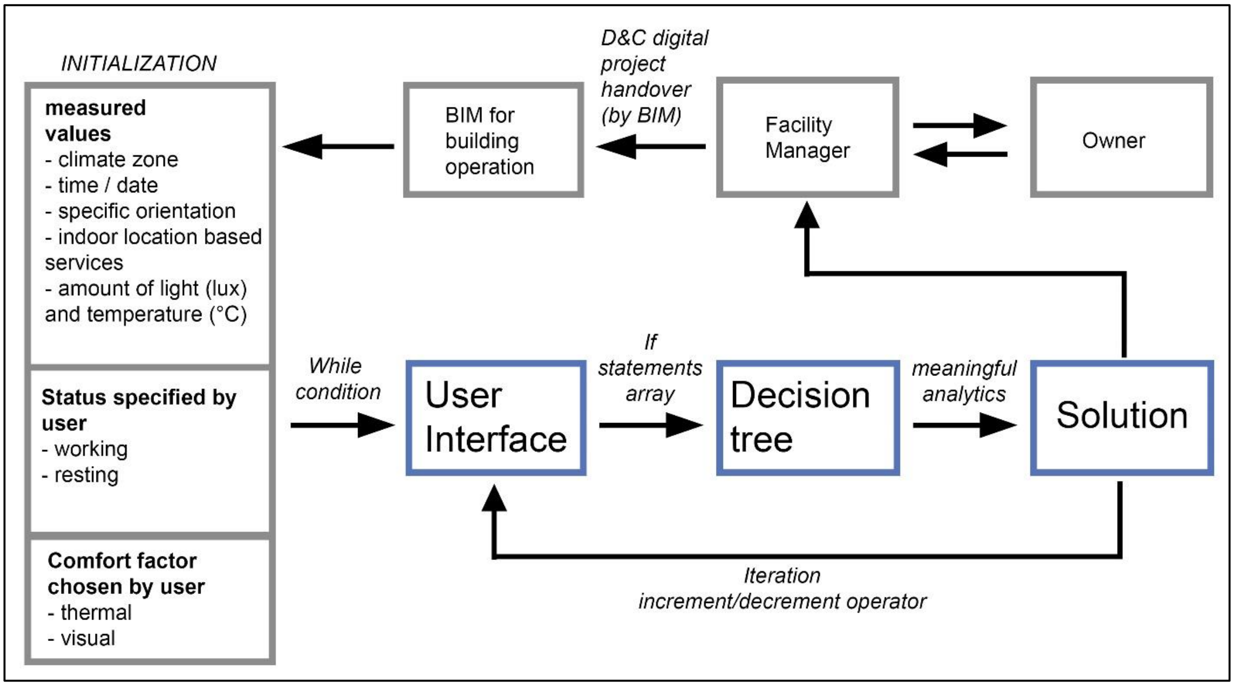


Figure 33: Conceptual flow chart of the interactive user feedback mechanism

The tool aims to make the process more digitized and more user centered. With this strategy the building does not behave with the command of facility managers. Instead, the decision makers are the actual users now on whilst the facility managers are the executives and the control authority. The tool will be delivered to the user by a mobile interface to evaluate their comfort index based on your experiences. The conceptual flow chart presented in Figure 34. The base data comes from the digital model of the facility created by BIM tools in the design and construction (D&C) phase and the measured values by the ICT infrastructure. The environmental conditions like the climate zone, time and date taken by location coordinates are specified in digital handovers. On the other hand, the measured values of light (lux) and the temperature (°C) are based on the resolution of predicting location. Although accuracy of location-based services have some challenges for indoor environments and localization technologies address the inefficiency of GPS (Global Positioning System), there are some available technologies for positioning with high accuracy such as Wireless Local Area Networks (WLAN) with 2-4 m and Bluetooth low energy (BLE) services with 2-5 m [65].

Additionally, the information about the status of the user and his/her comfort factor. For example, the status can be specified as working or resting, and thermal comfort factor can be chosen to be evaluated. According to the input base data, the user is taken in a loop and asked with a sequence of questions to be responded as like “yes” or “no”, “hot” or “cold”. The responses lead a choices map with the “if statements” to generate a solution. The solution may be operated by the building automation and learning systems directly. Then, the new spatial conditions are obtained, the loop starts for the new conditions.

The loop always starts with the question “are you comfortable now?”. When the answer is “yes”, the user exists from the loop and his/her answer contributes to the comfort index in positive. While increasing the number of the responses as “yes”, the comfort index converges to the 100%, yet it never reaches to 100% for that space and the users.

On the other hand, if the condition starts with “no” for that question, a group of questions as “if statements” follows. The “if conditions” are expected to be answered true-false statements. Then, the flow continues until reaching the maximum comfortable conditions which is out of the loop when the while condition is answered as “yes”. In this way, the incremental data will be collected and managed easily by the learning system as well as automation.

The one limitation in this algorithm and the technology “while conditions” go to infinity, therefore may be boring for the participants. The loop can be expanded by many breaks for various conditions. For example, unless the second iteration starts with the new conditions, the loop must be broken, and warning must drop down to the facility managers for corrective maintenance on heating, ventilation and air conditioning (HVAC) system.

One simple system is presented in Figure 34 to make it more understandable. Demand based mobile application logic is developed to engage the users of the buildings into the operation for more comfortable environments. In this example, initial conditions are determined by the measured values and the digital handouts. Those conditions demonstrated on the user interface of the application. If the response is stated as uncomfortable for the base conditions the while loop starts and if questions are asked to the user one by one. If statements can be extended to obtain details about the feelings. However, the number of questions and the sequence should be user friendly and not boring. Therefore, the number of the questions should be limited either way.

