DIPLOMARBEIT | MASTER THESIS

BUILDING PHYSICS ASPECTS IN THE BUILDING DELIVERY PROCESS: A CASE STUDY FROM VIENNA

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ABSTRACT

With the goal of decarbonizing the building sector, the European Union and its Member States are enacting increasingly restrictive building regulations directed at improving building energy performance. On one hand, this continuous flow of building legislation emphasizes the strong interdisciplinary character of architecture projects. On the other hand, it requires extensive technical expertise to handle its contents, changing building delivery process dynamics.

Understanding how building physics aspects are handled in practice seems fundamental to support the goal of designing more energy-efficient buildings. This requires not only adequate building construction solutions but also an efficient architectural- and technical building systems design.

However, specialized literature on building physics tends to focus primarily on theoretical and calculation aspects, widely excluding or omitting practical implementation. Therefore, this thesis pursues the objective of developing an evaluation method to examine how the thermal insulation and energy efficiency aspects of building physics are incorporated throughout the building delivery process. A residential project in the city of Vienna, built with public subsid support during the years 2015-2020, serves as case study. Thereby, its building delivery process is analyzed and documented with specific focus on building physics related aspects.

The data used to conduct this study encompasses the extensive documentation of the project, which ranges from architectural plans and construction details till specialized reports produced by the project partners. The views of the experts involved in the planning of the project have also been considered via interviews.

The methodology includes a comprehensive review of the building legislation in force at the time of the planning of the case study, together with selected specialized literature providing a practical approach to building physics. From these two sources, together with the expert interviews, a generic building physics task list has been generated. The building delivery process of the case study is also thoroughly analyzed, and its main steps divided in descriptive categories.

Via this process it was possible to identify the specific building physics tasks performed during the planning process of the case study, as well as key planning experts responsible for the task implementation. Moreover, it was established which are the changes in the building components happening along the building delivery process that cause planning modifications with building physics repercussions. The phase definition of the building components relevant for energy analysis is also determined.

The findings of this thesis point out the following aspects: most of the building physics tasks focus on the correct planning and execution of construction details and occurred during the execution phase at the end of the delivery process, rather than in the early phases when building performance could still be influenced via assessment. The time resources invested for building physics related tasks in the early stages of the project planning is limited. Nevertheless, half of the building components relevant for energy analysis were defined at the beginning of the planning process, which is favorable in case assessment tools, such as performance simulations are implemented. Furthermore, the fact that costs are only evaluated towards the end of the building delivery process means that the final building fixture stays largely undefined, making energy and heating demand predictions uncertain.

Keywords:

Building delivery process, Project planning, Project execution, Building physics aspects, Building legislation, Building project phases, Energy performance analysis.

KURZFASSUNG

Mit dem Ziel vor Augen den Bausektor zu dekarbonisieren, erlassen die Europäische Union und ihre Mitgliedstaaten zunehmend restriktive Bauvorschriften zur Verbesserung der Energieeffizienz von Gebäuden. Einerseits unterstreicht die kontinuierliche Entwicklung der Baugesetzgebung den starken interdisziplinären Charakter von Architekturprojekten. Andererseits erfordert dies auch ein umfassendes, technisches Fachwissen, um deren Inhalte anzuwenden, was den Planungs- und Bauprozesses dynamisiert.

Das Verständnis, wie bauphysikalische Aspekte in der Praxis angewendet werden, scheint von grundlegender Bedeutung zu sein, um einen Beitrag bei der Gestaltung energieeffizienterer Gebäude mitzuwirken, da hierfür nicht nur geeignete Baukonstruktionen erforderlich sind, sondern auch effiziente architektonische und technische Designs von Gebäudesystemen.

Die Fachliteratur zur Bauphysik konzentriert sich jedoch in der Regel auf theoretische und rechnerische Aspekte und lässt die praktische Umsetzung unberücksichtigt. Daher verfolgt diese Arbeit das Ziel, eine Evaluierungsmethode zu entwickeln, um zu untersuchen, wie die Aspekte Wärmeschutz und Energieeffizienz als Teil der Bauphysik während des gesamten Bauprozesses berücksichtigt werden. Dafür wird ein von der Stadt Wien mit Subventionen erbautes Wohnprojekt aus dem Jahr 2020 als Studienobjekt herangezogen und dessen Bauprozess analysiert und dokumentiert.

Die für die Durchführung dieser Studie verwendeten Quellen umfassen die Dokumentation des Projekts, von Architekturplänen und Konstruktionsdetails bis hin zu spezifischen Berichten der Projektpartner. Die Ansichten der Experten, die an der Planung des Projekts beteiligt waren, werden ebenfalls mittels Fragebögen berücksichtigt.

Die Methodik umfasst eine Überarbeitung der zum Zeitpunkt der Planung des Objekts geltenden Baugesetzgebung sowie ausgewählte Fachliteratur mit einem praxisorientierten Ansatz aus der Bauphysik. Aus diesen beiden Quellen wurde zusammen mit den Experteninterviews eine zusammenfassende Liste der bauphysikalischen Aufgaben erstellt. Als nächstes wurde der Planungs- und Bauprozess des Objekts analysiert und dessen Inhalte in deskriptive Kategorien unterteilt.

Dadurch kann gezeigt werden, welche spezifischen bauphysikalischen Tätigkeiten während des Planungsprozesses durchgeführt werden und wer die Planungsexperten sind, die für deren Umsetzung verantwortlich sind. Es konnte auch festgestellt werden, welche Änderungen an den Gebäudekomponenten zusätzliche bauphysikalische

Planungsänderungen hervorriefen und in welchen Phasen des Planungs- und Bauprozess die für die Energieanalyse relevanten Komponenten definiert wurden.

Die Ergebnisse dieser Arbeit weisen darauf hin, dass die meisten bauphysikalischen Tätigkeiten am Ende der Ausführungsphase auftreten, in welcher der Schwerpunkt auf der korrekten Planung und Ausführung von Konstruktionsdetails liegt und nicht auf den frühen Phasen, in denen die Bewertung der Gebäudeleistung noch möglich erscheint. Die Ergebnisse zeigen auch, dass in den frühen Phasen der Projektplanung wenig Zeitaufwand oder bauphysikalische Tätigkeiten erledigt werden, jedoch zu Beginn mindestens die Hälfte der für die Energieanalyse relevanten Gebäudekomponenten definiert werden. Auch die Tatsache, dass die Kosten erst gegen Ende des Planungs- und Bauprozesses beurteilt werden, bedeutet, dass die endgültige Gebäudekonfiguration weitgehend undefiniert bleibt, was die Vorhersage des Energie- und Wärmebedarfs nicht feststehend macht.