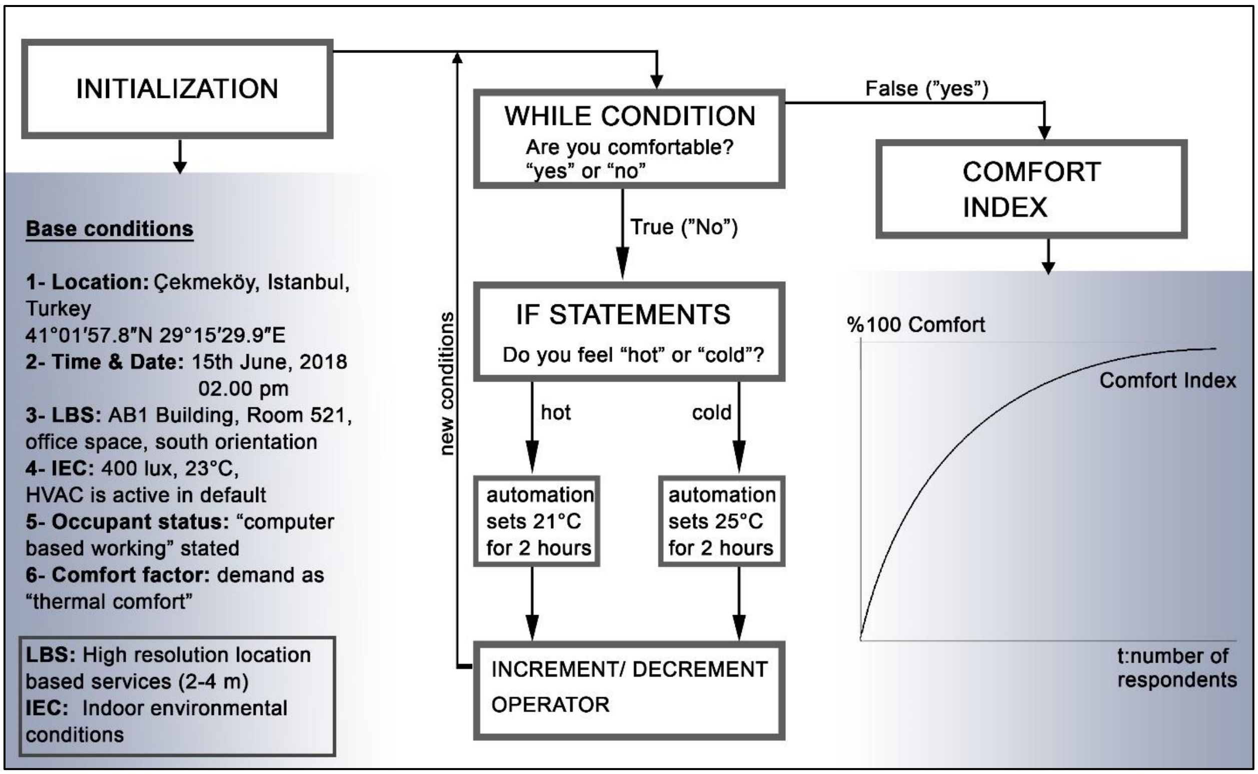


Figure 34: A simple system presentation for thermal comfort problem in an office environment

As an example (in Figure 34), the feedback system runs for improving thermal comfort index and only askes one question in the loop. The system is designed at 2°C increments or decrements for 2 hours operational tests. Then, the loop continues with the new conditions. If the while condition is answered as false which means "yes, I am comfortable", the system exits from the loop and the temperature level contributes to the thermal comfort index for that location, time, date and status. Comfort index is determined by the increase of the responses and produce a statistical data corresponding to the condition. Comfort index always converges 100% of comfort by increasing number of the respondents, yet, it never reaches 100%.

The similar examples can be derived for the different conditions. The application is designed for limited conditions and parameters for now just to simplify the complex system. For example, the application is just to control comfort factor in lighting and thermal conditions in an office environment. The status of the occupants can be diversified as "working" or "resting". Only one "if statement" is analyzed in the example to reach the solution easily. The most important approach in this system, users' choices in other words their demands and feelings can be mapped by the yes/no questions and easily converted to the analytics, yet, the system should be adapted a strategy to make it friendly, appealing and desirable for the users.

At the result, a large amount of data will be collected to be used in operational activities as well as to integrate to the D&C phases in building sector. The data will be generated as "true or false" and contribute to the 'big data' applications, eventually. With such an approach, the responses become specific and very significant to predict the desired environmental conditions of the users even if the indoor environmental control mechanism is not easily adaptable for the interactive feedback tool at first.

5.3 Discussions and Results

The conceptual framework which is presented in Figure 32 shows that the three pillars of the circular operation model. According to this model, users are the only decision makers where the facility managers are the executers and the controllers. The building itself represents the data center. The important thing is here to suggest a solution for the connection lines which are systematic feedback mechanism, data management and behavior models. If the behavior models regarding to the building is quantified by a systematic feedback mechanism, the data can be operable by the automation systems and the facility managers.

For all that, an interactive user feedback tool has been developed to collect the data regarding users' desires and the preferences to convert them "true-false" analytics to be operable by the building or service providers.

The tool enables to convert the desires to the "true-false" data and cumulate in a statistical fashion. When the users determine that they are comfortable, the loop ends, and the comfort index increases corresponding to the measured indoor conditions. In this way, we can realize that the most desirable conditions.

This system can accumulate the data and turned to a learning system while different initial conditions and the if statements progressively are programmed.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Most of the recent studies in building facility management have focused on optimizing strategies financially by favoring energy efficiency against the indoor environmental quality. Yet, in the long run, favoring IEQ adds more value to the comfort and wellbeing of the occupants, which increases the value of a building. Only a few studies refer to human factor in building management. The new facility management strategies should be formulated by prioritizing the corporate owner's objectives as well as considering the users as the key determinant in the process.

A building cannot be imagined apart from its end users. The users should be engaged into the process actively and to support continual improvement of the facility to make a building truly sustainable. This requires a new circular operation concept for the building, apart from the financial based strategies. One way of doing it is possible using an "occupant-oriented circular facility management strategy", which can be best described by understanding the basic steps discussed in the modified version of Max-Neef's transdisciplinary concept.

As discussed in Figure 1, the integration of technology and behavior models at the so called *instrument* level means that the users will be able to reach to comfort, well-being and productivity in predictable way as the overall CO strategy is geared towards maximizing the building IEQ, that is its *value*. If the behavior models are quantified and converted to meaningful data by the help of today's technologies, the data may lead the facility management strategy in such a CO and allows the continues improvement of D&C, FM, IEQ and the entire CO. This is the way to come out with the future sustainable buildings.

The behavior models mean that the users will have comfort, well-being and productivity, regarding to the IEQ. If the behavior models are quantified and converted to meaningful data by the help of today's technologies, the data may lead the facility management strategy and continues improvement. Comfort and well-being can be observable by the measurement of productivity. Productivity can be quantified financial implications as well as work performance.

As discussed above, improving the occupant engagement in a building with the introduced circular operation model requires transdisciplinary research challenges. This paper shows the necessity of a bottom to top approach in transdisciplinarity. This approach is starting with the help of fundamental sciences and built on five levels. The research based on the fundamental sciences triggers the cutting-edge developments in upper levels by interacting with them. Integrated "engineering", "architecture" and "management" helps us to establish a CO and changes the traditional FM concept. To do so, an extra level is added to Max-Neef's model between the *purposive* level and *normative* level. This *instrumentation* level is inspired by our integrated engineering and architecture studies geared towards developing new measurements devices, tools and gadgets. Such instruments are driven and based on "technology" and "behavior" tools to achieve comfort, well-being and productivity. Thus, the value can be created at the top if high-quality indoor environment is established.

To design this strategy, a series of qualitative research has been conducted. The results of the surveys, interviews and the documents were correlated and demonstrated by a gap analysis. The most significant result of the correlation is the difference between the occupants' expectations and the understanding of the facility managers which is called "communication gap". The major "communication gap" was identified between the students and the FM service providers. Therefore, gamification is a solution to overcome this gap by designing the feedback mechanism. TRIBE Project which is conducted in AB1 also proves that the potential of behavioral change program by using gamification in mobile applications.

According to the user responses and the interviews some key aspects were concluded.

1. Because of the major challenge in the current strategy is the trade-off between energy efficiency and comfort for service providers, an optimization method should be developed. This is one of the requirements of transdisciplinary approach.
2. For example, there is a south oriented room, and occupants complains about the high temperatures because of full transparent façade. Solution is to increase the power of the air conditioning and cool the place down. However, this will increase the energy consumption. Instead, an optimizer may calculate the cost and benefit of a shading device to reduce the energy consumption and increase the comfort. The only solution may not be the air

conditioner. The best solution can only be possible with an extensive coordinated strategy among the service providers and transdisciplinary innovations.

3. On the other hand, even though small technical differences and same operational strategy in the case buildings, the user responses are quite different in comfort and IEQ. Figure 20 and Figure 26 show the difference in user comfort in their case buildings. We may say the comfort level differences may be caused because of the design principles as well as demographic structure. The individual comfort results show that in what extent the early phases influence the operational phase. Also, it refers why we need to understand the demographic structure of the future users before designing a building.
4. The interviews are conducted non-case specific. As a result, they believe that facility management is a collaborative work including information technologies (IT), health-safety and environment (HSE), technical services, human resources (HR), finance and operation manager. The collaboration should be extended and supported by state-of-the-art innovations by enabling transdisciplinary work methods.
5. The interviewees agree on their impact on D&C phase to improve operational service quality for *"future vision"*. The both interviewees are engaging and contributing the third case building (AB4) based on their experiences. The systematic and learning feedback mechanism by its accumulated data is also adaptive for next projects in D&C.

The study established the necessity of an interactive user-friendly tool which enable to collect user behavior data. This data is converted to meaningful analytics to be executed by facility managers as well as owners. Not the code but the logic behind the tool has been developed by collecting quantifiable data from the users. In this way, it is possible to achieve maximum comfort index based on the continuous responses corresponding to the specific indoor environmental conditions in a specific area.

Based on these researches a conceptual framework was generated to identify the position and the importance of circular operation. This framework showed us the key participants of the new strategy as well as the new parameters should be considered. The conceptual framework which defines the important three pillars of circular operation model has been developed and detailed. The three pillars of the loop in CO are defined as 1) building, 2) actual users and 3) the FM leaders. According to this model, users are the only decision makers where the facility managers are the executers and the controllers. The building itself represents the data center. The important thing is here to suggest a solution for the connection lines which are systematic feedback mechanism, data management and behavior models. If the behavior models regarding to the building is quantified by a systematic feedback mechanism, the data can be operable by the automation systems and the facility managers.

For all that, an interactive user feedback tool has been developed to collect the data regarding users' desires and the preferences to convert them "true-false" analytics to be operable by the building or service providers.

The tool enables to convert the desires to the "true-false" data and cumulate them statistically. When the users determine that they are comfortable, the loop ends, and the comfort index increases corresponding to the measured indoor conditions. In this way, we can realize that the most desirable conditions. This system can accumulate the data and turned to a learning system while different initial conditions and the if statements progressively are programmed.

This tool has been developed without considering the consequences of energy consumption and other additional cost regarding the specific desires. On the other hand, to develop a user friendly and applicable mobile application is additional concern should be explained. Gamification and awards can be a solution to attract the occupants to use such applications. Yet, the study does not verify the fascination of the tool from the users' perspective.

FUTURE WORK

The result of the questionnaires is analyzed by rating only for each question, then the individual responses are not correlated in a statistical concept. Therefore, any statistical significance (p-level) is not determined. However, response data is available for each individual respondent and each question. Therefore, it is possible to indicate the strength of the statistical relationship between two survey questions in future.

This tool has been developed without considering the consequences of energy consumption and efficiency, or the other additional cost regarding to specific requests. Gamification and awards can be a solution to attract the occupants to use such applications. The tool developed in this study can be further expanded to quantify human behavior data and integrate it with a mobile application. The qualitative research to collect individual data would be the real challenge to generate the sensible behavior patterns in a building. The framework can be streamlined and expanded cumulatively with the help of ‘if’ statements and the corresponding user responses. The final product should be adapted by the engineers and architects working on the D&C phases. This, in turn becomes the “*future vision*” as shown in Figure 11, for the future FM service providers. “*Future vision”* for CO is used as a statement to represent FM knowledge transfer from previous operational phases to the next buildings’ early phases. This approach is to be built on the behavior data from the previous operation experiences to the next D&C experience for continual improvements of high performance buildings. Of course, all these efforts should be carried out in tandem with the energy efficiency studies.