Schlagwörter:

Planungs- und Bauprozess, Projektplanung, Projektdurchführung, Aspekte der Bauphysik, Baugesetzgebung, Bauprojektphasen, Energieeffizienzanalyse.

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Last but not the least, I want to dedicate this thesis to my dad. You were always a source of motivation and inspiration in my life. This work is for you.

Arq. Soledad Di Croche

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1 Introduction

1.1 Overview

Although the laws of physics have been applied to the human shelter since ancient times, building physics (BP) as a scientific discipline is a relatively new one. Its importance grew after the global 1973 oil crisis, and has since assumed a major role mainly, but not only, in the field of energy efficiency (Künzel 2002). While in German-speaking countries the first standards aiming to improve the thermal performance of buildings date back to the 1950s, it was with the global surge of climate change related issues that the potential in the building sector to reduce CO_2 emissions started to spark interest (Bozsaky 2010).

In the European Union (EU), these developments have triggered a promulgation of directives and subsequent transpositions into national laws in Member States. The bulk of new legislation addressing energy efficiency on one side and the push for renewable resources on the other side caused also in Austria in a continuous actualization of building legislation (Austrian Energy Agency 2013).

Above all, the promulgation of the first *Energy Performance of Buildings Directive* (*EPBD*) of 2002 and the ensuing introduction of energy certificates brought changes in the dynamics of the building delivery process. Whereas till the end of the 20th century building physics was addressed in practice by architects, in the last twenty years, particularly within German-speaking areas, the building physicist has emerged as a new agent, and an important consultant involved in the building planning process (Interview 2 2020).

More stringent energy efficiency specifications, higher comfort standards, and an overall advance in research has raised building performance expectations. The tightening of requirements regarding indoor thermal comfort, thermal-, acoustic-, and visual performance, and building ecology aspects, has further accentuated the already strong interdisciplinary character of architecture projects (Pont et al. 2018). In addition, the pressure added by the constantly tightening building legislation has resulted in increasingly complex technical content, which then requires specialized expertise to handle. Thus, it can be stated that managing aspects of building physics in practice in the present day is not only a task of the building physicists but involves other project consultants and stakeholders as well.

Researchers agree that the planning and building delivery processes of architecture projects has become extensively complex in recent years. Aside from legislation constrains, the challenges faced by planners include the cyclic adaptation of the architectural design to include structural and technical building systems requirements, the multifaceted interrelationship between building elements, the constant progress made in construction technologies, cost- and time limitations, the continuous flow of data between project partners, the considerable degree of coordination steps, and the project developer and users expectations, among others (Huber et al. 2013, Pont et al. 2016).

However, little has been written about how building physics aspects are addressed in the everyday building delivery processes. Perhaps due to the relative novelty of the field, most of the literature addressing building physics does so rather from a theoretical and calculational perspective. Other aspects, such as planning fundamentals, remain widely undocumented, e.g. (i) which consultants are responsible for which tasks, (ii) how the interaction between consultants takes place, (iii) how a project should be developed from a building physics perspective, (iv) at which point of the building delivery process the building components relevant for improving energy performance are defined, or (v) which issues that may occur during the planning process require reprocessing.

1.2 Motivation

It can be considered as widely accepted domain knowledge that to reduce the total energy demand of buildings, efficient architectural- and technical building systems design are required in addition to adequate constructive solutions. Understanding how building physics aspects are incorporated and developed from a practical point of view during the building delivery process is particularly important when looking towards potentially improving the thermal and therefore energy performance of buildings. The point in time when specific building design aspects that have a strong impact on performance are defined or assessed (e.g., building form, facade design, shading elements, etc.) is of high importance. If things are decided in a cumbersome way, later improvements might prove difficult or even impossible.

Working as an architect, the author had the possibility to examine the building delivery process of a residential project built with subsidies in the city of Vienna firsthand. This building was planned by the architecture office the author works for. Being part of the planning team provided access to the comprehensive planning documentation of the project, not only from the architecture perspective but also reports and protocols provided by other project consultants, including the building physicist.

The main goal of this thesis is therefore to propose an evaluation method for building physics aspects in the building delivery process. It will examine how building physics is incorporated into the different planning stages of the case study, beginning at its first conception through project execution until its initial commissioning. To narrow the scope to one field that has been receiving more attention in current building legislation, this work focuses on thermal protection and energy efficiency aspects and does not specifically pertain to other aspects of building physics, such as acoustics and lighting assessment. This thesis also incorporates experts' opinions on the planning process in general and on the role of building physics in particular.

1.3 Research objectives

By documenting and analyzing building physics aspects in the building delivery process of a specific real-life sample project, this thesis pursues two main research objectives (RO):

RO1: Identifying, which specific building physics related tasks are performed during the different project phases, and which consultants are involved in their execution.

This objective encompasses the following research questions (RQ):

- RQ1: Are building physics related tasks and requirements in the project driven only by building legislation?
- RQ2: Which consultants are responsible for securing the correct planning and execution of building physics related construction details?
- RQ3: Do the invested working hours in each planning phases correlate with the building physics related planning efforts?

RO2: Identifying which components changes/change requirements occur during the building delivery process that require planning modifications with subsequent building physics implications.

This objective is elaborated via the following research question:

- RQ4: At which point of the building delivery process are the building components defined in a level of detail that can be considered as influencing the (final) thermal and energy performance?

1.4 Structure of the thesis

The thesis has been divided into six chapters. The first chapter presents the general motivations, research objectives and structure of the thesis.

In the second chapter, the research methodology is described. This section also contains the interviews that have been conducted with four planning experts (architects, building physicist, construction site manager and project developer) which were involved in the planning of the case study.

To acquire a better understanding of the current State of the Art of applied building physics in the building delivery process in Austria, it is important to revise the events and circumstances that have paved the way. As said by the Historian William Lund (1886-1971): *"We study the past to understand the present; we understand the present to guide the future."* Hence, chapter *3.1 Brief history of building physics* offers a review of the key developments (from a European perspective) that set building physics as a scientific discipline in motion. Thereby, the emergence of the study of building physic aspects is described, as well as its evolution and incorporation into architectural planning routines.

In the subchapter *3.2 Historical and legal framework for the energy performance of buildings,* historical events from a legislative point of view are documented. In the first part, the transposition into Austrian building legislation of the main legal acts enacted by the European Union related to the thermal performance of buildings is covered. This section describes both the historical context in which these building regulations were introduced in Austria and the mechanisms and legal framework in which they operate. The second part of this section discusses the most important set of construction provisions at municipality level that currently govern the thermal protection and energy efficiency aspects of buildings in Vienna, including those for projects built with subsidies. To be able to identify which building physics related tasks had to be performed in the case study project, it was essential to get a detailed picture of the regulations in force at the time of its planning and execution. Consequently, a summary of the main content of the *OIB-Guideline 6,* the *OIB-Guideline 3* and the *Viennese housing promotion and dwelling renovation act* has been added to the appendix of this thesis. These documents encompass all of the essential legislative acts that regulated the thermal performance of buildings in Vienna at the time of writing.