APPENDIXES

Appendix 1

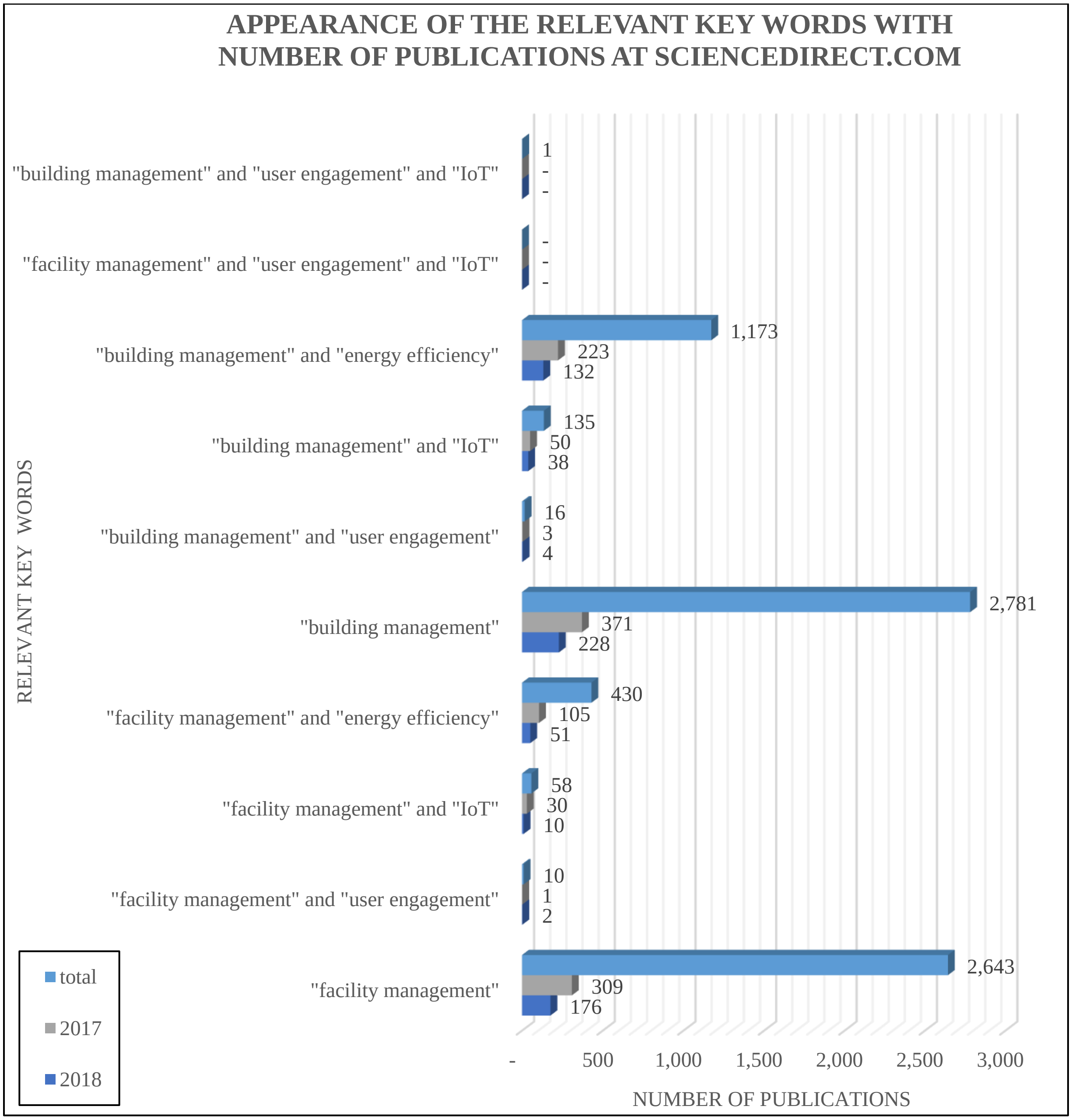


Figure 35: Appearance of coupled important key words research with the number of publications at ScienceDirect.com.

A recent literature search using the most relevant keywords shows how limited the cross-disciplinary studies, as seen in Figure 35. In constructing Figure 35, the relevant keywords are searched in a systematic way. “Building management” is searched first as an alternative key word to “facility management” even if there are systematic differences between the terms. It is obvious that there are only a few studies about “facility management” coupled with other factors. Also, there is no study coupling “facility management”, “user engagement” and “IoT”.

Appendix 2

The interview with the Director of Technical Services

Profession: Mechanical Engineer

Occupancy: Director of technical services

Responsibility scope: all university campus

Responsibility area: This task is to maintain the comfort of students, academic / administrative staff and campus environment at maximum level, to continually improve the environment with continuous measurement and improvement methods, to protect the natural environment of our university and to support energy policies without sacrificing comfort conditions. We are involved in continuity of service to meet the needs and expectations of our entire campus today and tomorrow by following developments in order to provide the building, infrastructure, technology, comfort, aesthetics, equipment and technical support required by all units.

SCOPE	QUESTIONS	ANSWERS
General insight about FM approach	How do you describe FM profession with respect to your professional experiences?	It is service business is to maintain the comfort of students, academic / administrative staff and campus environment at maximum level, to continually improve the environment with continuous measurement and improvement methods, to protect the natural environment of our university and to support energy policies without sacrificing comfort conditions. Technical services are not the visible picture of the services such as catering, security, cleaning services. Our job is back of the house; however, our responsibility is to provide the building, infrastructure, technology, comfort, aesthetics, equipment and technical support required by all units.
	What are the departments that you collaborate?	Purchasing, Financial Affairs, HSE and Administrative Affairs, CEEE are the most collaborated units in the university.
	What are your major activities?	Electrical infrastructure including energy distribution center feeds the lighting, switches and so on. Mechanical infrastructure including heating/ cooling, ventilation, fire safety system, water installations,

		automation and so on. IT infrastructure. Even the university is very young, it needs many technical maintenance and repair requirements starting from the first day of using. Architectural needs, furnitures, façades, landscape maintaining. Following energy policies of the campus while providing appropriate living conditions for the occupants. So, we operate an optimization strategy.
Business unit strategy	How is your management strategy? a – How many people do you work in your team? b – which units are under responsibility of technical services department? c- How do you measure performance of your team members? d- Do you have any control mechanism for each work item and related person?	We are always in the site. We behave proactive and, predict the potential failures, needs and demands to perform preventive strategy. We have widespread automation system and monitoring systems for all campus to diagnostic the failures. Our systems are majorly centered and controlled by automation. We also conduct periodic maintenance to meet the standards, lengthen the life of the equipment and use efficiently. Also, we prepare annual budget plan based on previous years. This budget plan includes predictable and unpredictable items. We collaborate with each faculty members or administrative staff for their specific demands to add in the budget. And

		expenditure schedule is developed with the budget each year that presents when and how much will be spend each year. a- Total 32 team members. 27 technicians (i.e. electric, mechanic, carpenter and subcontractors) are always inspect the field. 5 office group includes mechanical engineers, electrical engineers and civil works technicians. b- The Technical Services Department is responsible for the planning and performance evaluation of the Mechanical Engineer, Electrical Engineer, Construction Technician, Electrical Technicians, Mechanical Technicians and Furniture Wooden Technician within the organization. c- We have annual performance evaluation reports. d- Özyeğin University Solution Center is very critical IT based infrastructure for FM. Solution Center is a bridge between technical services and the occupants. When any demand or complain is

		submitted on solution system, there is restricted time schedule for related employees to take that job. Solution Center is available for mobiles and computers for occupants and the technicians. If the job taking process is delayed, the responsible technician will get warned. When the technician takes the duty, the solution is provided then the feedback is expected from the users about their experiences. Now it turned out a challenge for us. The response times, solution times are collected as data and compared the previous similar duties as well as it is like competition among the technicians to evaluate their performances. We always archive the data of requests and the solutions. We use all data for monthly reports.
Communication	How do you communicate with the users of the buildings?	Solution Center! Because the total population is 10.000 in the campus. Thus, i.e. we may see what times and which demands are requested; what the reasons are for those requests and

		who may be responsible for those happens. Solution Center is available for mobiles and computers for occupants and the technicians.
	How do you collaborate with IT department to improve user engagement into Solution Center? How do you contribute to enhance the user interface of the Solution Center application? a- How do you communicate with your team members and other teams to provide quick solution? b- What about the other interactive tools to communicate with the users? For example, kiosk, how do you use those tools?	Solution Center application has been a continuously improving since it was built. We always in collaboration with it to make it more user friendly. Digitalization strategy is in corporate level and adopted in all units. a- Apart from the all linked software systems i.e. purchasing, contracting; we use WhatsApp Groups actively. It is the easiest way to communicate among the team members in by sending pictures and immediate answers and quick solution. b- Of course, kiosks are interactive learning tools for students or the users. However, the latest generation students lose attention easily. We believe that we need to create games to catch their eyes.
	Do you think that user comfort may impact their productivity?	Yes, of course! a- Major systems like heating/cooling are centrally controlled by automation

	a- What do you think about the efficiency of feedback mechanism? b- Can you measure the impact of comfort and productivity?	system. There is a management plan for each service in accordance with the major users needs as well as optimizing energy efficiency. For example, in summers, cooling system is deactivated after 6 pm in offices and the classes. If a student would like to continue to study, s/he should use some specific places where is 24 h cooled. Also, the one problem is the users are not sure in which services have problem. For example, they cannot distinguish ventilation or cooling/heating. To come over this absence of knowledge, we organize workshops/trainings to students. Thus, they can understand what they see above, and they can predict the potential operational failures and costs. b- We have two accredited certificates ISO 14001 which is related to health and safety and OHSAS 18001 related to environment. We have some

		targets in annually according to our certificates to keep our certification. According to a research conducted by an independent agency, we have been chosen as number one in student satisfaction among Turkish Universities. Also, institutional basis surveys to measure users' satisfaction are often accomplished.
Cost	What are your most costly activities? a- What is your most environmentally impactful activity?	Heating/cooling is the most expensive activities. a- Electric consumption is very critical in this topic. Trigeneration system was invested last year and commissioned.
From business level to Corporate level strategy	How user comfort may contribute the school environment/core business? What do you observe?	It turns back as prestige in the market. It shows the student loyalty. Students take university entrance exam to qualify for this university, that means, quality of students will increase in the university. In the long term we may observe increase in academic success of the university.
Future Vision	How do you involve in the new building construction? Which benefits do you think that	I, personally involved in the game in construction process of this all campus. I experienced many operational faults coming from the

	technical services can provide in early phases?	D&C decisions. Now, we involved in the new building D&C process working with CEEE to work on energy as well as comfort. We also collaborate current academic staff, for example, research members majorly demand heating/cooling system for out of administrative working hours. Then we planned disjunctive heating/cooling equipment as initial investment for their spaces and collaborated architects/engineers. Thus, our operational cost will be decreasing. We experienced some users attempts during the years; i.e. opening the windows even if the indoor air quality in normal level. So, we recommend all the windows of the offices openable. In conclusion, I believe that if the owner and the operation are the same sources, the total cost of whole building cycle is managed more effective.

Appendix 3

The interview with the Director of Health Safety and Environment

Profession: Environmental Engineer

Occupancy: Director of Health Safety and Environment

Responsibility scope: all university campus

Responsibility area: Have two different position; first is coordinating health, safety and environment operations of overall campus organizations either academic or administrative. We are responsible for security, safety, comfort and wellness of each person in the campus, thus, should predict and prevent the risks for every sqm of the campus. The second position to coordinate administrative operations including cleaning, events, mobility, restaurants, catering services, post office. This position is distinguished from the HSE department, and the position serves for administrative operations.

SCOPE	QUESTIONS	ANSWERS
General insight about FM approach	How do you describe FM as a general term depending on your experiences?	FM is, as a broad meaning, the intent of meeting and predicting the todays and tomorrows needs of occupants as well the buildings while sustaining the occupancy comfort, health and safety during the service process.
	What are the departments that you collaborate mostly?	Operational service has three divisions now. 1) administrative operations include all managerial and financial works, 2) purchasing, 3) technical services which includes all building maintenance and repair, and information technology team (IT). Even if the HSE is involved in each department as an umbrella.
	What are your main activities?	Defining the procedure of the processes and control as HSE perspective. The population is 10.000 people and 12 entrance that means our priority is to provide security at the entrances. Another issue is health. In an emergency, stabilize the panic and transfer

		the patient to the hospital and the being responsible for care of patient. Control the convenience of all operational processes to the HSE policies. Catering services, selecting the meal menus, any materials that will be used at the school, convenience of setup a new lab…etc.
Business unit strategy	How is your management strategy? a – How many people do you work in your team?	Follow our certificates ISO 14001 and OHSAS 18001 procedures and requirements. We are always in the site, proactive, follow preventive and correction strategy and involve everything. a- 80-85 employees. 60-65 of all are technicians and the labors, the rest is engineers, doctors, managers and health team.
Communication	How do you communicate with the users of the buildings?	Solution Center and face to face. Students or academic personnel knock the door. For example, we join users in their lunch and get feedback about the catering services. We collaborate with the students

		and develop solution projects together. Our strategy here is to make the people who have complaints part of the solution process. I don't think there is no communication gap between the users and HSE. We do not collect the feedback systematically, but we are in bilateral relation with the users.
Cost	What is your costly activity?	Mobility and cleaning because of the high number of staff. Health and security are not the major; however, security has also high number of employees, so I may say it is costly. In health side, medical disposal process is a bit of costly.
From business level to Corporate level strategy	How your business unit strategy of HSE can contribute the core business? What do you observe?	Operational efficiency contributes the quality. On the other hand, HSE is a loss prevention unit. I can say that we contribute huge amount of money if you consider car accidents, fights, disorders health problems, lawsuits...etc. However, I cannot quantify this amount of money yet.

Future Vision	How do you involve in the new building construction?	We involve in the beginning of the design phase. We work on risk analysis and give some feedback for the potential risks.