The third part of chapter 3 presents a generic building physics related tasks list based on the reviewed Austrian building legislation, on the interviews with the experts and on the specialized literature.

Chapter *4 Case study* contains the analysis of the case study. It first includes a short introduction to the project. Subsequently, the building delivery process of the case study is shown structured in project phases. Moreover, building physics aspects within each phase are documented and analyzed.

In chapter *5 Results and Discussion* the obtained results are examined and presented in a set of tables. The first table consists of a list of building physics tasks that take place in each of the project phases of the case study. Moreover, this table lists the project consultants involved in the execution of the different tasks. The second table depicts a change evaluation template. In this table, changes of the building components which affect building physics design aspects are listed together with the reason for the change and the time of occurrence. In the last section of this chapter the results are discussed and interpreted.

In chapter *6 Conclusion* the research questions are answered. A summary of the major findings of the thesis is also provided. Finally, both the limitations of the present study and further research themes are described.

2 Method

2.1 Overview

Although a considerable amount of architecture projects are planned and executed every year and the knowledge about the planning processes is being applied in the field, the integration of building physics aspects in the building delivery process have not yet been extensively documented.

In contrast, a vast field of studies pertaining to the different aspects of BP can be found. To be able to describe building physics related tasks, it is useful to start by identifying the main building physics aspects addressed in the building delivery process that are relevant for building design. Figure 1 includes a list of such aspects according to Design Building Wiki (2019):

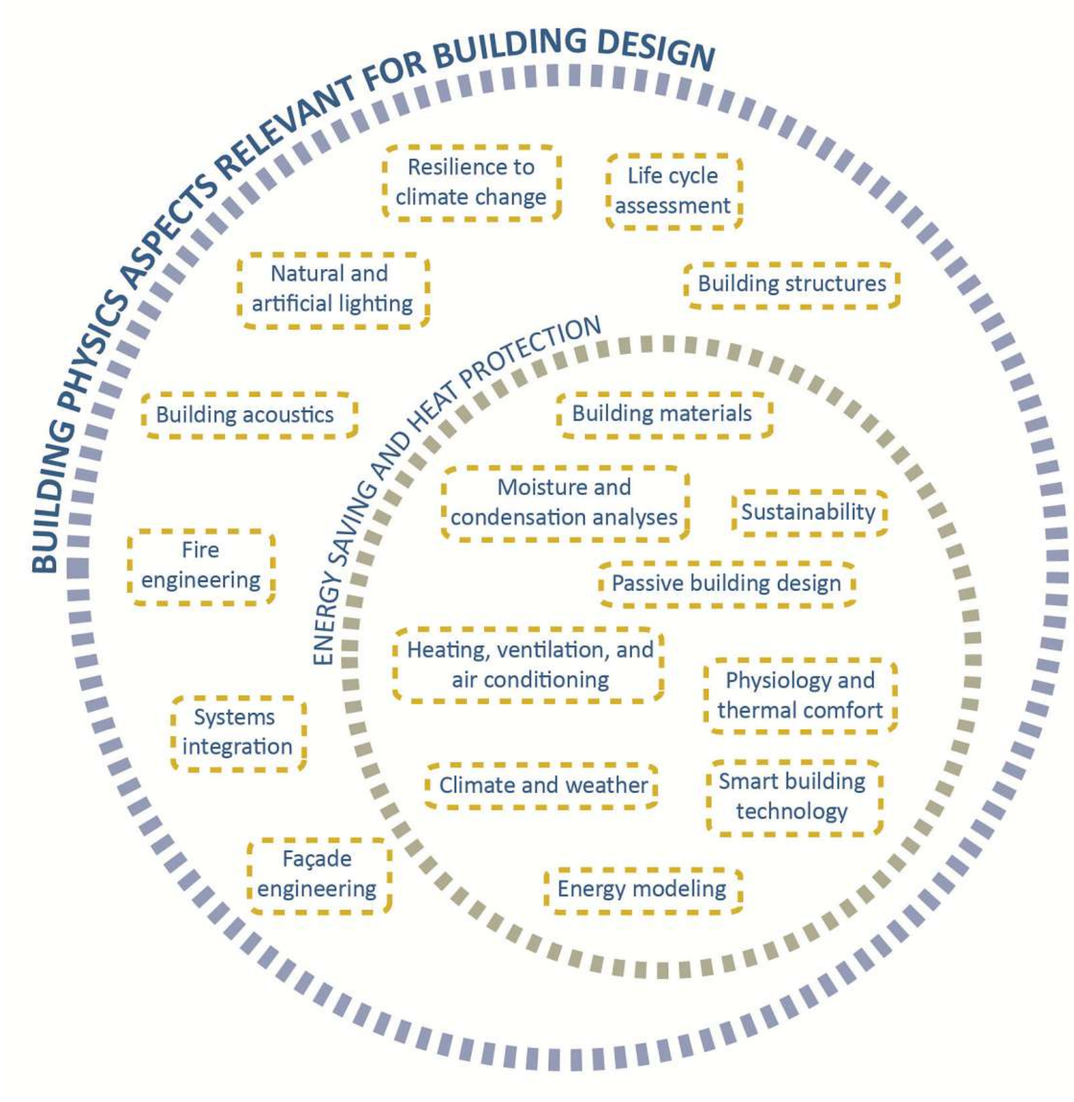

Figure 1. Building physics aspects relevant for building design (own authorship based on Design Building Wiki 2019)

As clearly visible, several planning aspects can be attributed to a subgroup *energy saving* and *heat protection*. To narrow the scope of the master thesis, the work concentrates on these building physics aspects, as it can be considered that this field is given most relevance both in contemporary building planning processes and in current building legislation.

According to the research carried out for this thesis, the aspects deriving in building physics tasks in practice are those that are either:

- mandatory by law, meaning required by current building legislation and that will end up being part of the tasks to be performed by consultants by contract;
- of interest to the project developer and the project partners; or
- the result of current scientific research and, therefore, represent the State of the Art.

Therefore, the first part of the methodology consists of generating a generic list of building physics related tasks addressed in the building delivery process, based on these sources.