Appendix 4

Occupancy Satisfaction Survey for SCOLA Building

1. Your sex?

- Male
- Female

2. Your age?

- under 20
- 20-30
- 30-40
- above 40

3. Your profession?

- Student
- Academic staff
- Administrative staff

4. How many hours do you spend in which spaces of SCOLA during the daytime?

	0-1	1-3	3-5	more than 5
Offices/study rooms	○	○	○	○
Classes	○	○	○	○
Cafeteria	○	○	○	○
Meeting Room	○	○	○	○
Toilette	○	○	○	○
Auditorium	○	○	○	○
Out of the building	○	○	○	○

5. How many hours do you spend in which spaces of SCOLA during the nights?

	0-1	1-3	3-5	more than 5
Offices/study rooms	◯	◯	◯	◯
Classes	◯	◯	◯	◯
Cafeteria	◯	◯	◯	◯
Meeting Room	◯	◯	◯	◯
Toilette	◯	◯	◯	◯
Auditorium	◯	◯	◯	◯
Out of the building	◯	◯	◯	◯

6. Please evaluate the overall indoor environment quality during the day.

	1 very bad	2	3	5	6	7 very well
Offices/study rooms	◯	◯	◯	◯	◯	◯
Classes	◯	◯	◯	◯	◯	◯
Cafeteria	◯	◯	◯	◯	◯	◯
Meeting Room	◯	◯	◯	◯	◯	◯
Toilette	◯	◯	◯	◯	◯	◯
Auditorium	◯	◯	◯	◯	◯	◯
Out of the building	◯	◯	◯	◯	◯	◯

7. Do you think that there is any impact of indoor air quality on your daily performance where you majorly spend your day?

- ◯ 1 not significant
- ◯ 2
- ◯ 3
- ◯ 5
- ◯ 6
- ◯ 7 very significant

8. How do you evaluate indoor freshness or staleness of the air where you majorly live?

	1 stale	2	3	5	6	7 very fresh
08:00-10:00	◯	◯	◯	◯	◯	◯
10:00-12:00	◯	◯	◯	◯	◯	◯
12:00-14:00	◯	◯	◯	◯	◯	◯
14:00-16:00	◯	◯	◯	◯	◯	◯
16:00-18:00	◯	◯	◯	◯	◯	◯
18:00-20:00	◯	◯	◯	◯	◯	◯
20:00-22:00	◯	◯	◯	◯	◯	◯
20:00-00:00	◯	◯	◯	◯	◯	◯

9. How do you evaluate indoor humidity of the air where you majorly live?

	1 too dry	2	3	4 ideal	5	6	7 too humid
08:00-10:00	◯	◯	◯	◯	◯	◯	◯
10:00-12:00	◯	◯	◯	◯	◯	◯	◯
12:00-14:00	◯	◯	◯	◯	◯	◯	◯
14:00-16:00	◯	◯	◯	◯	◯	◯	◯
16:00-18:00	◯	◯	◯	◯	◯	◯	◯
18:00-20:00	◯	◯	◯	◯	◯	◯	◯
20:00-22:00	◯	◯	◯	◯	◯	◯	◯
20:00-00:00	◯	◯	◯	◯	◯	◯	◯

10. How do you evaluate indoor smell of the air where you majorly live?

	1 too smelly	2	3	5	6	7 no smell
08:00-10:00	◯	◯	◯	◯	◯	◯
10:00-12:00	◯	◯	◯	◯	◯	◯
12:00-14:00	◯	◯	◯	◯	◯	◯
14:00-16:00	◯	◯	◯	◯	◯	◯
16:00-18:00	◯	◯	◯	◯	◯	◯
18:00-20:00	◯	◯	◯	◯	◯	◯
20:00-22:00	◯	◯	◯	◯	◯	◯
20:00-00:00	◯	◯	◯	◯	◯	◯

11. How is your air circulation at your place?

- ◯ 1 still
- ◯ 2
- ◯ 3
- ◯ 5
- ◯ 6
- ◯ 7 good circulation

12. Do you have control over ventilation in your space?

- ◯ 1 no control
- ◯ 2
- ◯ 3
- ◯ 5
- ◯ 6
- ◯ 7 full control

13. Do you think that there is any impact of indoor temperature on your daily performance where you majorly spend your day?

- ◯ 1 not significant
- ◯ 2
- ◯ 3
- ◯ 5
- ◯ 6
- ◯ 7 very significant

14. How do you evaluate the temperature in winter in your place? Is it too cold or too warm?

- ◯ 1 too cold
- ◯ 2
- ◯ 3
- ◯ 4 ideal
- ◯ 5
- ◯ 6
- ◯ 7 too warm

15. How do you evaluate the temperature in summer in your place? Is it too cold or too warm?

- ◯ 1 too hot
- ◯ 2
- ◯ 3
- ◯ 4 ideal
- ◯ 5
- ◯ 6
- ◯ 7 too cold

16. Do you have control over heating/cooling?

- ◯ 1 no control
- ◯ 2
- ◯ 3
- ◯ 5
- ◯ 6
- ◯ 7 full control

17. Which of the following do you personally adjust or control in your most used space? (Please tick all that apply)

- ☐ Window blinds
- ☐ Operable window
- ☐ Shades
- ☐ Thermostat
- ☐ Portable heater
- ☐ Portable fan
- ☐ Ceiling fan
- ☐ Adjustable air vent in wall or ceiling
- ☐ Adjustable floor air vents (diffuser)
- ☐ Door to interior space
- ☐ Door to exterior space
- ☐ None of the above

18. Do you think that there is any impact of noise on your daily performance where you majorly spend your day?

- 1 not significant
- 2
- 3
- 5
- 6
- 7 very significant

19. Is there significant distraction from the noise outside the space?
(Please tick)

- 1 not significant
- 2
- 3
- 5
- 6
- 7 very significant

20. Is there significant distraction from background noise?
(Please tick)

- 1 not significant
- 2
- 3
- 5
- 6
- 7 very significant

21. Do you think that there is any impact of light on your daily performance where you majorly spend your day?

- 1 not significant
- 2
- 3
- 5
- 6
- 7 very significant

22. Please evaluate the natural light level in your place?

- 1 too little
- 2
- 3
- 4 ideal
- 5
- 6
- 7 too much

23. Is there too much glare from the sun / natural light?

- 1 not comfortable
- 2
- 3
- 5
- 6
- 7 very comfortable

24. Please evaluate the artificial light level in your place?

- ◯ 1 too little
- ◯ 2
- ◯ 3
- ◯ 4 ideal
- ◯ 5
- ◯ 6
- ◯ 7 too much

25. Is there too much glare from the artificial light?

- ◯ 1 not comfortable
- ◯ 2
- ◯ 3
- ◯ 5
- ◯ 6
- ◯ 7 very comfortable

26. Are the blinds/shutters effective in blocking out natural light?

- ◯ 1 not effective
- ◯ 2
- ◯ 3
- ◯ 5
- ◯ 6
- ◯ 7 very effective

27. Do you have control over artificial lighting?

- ◯ 1 no control
- ◯ 2
- ◯ 3
- ◯ 5
- ◯ 6
- ◯ 7 full control

28. Which of the following controls do you have over the lighting in your most used space? (Please tick all that apply)

- ☐ Light switch
- ☐ Light dimmer
- ☐ Window blinds
- ☐ Shades
- ☐ Desk light
- ☐ None of the above

29. What is the energy use in units called?

- ◯ Kilowatt hours (kWh)
- ◯ Horsepower (hp)
- ◯ Volts (V)
- ◯ don't know

30. Compared to your friends how do you consider your energy use?

- ◯ Greater than average
- ◯ Less than average
- ◯ About average

31. Which of the below would motivate you to save energy?

- ◯ Benefiting the environment
- ◯ It is the right thing to do
- ◯ Saving money
- ◯ Seeing results in information display
- ◯ Setting example among co-workers / friends
- ◯ For comfort or other personal benefits
- ◯ None of the above

32. Which of the below are useful metrics for showing energy consumption?

- ◯ Amount of energy used
- ◯ Costs of energy used
- ◯ Pollution created / saved
- ◯ None of the above

33. Which of the below method would you prefer for displaying energy information?

- ◯ Websites
- ◯ Graphical displays in public spaces
- ◯ Graphical displays in elevators
- ◯ Other (please specify)
- ◯ Mobil application
- ◯ don't want to see

34. When you feel uncomfortable how do you act?

- ◯ Let the related department know
- ◯ Able to control myself
- ◯ Do nothing

35. If you let the related department know; could you evaluate the service quality, please. If you do not let them know please check N/A.

- ◯ 1 always poor quality
- ◯ 2
- ◯ 3
- ◯ 5
- ◯ 6
- ◯ 7 always good quality
- ◯ N/A

36. If you let the related department know; could you evaluate the speed of the service, please. If you do not let them know please check N/A.

- 1 too slow service response
- 2
- 3
- 5
- 6
- 7 very fast service response
- N/A

37. Could you evaluate the ease of communication with the solution department? If you do not let them know please check N/A.

- 1 too difficult to communicate/ don't know who I need to talk with
- 2
- 3
- 5
- 6
- 7 very easy to communicate/ I know who I need to talk with
- N/A

38. Could you evaluate the quality of communication with the solution department? If you do not let them know please check N/A.

- 1 cannot understand each other
- 2
- 3
- 5
- 6
- 7 understand each other very well
- N/A

39. If you have a chance to change, which one would you **prefer** to interact with the solution department?

- e-mail
- calling
- mobile app
- website
- Other (please specify)

40. Do you receive an electricity bill?

- Yes
- No

41. How would you prefer to receive your electricity usage information?

- ◯ paper
- ◯ website
- ◯ e-mail
- ◯ N/A
- ◯ mobil

42. If the consumption information was updated daily and available 24/7 how often would you look at it?

- ◯ daily
- ◯ weekly
- ◯ monthly
- ◯ Never

43. Which temperatures do you prefer in winters?

- ◯ 14-19 °C
- ◯ 19-25 °C
- ◯ 25-29 °C

44. Which temperatures do you prefer in summers?

- ◯ 14-19 °C
- ◯ 19-25 °C
- ◯ 25-29 °C

45. Do you have special needs for the services specified below? Please check boxes.

- ☐ heating
- ☐ cooling
- ☐ lighting
- ☐ ventilation
- ☐ domestic hot water
- ☐ Other (please specify)

46. Do you prefer building centered control system or room specific adjustable system?

	building centered system	room specific adjustable system			
target temperatures	◯	◯	◯	◯	◯
heating/cooling times	◯	◯	◯	◯	◯
ventilation rates	◯	◯	◯	◯	◯
illumination levels	◯	◯	◯	◯	◯

47. Which unit of measure can help you to understand building energy performance easily?

◯ consumption/m2

◯ consumption/class-office

◯ consumption/person

◯ consumption/generation

◯ consumption/hour-day-week-month-year

48. How can you understand building energy performance easily?

◯ carbon footprint

◯ number of trees cut

◯ amount of plastics thrown to the nature

◯ your share in climate change

Occupancy Satisfaction Survey for AB1 Building

1. Your sex?

- Male
- Female

2. Your age?

- under 20
- 20-30
- 30-40
- above 40

3. Your profession?

- Student
- Academic staff
- Administrative staff

4. How many hours do you spend in which spaces of AB1 during the daytime?

	0-1	1-3	3-5	more than 5
Offices/study rooms				
Classes				
Cafeteria				
Meeting Room				
Toilette				
Auditorium				
Out of the building				

5. How many hours do you spend in which spaces of AB1 during the nights?

	0-1	1-3	3-5	more than 5
Offices/study rooms	○	○	○	○
Classes	○	○	○	○
Cafeteria	○	○	○	○
Meeting Room	○	○	○	○
Toilette	○	○	○	○
Auditorium	○	○	○	○
Out of the building	○	○	○	○

6. Please evaluate the overall indoor environment quality during the day.

	1 very bad	2	3	5	6	7 very well
Offices/study rooms	○	○	○	○	○	○
Classes	○	○	○	○	○	○
Cafeteria	○	○	○	○	○	○
Meeting Room	○	○	○	○	○	○
Toilette	○	○	○	○	○	○
Auditorium	○	○	○	○	○	○
Out of the building	○	○	○	○	○	○

7. Do you think that there is any impact of indoor air quality on your daily performance where you majorly spend your day?