The first step - to identify these tasks - requires reviewing specific building physics related building legislation pertaining to the thermal and energy performance of buildings stipulated at the time of the planning of the project provided as case study (which is the year 2016). The main legislative acts addressing energy efficiency and heat protection in Austria and Vienna are covered in chapter *3 Building physics in the building delivery process*. In addition, a comprehensive description of the *OIB-Guideline 6,* the *OIB-Guideline 3* and the *Viennese housing promotion and dwelling renovation act* is provided in the appendix. This step consists of extracting and listing potential building physics related tasks resulting from these regulations. Altogether, the list includes building legislation for the State of Vienna *(Wiener Bauordnung, WBO)*, legislation in force for building subsidies for the State of Vienna (*WWFSG* 1989/*Neubauverordnung 2007*) and national guidelines (*OIB-Richtlinien*).

The second step consists of conducting interviews with the experts that were involved in the planning process of the case study. In these interviews, the project participants are asked among other questions, which building physics aspects they addressed in the planning and execution of the project, and how. The interviews are described in more detail in subchapter *2.2 Interviews*.

The third step includes a review of literature addressing building physics aspects with a praxis-oriented approach. As previously mentioned, much of the literature in the German speaking community addressing building physics aspects do so rather from the theoretical and calculational perspective of building physics. Examples of this are the books of Pöhn et al. (2018), Willems et al. (2017), Hence (2012), Lübbe (2009), and Häupl (2007). Hence, to generate the building physics related tasks list, specialized literature was selected that has a more praxis-oriented approach, for instance the books of Mezera et al. (2018, 2017a, 2017b) and Usemann (2005). Most of the identifiable building physics related tasks in this literature focus in recommendations for the design of energy-efficient buildings and the correct execution of building physics critical construction details. Therefore, this third step also includes potential building physics tasks that are to be performed both during the planning of a project and during its construction.

The last step involves integrating the building physics tasks obtained from the three previous sources into one list of building physics related tasks. The resulting tasks are sorted into project phases. This will be explained in more detail in the subchapter *3.3 Generic building physics tasks list.*

In the second part of the methodology, the building delivery process of a residential project built with subsidies of the city of Vienna is presented. The content of this section is based on project documentation such as architectural plans, sections and views, constructional plans, details, emails, planning protocols, call for bids, contracts, reports, and documentation produced by the project partners. Here the interviews with the project partners are also included. The description addresses the different building physics aspects which influence the energy performance of buildings (thermal protection, sun protection, moisture protection, airtightness, and wind tightness), and other aspects which affect the ecological footprint of the building.

The building delivery process of the case study is also divided in project phases according to the factual planning structure in practice, as it emerges from project documentation and interviews. To make the project phases comparable, each of the phases is split into five descriptive categories: *timeframe, used tools, time effort, input,* and *outcomes*. Timeframe describes the duration of the phase till the final deliverables (plans, reports, calculations) were handed out. Used tools describes the software employed by the architects and building physicist to produce their deliverables. Time effort describes the total amount of hours invested by the architects and building physicist in each phase of the project. Input refers to additional documents and reports provided to the project participants during each phase, which were used as a reference or input data. These documents are used to add detail to the project, set planning parameters or give a framework for the planning of the project. Thus, their content is not a result of the planning process of the building but rather are used to build up or add detail to the project. In this category the building regulations, norms, and guidelines that had to be observed are not mentioned separately, as these are already described in chapter 3.2. Because each phase builds upon the deliverables and knowledge produced in the previous phase, architectural plans and other reports are also not additionally listed. These are, however, listed in the category outcomes, in which both the conceptual and the documental results of each phase are described.

Additionally, in each project phase a second subsection *project development* describes and explains the input data, the information exchange between project partners, the content of the reports and documents produced in each phase, as well as the identification of which consultants produced the documents and who is involved in their approval. All in all, the analysis focuses on the building physics related work produced by the architects (ARC), the building physicist (BPt), the building systems engineer (BSE), the project developer (PD) and the construction site manager (CSM), mostly leaving out other planning aspects as structural calculations, fire protection, acoustics, rainwater infiltration planning, and other planning aspects less related to energy efficiency and heat protection or ecological footprint.

2.2 Interviews

The interviews with the planning and execution experts involved in the project consisted of written questionnaires. The four experts that took part in the interviews were the architects, the building physicist, the construction site manager, and the project developer. Every interviewee received a tailored questionnaire per email with questions addressing their field of work and expertise. If further clarification was necessary, additional questions were delivered and answered by the interviewees per email. The questions ranged from how specific building physics aspects are evaluated, to more general questions related to the building process. The interviews also aimed to clarify how specific legislation requirements are implemented in the project and if recommendations for an efficient energy and thermal performance design are considered. The issues addressed through the questionnaires are: interest in sustainable aspects, passive design strategies, relevance of building physics aspects in architecture and their influence in the project, the planners' contractual services, specific project requirements, specific procedures for evaluation or calculation of diverse building physics aspects, planning and execution of critical construction details, building physics testing during the execution phase, the role of costs in building physics planning aspects, evaluation of the technical buildings systems and alternative sources of energy, development of the building physics field in the last twenty years, and others.

The names of the experts and the company they work for are not provided at their request, as they wish to remain anonymous. In this subchapter, a summary of each of the questionnaires is provided in English. The full versions can be found in their original language in the appendix.

Interview 1: the architecture office

Received per email: 20.10.2020, 12.01.2021 and 01.04.2021

1. Did your company have a particular interest in **promoting aspects of sustainability** in this project? If yes, which aspects?
2. Please describe in general which **specific requirements** had to be considered in the project (e.g., building optimization targets, budget, etc.).
3. In your opinion, which **aspects of building physics** were particularly **important** for the planning and execution of the project?
4. How it is decided which are the **critical details** that need to be drawn? At what point of the planning process were these critical details drawn? Were these coordinated with other consultants?
5. In your opinion, did the building physics measures **influence** the originally planned **architecture**? If so, which aspects and to what extent?
6. For the **design of facades and windows**, which aspects were considered? Were orientation and glass areas specially evaluated?
7. How do you think the **construction industry** has **changed over the last twenty years** due to the development of the building physics field?
8. Do you have any suggestions how the process/**cooperation between consultants**, planners and the construction site manager could be **improved**?
9. How many **working hours** were invested in each phase of the project?
10. According to your experience, do you consider the **building delivery process** of the case study **representative** in comparison to other building planning and execution processes?

Interview 2: the building physicist

Received per email: 07.01.2020, 25.10.2020, 11.01.2021 and 31.03.2021

1. Please describe for which **services** where you commissioned in each phase.
2. Please describe which **aspects of sustainability** and which specific requirements had to be considered in the project (e.g., building optimization targets, budget, etc.).
3. Please describe the **workflow** of your work during the different phases of the project (e.g., preparation of the energy certification, creation of the components catalog, development of details, assessment of architecture plans, building physics advice, etc.).
4. In which phase of the project was the **energy certificate** issued? Has the energy certificate been repeated in each phase? How do you **deal with changes** in planning?
5. How was the **summer heat protection** against overheating as well as the **air- and wind tightness** evaluated in the project?
6. How was the **risk of condensation** and mold formation evaluated in the project? How did you decided which constructions needed to be examined for potential condensation and mold formation?
7. How was the potential applicability of **alternative sources of energy** evaluated in the project?
8. Has software-modelling been carried out for the evaluation of **thermal bridges**? How did you decided which building components needed to be examined for potential thermal bridges?
9. In your opinion, did the results of the building simulation/energy certification/building certification **influence** the originally **planned architecture**? If so, to what extent?
10. Which **building physics services** were provided during the **execution phase**? Did you visit the construction site during that phase?
11. How were **alternative materials** evaluated?
12. In your opinion, did the planners provided **sufficient details** for the execution of important building parts? If not, what details would have been helpful?

13. How do you think the **construction industry** has changed over the **last twenty years** due to the development of the building physics field?
14. Do you have any suggestions how the process/**cooperation between consultants**, planners and the construction site manager could be **improved**?
15. How many **working hours** were invested in each phase of the project?
16. According to your experience, do you consider the **building delivery process** of the case study **representative** in comparison to other building planning and execution processes?

Interview 3: the construction site manager

Received per email: 29.09.2020, 23.10.2020 and 30.03.2021

1. From a building physics perspective, which **details**/building elements were, in your opinion, the most difficult / **problematic**?
2. Did you receive **enough details** from the architects/the building physicist for the execution of important constructions/building parts? If not, which details would you have needed?
3. How is the **correct execution** of building physics measures **controlled** on the construction site (thermal insulation, moisture protection, airtightness, critical details)?
4. The correct **execution of windows and portals** is generally considered to be very important (keywords moisture protection, airtightness, and wind tightness). Please describe the execution **procedure**.
5. Were **construction workers supervised** and instructed about the correct execution of insulation works?
6. In your opinion, are the **trade workers sufficiently qualified** to execute critical details?
7. How did you guaranteed that the increased airtightness requirement ($n50 \leq 1.5$ /h) according to the *WWFSG 1989* was achieved in the project?
8. Which of the following **measurements** were carried out during the building process? Please describe their **procedure** (number of measurements, selected rooms,

schedule, etc.): thermal insulation report, blower door test, airborne sound measurements, thermal photographs, building materials assessment, etc.

9. The tender documents state that **thermal bridges** must be avoided. How does the construction company assess this?
10. How high was the total **construction costs** per m^2? Can you make an estimate of how much of it was invested **for building physics measures** (thermal insulation, moisture protection, airtightness)?
11. In your opinion, did the **building physics** measures **influence** the originally planned **architecture**? If so, which aspects and to what extent?
12. Were you involved in creating the **information media for users**? Were building physics aspects particularly considered in this information media?
13. How do you think the **construction industry** has changed over the **last twenty years** due to the development of the building physics field?
14. According to your experience, do you consider the **building delivery process** of the case study **representative** in comparison to other planning and execution processes?

Interview 4: the project developer

Received per email: 13.10.2020, 27.10.2020 and 30.03.2021

1. Did your company have a particular interest in promoting **aspects of sustainability** in this project? If yes, which aspects?
2. How was it decided for the project which model was better for **awarding contracts** to consultants and planners?
3. Regarding building physics aspects, which **details**/building elements were, in your opinion, the most difficult/**problematic**?
4. During the competition phase, an **environmentally friendly construction site management** was considered very important. How was that implemented in practice?
5. How was the applicability of **renewable energy technologies** (heat recovery systems, photovoltaics, geothermal energy, etc.) **evaluated** in the project? At what

stage was the decision made? Did you research available subsidies (*Klimafonds*, etc.)?

6. How was it **decided** which **technical building systems** (heating, air conditioning, ventilation) should be used in the project?
7. How did you guaranteed that the **increased airtightness requirement** (n50 ≤ 1.5 /h) according to the *WWFSG 1989* was achieved in the project?
8. Which **building physic measures** were eliminated for **cost** reasons?
9. As the local construction supervisor, how often did you **visit the construction site** during the construction phase?
10. How is the **correct execution** of building physics measures **controlled** on the construction site (thermal insulation, moisture protection, airtightness, critical details)?
11. Which of the following **measurements** were carried out during the building process? Please describe their **procedure** (number of measurements, selected rooms, schedule, etc.): thermal insulation report, blower door test, airborne sound measurements, thermal photographs, building materials assessment, etc.
12. Do you see **advantages** in **subsidized housing projects** compared to privately financed ones?
13. How do you think the **construction industry** has changed over the **last twenty years** due to the development of the building physics field?
14. According to your experience, do you consider the **building delivery process** of the case study **representative** in comparison to other building planning and execution processes?

3 Building physics in the building delivery process

3.1 Brief history of building physics

To begin telling the story of building physics (in English more commonly referred to as building science) it is central to start by defining its field of studies. In specialized literature, building physics includes the study of heat protection, moisture protection, air and ventilation, acoustics, fire protection, and daylight. Designing Buildings Wiki (2019) defines it as "*a broad term that refers to our knowledge of the physical behavior of buildings and their impact on energy efficiency, comfort, health, safety, durability and so on. It is the application of the principles of physics to the built environment*". Hens (2012, p. 1) claims that it *"is broader in its approach as it encompasses all subjects related to buildings that claim to be -scientific".* Building physics is a considerably wide discipline, and a modern one. Thought by some authors as new scientific field, it remains almost *geschichtslos*, meaning that it has no written past (Künzel 2002).

Nonetheless, building physics is as old as physics itself, having its origins in philosophy. For centuries, the knowledge about building physics had being applied to simple shelter constructions and to whole urban areas and cities but in a *trial-and-error* manner. It was only towards the 16th century through the works by Galileo Galilei (1564-1642) and Isaac Newton (1642-1726) that a methodology of physical knowledge was developed, based primarily on empirical and experimental standards. This allowed physical phenomena to be explained and therefore *science* could be applied to buildings.