- ○ 1 not significant
- ○ 2
- ○ 3
- ○ 5
- ○ 6
- ○ 7 very significant

8. How do you evaluate indoor freshness or staleness of the air where you majorly live?

	1 stale	2	3	5	6	7 very fresh
08:00-10:00	○	○	○	○	○	○
10:00-12:00	○	○	○	○	○	○
12:00-14:00	○	○	○	○	○	○
14:00-16:00	○	○	○	○	○	○
16:00-18:00	○	○	○	○	○	○
18:00-20:00	○	○	○	○	○	○
20:00-22:00	○	○	○	○	○	○
20:00-00:00	○	○	○	○	○	○

9. How do you evaluate indoor humidity of the air where you majorly live?

	1 too dry	2	3	4 ideal	5	6	7 too humid
08:00-10:00	◯	◯	◯	◯	◯	◯	◯
10:00-12:00	◯	◯	◯	◯	◯	◯	◯
12:00-14:00	◯	◯	◯	◯	◯	◯	◯
14:00-16:00	◯	◯	◯	◯	◯	◯	◯
16:00-18:00	◯	◯	◯	◯	◯	◯	◯
18:00-20:00	◯	◯	◯	◯	◯	◯	◯
20:00-22:00	◯	◯	◯	◯	◯	◯	◯
20:00-00:00	◯	◯	◯	◯	◯	◯	◯

10. How do you evaluate indoor smell of the air where you majorly live?

	1 too smelly	2	3	5	6	7 no smell
08:00-10:00	◯	◯	◯	◯	◯	◯
10:00-12:00	◯	◯	◯	◯	◯	◯
12:00-14:00	◯	◯	◯	◯	◯	◯
14:00-16:00	◯	◯	◯	◯	◯	◯
16:00-18:00	◯	◯	◯	◯	◯	◯
18:00-20:00	◯	◯	◯	◯	◯	◯
20:00-22:00	◯	◯	◯	◯	◯	◯
20:00-00:00	◯	◯	◯	◯	◯	◯

11. How is your air circulation at your place?

- ◯ 1 still
- ◯ 2
- ◯ 3
- ◯ 5
- ◯ 6
- ◯ 7 good circulation

12. Do you have control over ventilation in your space?

- ◯ 1 no control
- ◯ 2
- ◯ 3
- ◯ 5
- ◯ 6
- ◯ 7 full control

13. Do you think that there is any impact of indoor temperature on your daily performance where you majorly spend your day?

- ◯ 1 not significant
- ◯ 2
- ◯ 3
- ◯ 5
- ◯ 6
- ◯ 7 very significant

14. How do you evaluate the temperature in winter in your place? Is it too cold or too warm?

- ◯ 1 too cold
- ◯ 2
- ◯ 3
- ◯ 4 ideal
- ◯ 5
- ◯ 6
- ◯ 7 too warm

15. How do you evaluate the temperature in summer in your place? Is it too cold or too warm?

- ◯ 1 too hot
- ◯ 2
- ◯ 3
- ◯ 4 ideal
- ◯ 5
- ◯ 6
- ◯ 7 too cold

16. Do you have control over heating/cooling?

- ◯ 1 no control
- ◯ 2
- ◯ 3
- ◯ 5
- ◯ 6
- ◯ 7 full control

17. Which of the following do you personally adjust or control in your most used space? (Please tick all that apply)

- ☐ Window blinds
- ☐ Operable window
- ☐ Shades
- ☐ Thermostat
- ☐ Portable heater
- ☐ Portable fan
- ☐ Ceiling fan
- ☐ Adjustable air vent in wall or ceiling
- ☐ Adjustable floor air vents (diffuser)
- ☐ Door to interior space
- ☐ Door to exterior space
- ☐ None of the above

18. Do you think that there is any impact of noise on your daily performance where you majorly spend your day?

- 1 not significant
- 2
- 3
- 5
- 6
- 7 very significant

19. Is there significant distraction from the noise outside the space?
(Please tick)

- 1 not significant
- 2
- 3
- 5
- 6
- 7 very significant

20. Is there significant distraction from background noise?
(Please tick)

- 1 not significant
- 2
- 3
- 5
- 6
- 7 very significant

21. Do you think that there is any impact of light on your daily performance where you majorly spend your day?

- 1 not significant
- 2
- 3
- 5
- 6
- 7 very significant

22. Please evaluate the natural light level in your place?

- 1 too little
- 2
- 3
- 4 ideal
- 5
- 6
- 7 too much

23. Is there too much glare from the sun / natural light?

- 1 not comfortable
- 2
- 3
- 5
- 6
- 7 very comfortable

24. Please evaluate the artificial light level in your place?

- ◯ 1 too little
- ◯ 2
- ◯ 3
- ◯ 4 ideal
- ◯ 5
- ◯ 6
- ◯ 7 too much

25. Is there too much glare from the artificial light?

- ◯ 1 not comfortable
- ◯ 2
- ◯ 3
- ◯ 5
- ◯ 6
- ◯ 7 very comfortable

26. Are the blinds/shutters effective in blocking out natural light?

- ◯ 1 not effective
- ◯ 2
- ◯ 3
- ◯ 5
- ◯ 6
- ◯ 7 very effective

27. Do you have control over artificial lighting?

- ◯ 1 no control
- ◯ 2
- ◯ 3
- ◯ 5
- ◯ 6
- ◯ 7 full control

28. Which of the following controls do you have over the lighting in your most used space? (Please tick all that apply)

- ☐ Light switch
- ☐ Light dimmer
- ☐ Window blinds
- ☐ Shades
- ☐ Desk light
- ☐ None of the above

29. What is the energy use in units called?

- ◯ Kilowatt hours (kWh)
- ◯ Horsepower (hp)
- ◯ Volts (V)
- ◯ don't know

30. Compared to your friends how do you consider your energy use?

- Greater than average
- Less than average
- About average

31. Which of the below would motivate you to save energy?

- Benefiting the environment
- It is the right thing to do
- Saving money
- Seeing results in information display
- Setting example among co-workers / friends
- For comfort or other personal benefits
- None of the above

32. Which of the below are useful metrics for showing energy consumption?

- Amount of energy used
- Costs of energy used
- Pollution created / saved
- None of the above

33. Which of the below method would you prefer for displaying energy information?

- Websites
- Graphical displays in public spaces
- Graphical displays in elevators
- Other (please specify)
- Mobil application
- don't want to see

34. When you feel uncomfortable how do you act?

- Let the related department know
- Able to control myself
- Do nothing

35. If you let the related department know; could you evaluate the service quality, please. If you do not let them know please check N/A.

- 1 always poor quality
- 2
- 3
- 5
- 6
- 7 always good quality
- N/A

36. If you let the related department know; could you evaluate the speed of the service, please. If you do not let them know please check N/A.

- ◯ 1 too slow service response
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- ◯ calling
- ◯ mobile app
- ◯ website
- ◯ Other (please specify)

[ ]

40. Do you receive an electricity bill?

- ◯ Yes
- ◯ No

41. How would you prefer to receive your electricity usage information?

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ventilation rates	◯	◯	◯	◯	◯
illumination levels	◯	◯	◯	◯	◯

47. Which unit of measure can help you to understand building energy performance easily?

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- ◯ consumption/person
- ◯ consumption/generation
- ◯ consumption/hour-day-week-month-year

48. How can you understand building energy performance easily?

- ◯ carbon footprint
- ◯ number of trees cut
- ◯ amount of plastics thrown to the nature
- ◯ your share in climate change

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