3.1.1 Development until the end of the First World War

The history of building physics is also the history of constructions, materials, and bioclimate architecture. Buildings have been continuously evolving ever since humans started building shelters to protect themselves against the forces of nature. Once this primary need was satisfied, humans looked for ways of improving the internal environment and comfort of their homes. One important issue was the need for an efficient form of life and habitation. As the Royal Academy of Engineering (2010) puts it *"[a]ny energy expended unnecessarily by humans on keeping warm meant less energy available for gathering food or for reproduction."*

Examples can be drawn from Ancient Greece where houses were oriented towards the south and had projecting roofs to prevent overheating in summer, keeping the rooms warm in winter (Bozsaky 2010); till pre-colonial North American native building techniques for

Tipis, using openings and double layered tent-covers to guarantee fresh air circulation through the tent in summer and preheating the air in winter before entering the space (Waldman 2006).

During the European Middle Ages, health and hygiene conditions became main issues due to dense and overpopulated cities. Buildings codes started to play an important role – the first known one issued in 1155 – (Tomlow 2007) setting out guidelines for fire protection, avoidance of smoke pollution indoors, limitations about living in basements due to poor illumination or dimensions of the inner courtyards. It was through these codes that knowledge of the young building physics discipline was collected (Bozsaky 2010).

Large-scale epidemics and water- and air contamination in urban areas led physicians (hygienists) in the 19^{th} century to investigate human habitation conditions (Bozsaky 2010). Max von Pettenkofer (1818-1901) researched the relationship between ventilation, CO_2-concentration, and indoor air quality (Hens 2012). In this period, crucial discoveries were also made, e.g., the fluid permeability of building materials and that not only air but also water vapor could pass through the pores of the building envelope (Bozsaky 2010).

From the first *caloric theory* to the distinction of forms of heat transfer (thermal radiation, conduction, convection), the empirical law of heat conduction (λ-value, 1807), the determination of heat transfer coefficient of building materials (1829), the introduction of the *Principle of conservation of energy* (1847), the discovering of *The second law of thermodynamics* (1850), the concept of entropy (1865) and formulation of *The third law of thermodynamics* (1906), till the publication of *The fundamental law of heat transfer* in 1915, there were innumerable scientific discoveries (Bozsaky 2010, Kaviany 2011) that allowed a better understanding of the physical world, opening the path to the study of building behavior. The first calculation of the heat transfer coefficient (then called k-value, today U-value) was particularly crucial, because of its role in regulating temperatures in buildings (Tomlow 2007).

Moreover, scientific progress also reached the construction technologies, with new building materials such as steel and concrete. This caused new problems because of their inefficient thermal insulation properties (Bozsaky 2010).

It is maybe due to the importance of energy efficiency in today´s building physic field that the written historical accounts of building physics seem to focus mainly on the evolution of insulation materials. Nevertheless, new developments in insulation materials originated not from the building industry, but from the need to reduce the heat losses of the steam engines that were developed during the industrial revolution (Wolkenstein 2015).

Analogous to today's requirements to reduce fossil fuel consumption due to ecological motivations, the push for energy efficiency in the 19th century came from the high costs of fossil fuels and the necessity to reduce them. Needing reliable parameters for the development of their materials, thermal insulation fabricants became the main financial supporters of research laboratories (Bozsaky 2010).

Acoustics, although not so intensively studied as other fields of building physics, were also further researched in the 19th century. The physicist Wallace Clement Sabine (1868-1919) for example, established the relationship between reverberation time, dimensions and materials, and in the 1930s Lothar Cremer (1905-1990) discovered the basic laws of sound transmission (Bozsaky 2010).

Since the mid-19th century, when heat losses in heating systems became a main research topic, the field of heating and ventilation has also gained relevance. The work in this field at certain times combined commercial activity with scientific research, helping to set high standards for heating and ventilation systems regarding security, fire protection and quality. Key agents in these fields were also the first ones world-wide to become professors at German universities (Tomlow 2007).

3.1.2 First steps towards applied building physics in modern architecture

Heat transfer tests have been conducted since the year 1907 briefly after the foundation of the laboratory for technical physics at the Technical University of Munich in Germany, which could be considered the core cell of today´s building physics (Künzel 2002). Around 1920 the term *Mindestwärmeschutz* (minimum requirements for thermal insulation) started to be used. However, the standard at that time was uninsulated components with U-values over 1.0 W/m²K (Baunetz_Wissen 2020). In the 1930s, mineral wool insulation materials were first manufactured, but they were initially implemented only in industrial buildings (Künzel 2002).

Although by this time physical knowledge had developed much further, it was not yet incorporated by architects. One primary reason for this was that the language of most building physics publications was too abstract and scientific and therefore not easily understood by architects (Bozsaky 2010). Furthermore, there was a lack of contact between architects, architecture students and building physics laboratories (Tomlow 2007).

Progress was also made internationally, not only through individual contributions, but also through several institutions in France (fields of heating and plumbing), the United States of

America (air conditioning and industrialized construction) and Great Britain (air pollution) (Tomlow 2007). According to Bozsaky (2010) the USA made important steps in the field of water vapor diffusion and condensation, as well as Germany in the 1950s, where the so-called Glaser-diagram was developed, to graphically describe vapor diffusion.

Standardization as an instrument to rationalize working methods with the goal of quality control in the German speaking regions became an important issue, put forward by the architect's organization Werkbund and later by the Bauhaus staff, and in general pushed forward in the academic and technical world. Results of this trend were the foundation of the *Deutsches Institut für Normung* (DIN) in 1917, the institute responsible for Austrian standards, *Austrian Standards International* (ASI) in 1920, and the *International Standardization Organization* (ISO) founded in Geneva in 1946.

In time, an increasing number of architecture faculties at German speaking universities were founded, as well as specialized institutes for building physics (Tomlow 2007).

According to Bozsaky (2010) the first designs that considered the principles of building physics were completed in the 1930s. The architects who were influential in the application of building physics in modern architecture were either practicing architects or architects that did their own building physics research, either through experimental houses or doing field research about building methods. At the congress CIAM IV in 1933 it was concluded that only when building physics was considered as an elemental feature in the design process, could modern architecture really evolve (Tomlow 2007).

Tomlow (2007) also suggests that this experimental viewpoint of modernist architects resulted sometimes, from a building physics perspective, in technical errors. Many of these experimental buildings brought new ideas and innovations but were carried out with the – old – building knowledge, causing construction and planning errors, such as cracks in lightweight concrete, moisture damage in flat roofs and poor thermal insulation (Künzel 2002). In this context, Hens (2012, p. 4) emphasizes: "*Architects designed buildings without any concern for either energy consumption or comfort, nor any understanding of the physical quality of the new outer wall and roof assemblies they proposed.*" Nevertheless, these criticisms as well as the collection of technical experience, contributed to bring forward building physic as a discipline (Tomlow 2007).

In the context of the reconstruction efforts after the Second World War new building materials and building systems came on the market which required research regarding their physical properties and behavior. With the introduction of the thermal insulation norm DIN 4108 *(Wärmeschutznorm)* in 1952 the term building physics came into practical use. By then *"all calculation methods were well-known by practicing architects (...). However, these elementary prescriptions included only submissive instructions about the heat transmission coefficient of building structures"* (Bozsaky 2010, p. 6).

3.1.3 Developments after the 1973 energy crisis

There was already a tendency to increase the building insulation before the 1970s, to improve comfort standards. However, because of the low prices for fossil fuel, the reduction of energy consumption was not being taken seriously. Other aspects such as fire protection and acoustic insulation seemed to be more relevant (Künzel 2002). From 1973 on there was a paradigm change, caused by the international oil crisis. Wolkenstein (2015, p. 7) explains: *"Energy efficiency as a concept stopped being a purely technical aspect and started being a distinct topic on its own, with political, economic and social implications."* Bozsaky (2010, p. 6) adds that *"the rising costs of energy and the environmental pollution made it reasonable to decrease the energy consumption of households."*

From then on thermal insulation was given a higher priority. In Germany and Austria, thermal protection norms were followed by new regulations, explanation reports and updates in building codes. The first step towards energy consumption reduction was an increase in the thickness of thermal insulation. Next came the harmonization of heating systems through the implementation of thermostatic valves and the reduction of heating losses through the assembly of airtight windows. Finally, the airtightness of the whole building was also tested and assessed. In this sense, step by step, low-energy, passive and zero-energy houses were developed (Künzel 2002).

The field of water vapor diffusion also experienced a change of concept. According to Künzel (2002) the new estimations that were possible thanks to Helmuth Glaser resulted in an overestimation of the diffusion processes. Realistic evaluations were only possible much later when processes of moisture transport due to capillary conduction could be recorded by numerical methods. The rule of thumb – *the tighter, the better* – no longer applied. The new rule was breathable materials and vapor brakes (*Dampfbremsen*) instead of vapor barriers (*Dampfsperren*).

Since the second part of the 20th century discourses on global warming and climate change boosted building physics as a discipline, especially regarding energy efficiency. Particularly in the European Union, after the introduction in 2002 of the *EPBD* and with the consequent implementation of energy certificates in Member States, the focus continued to be thermal performance. The transposing of the directive proved to be a challenge for many European countries, as calculation and implementation mechanisms had to be designed from scratch (BPIE 2014). With the introduction of the second directive, the focus moved to the designing of – *Nearly Zero Energy Buildings* – and to a further development of technical building systems and alternative sources of energy as a path to energy-efficient buildings.

Nowadays, building norms include not only requirements about heat transfer coefficients but enforce the calculation of the complete energy consumption of buildings. Current building regulations and codes also include rules for ventilation, lighting, acoustics, fire protection and moisture protection (Bozsaky 2010).

3.2 Historical and legal framework for the energy performance of buildings

3.2.1 In Austria

Overview

Energy Performance Building Directives are considered the main legislative instruments to achieve energy-efficient buildings at EU level. European directives enacted by the European Parliament and the Council are to be transposed into national law by Member States in predefined time limits. Austria, as a Federation (*Föderaler Bundesstaat*), is constituted by nine independent States whose distribution of responsibilities between the Federal Government (*Bundestaat*) and the Federal States (*Bundesländer*) is regulated in the so called *Kompetenzenartikel* of its *Federal Constitution* (B-VG 2021, art. 10-15). These jurisdiction articles declare that matters related to building legislation are regulated by the Federal States (in contraposition to a central government), through their own building codes (*Bauordnungen*), building laws (*Baugesetze*) and regulations (*Verordnungen*).

In 1993, the Austrian Federal States agreed to implement the *EU Directive 89/106/EEC on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products* (European Council 1989), and to further strengthen their collaboration in issues related to building legislation. The agreement resulted in the 1993 creation of the *Austrian Institute of Construction Engineering* (*Österreichisches Institut für Bautechnik – OIB*) which pursues the goal of harmonizing construction and building regulations across Austria (Wolkenstein 2015). The guidelines released by the *OIB* enter into force when its latest editions are anchored in the respective building codes of each Federal State, this being voluntary. Therefore, the dates of implementation differ.

It is possible not to follow the guidelines if construction solicitors can demonstrate that an equivalent level of protection is achieved. In the Federal State of Vienna, this is specified in its *Viennese Construction Ordinance* (*Wiener Bautechnikverordnung 2020 – WBTV 2020*, §2). Moreover, *OIB-Guidelines* follow the principle of *performance-oriented building requirements*, whereby target-oriented provisions are laid out in laws and regulations (level 1), technical requirements are laid out in guidelines (level 2), and methods and solutions are developed in norms and other standards (level 3). The three level of requirements are illustrated in Table 1:

Table 1. Performance-oriented building requirements (Schlossnickel 2015, p. 28)

Level 1	performance-oriented requirements	laws and regulations
Level 2	technical requirements	guidelines
Level 3	methods and solutions	norms and other standards

This means that norms should offer constructive and technical solutions but should not tighten the level of requirements established in building codes (Schlossnickel 2015). Norms are by definition qualified recommendations, i.e., are applied on a voluntary basis. In technical domains norms *"represent the State of the Art, which describes the technical possibilities at a certain point in time, based on reliable scientific findings, technology and experience, thus setting a certain quality standard"* (Mlinek 2018, p. 10). Nevertheless, in some cases legislators can make ÖNORM´s, or parts of them binding by law attaining then the legal rank of regulations (WKO 2020, Mlinek 2018).

The flooding of building legislation experienced in the last decades has led to great confusion in architectural and construction offices with respect to which guidelines or norms have hierarchy over others and if they are anchored to building codes or not. Not to mention other issues such as liability risks, higher construction and planning costs, planning uncertainties and obstacles for innovation (Dialogforum Bau Österreich 2020). The fact that there are more than 9.000 norms in the building sector clearly portrays the complexity of the issue. As Mlinek (2018, p. 69) notes: *"Planners question the technical necessity of the numerous standards, see their design options restricted and their competence questioned".*

In 1995, Austria became a full member of the European Union, and with it came the afore mentioned obligation of transposing directives into national law. The first *Energy Performance of Buildings Directive* of 2002 was transposed into Austrian federal law in 2006 in part through the *Energieausweis-Vorlage-Gesetz – EAVG* (BGBl. I Nr. 137/2006), which stipulated for the first time the obligation for building sellers or lessors to present buyers or tenants with an energy performance certificate. Just two years after this entered into force, in 2008 the EU launched the *EPBD:2010* (European Parliament, Council of the European Union, 2010), which meant an update of the *EAVG* was necessary. The *EAVG* recast (BGBl. I Nr. 27/2012), which entered into force on December 1, 2012 adding the obligation to include *"specification of certain indicators about the energy quality of the building"* in property listings (in paper and in digital form) for renting or selling, as well as exceptions of issuing energy certificates depending on building categories, and administrative penalties in the case of noncompliance.

De facto, the responsibility for the provisions for the calculation method and the content of the energy certificate resides at the Federal States within the framework of their building codes. To avoid having nine different calculation methods and performance requirements, the *Austrian Institute of Construction Engineering* issued the *OIB-Guideline 6 Energy saving and heat protection (OIB-Richtlinie 6 Energieeinsparung und Wärmeschutz)* (OIB 2015b), which was unanimously approved by all Federal States in 2007 (LGBl. Nr. 32/2005). With it, the Federal States adopted a uniform method for the calculation of energy performance indicators, which is subsequently based on the correspondent national ÖNORM´s as well as known preexistent procedures.

Since the first issuance of *OIB-Guidelines* (there are six in total), there have been three more revisions: in 2011, 2015 and the latest one in 2019. Of relevance to this thesis are the ones launched in 2015, since the building permit of the case study was obtained in 2016. Of the last package of guidelines, the *OIB-Guideline 6:2019* was updated after the last *EPBD:2018* (European Parliament, Council of the European Union, 2018) was enacted and entered into force in Vienna on February 1, 2020 through its inclusion in the *WBTV 2020* (LGBl. Nr. 04/2020).

As discussed earlier, the Viennese building code sets mainly target-oriented building requirements. Some of these are replicated in the *OIB-6* Guideline *Energy saving and heat protection* and in its technical attachment *Guideline for energy performance of buildings* (OIB 2015c).

3.2.2 In Vienna

Overview

Because the case study is situated in Vienna, apart from federal legislation, this thesis will henceforth refer exclusively to building legislation relevant to the Vienna Federal State, which is stipulated in the Viennese building code (WBO 2021).

The first *OIB-Guideline 6:2007* was originally bound to Viennese state law through the *Techniknovelle 2007,* a change in the *WBO* promulgated in 2008 (LGBI. Nr. 24/2008) in combination with the *WBTV* (LGBl. Nr. 31/2008).

In 2015 the *Energieausweisdatenbank-Verordnung (EADBV)* was introduced in Vienna, through which the *Wiener unabhängiges Kontrollsystem für Energieausweise – WUKSEA* online database was created with the explicit purpose of digitally collecting energy certificates of Viennese buildings emitted after 2015 (LGBl. Nr. 23/2015). The obligation to register energy certificate records is accordingly specified in the §118 (a) of the *WBO* as well as in the *Wohnungregister-Gesetz* (Stadt Wien 2020a). Presently, is even possible to upload energy certificates automatically through software packages that work with geodata services, as is the case of the *ArchiPHYSIK* software (A-Null 2021).

In addition to the online collection of energy certificates, the §118 (3c) of the *WBO* stipulates that three years after notification of completion of newly constructed buildings, building owners have the obligation to deliver a document including data that relates the energy requirements calculated for the building in question to the effective consumed energy per year for that three-year period, specifying whether the energy consumed includes the energy necessary for the energy generation process.

Other relevant provisions that influence the energy performance of new buildings are those related to technical building systems. The enactment of the *Techniknovelle 2007* in the Federal State of Vienna responded in part to the compulsion of implementing alternative systems for new buildings, as set out in article 5 of the *EPBD:2002*. On those grounds, the *WBO* includes some sections with requirements. Among them, §88 (1) requires buildings and building parts to be executed in accordance with technical construction requirements listed in corresponding sections. The *Energy saving and heat protection* requirements – nr. 6 of six technical requirements in total, as listed in §88 (2) – are formulated in section 7 of the *WBO*. In it, §118 (1) stipulates that buildings should be built in a way that limits the energy required for their associated needs (heating, water heating, cooling, ventilation, and lighting according to what is considered the State of the Art. The aspects that have to be taken into consideration to assess the amount of energy a building requires are listed in §118 (2), i.e., the type and purpose of the structure, ensuring the room climate is appropriate for the intended use, the avoidance of unfavorable effects such as insufficient ventilation or summer overheating, and the proportionality of effort and benefit in terms of energy saving.

In addition, §118 (3) requires new buildings to implement highly efficient alternative systems when technically, ecologically, and economically feasible, including decentralized energy supply systems based on energy from renewable sources, cogeneration, district or local heating or cooling, heat pumps, etc.

In §118 (3a), it is stated that the feasibility of highly efficient alternative systems has to be evaluated by professionals with relevant training or by accredited test centers. In this case, the field of incumbency extends beyond the building physicist, as these tasks are normally carried out by building systems engineers, whereas the evaluation of the technical building system's economic workability lies within the realm of the investor.

In the last section related to building technologies, §118 (3d) offers alternatives in the case that highly efficient alternative systems for heating and water heating prove not to be practicable. These are solar thermal, photovoltaics and heat recovery systems. This subsection of the *WBO* was added after 2019 and, therefore, has no validity for the project referred to in this thesis.

Another set of regulations that were also included in the first *EPBD:2002* (European Parliament, Council of the European Union, 2002) as part of the efforts to improve the energy performance of buildings are those dealing with boiler inspections (article 8) and air-conditioning system inspections (article 9). These provisions were originally part of the *Viennese fire authority, air monitoring control and air-conditioning act* (*Wiener Feuerpolizei-, Luftreinhalte- und Klimaanlagengesetz – WFLKG*; LGBI. Nr. 35/2007). However, this act was ruled out in 2016 and those provisions were later included in the *Viennese heating and air-conditioning act (Wiener Heizungs- und Klimaanlagengesetz – WHKG*) of 2015 (LGBl. Nr. 14/2016). These mandatory inspections aim to ensure that these systems meet the requirements regarding emission limit values, exhaust gas losses and the use of permissible fuels (Stadt Wien 2020b) as well as pursue the goal of keeping systems working efficiently and with an adequate dimensioning.

Energy performance requirements for building subsidies in Vienna

Austria has a long tradition of housing subsidies. They were first introduced during the industrial revolution because of the housing shortage, which, particularly in Vienna, required new concepts to create quarters for the urban masses. The first organization leading the way was the *Kaiser Franz Joseph I. Jubiläums - Stiftung für Volkswohnungen und Wohlfahrtseinrichtungen* founded in 1898, which, with help of the *Vienna urban renewal fund,* subsidized the early form of social housing (Eigner et al. 1999). Since then, housing subsidy policies have developed steadily by virtue of new forms of subventions and numerous legislative changes, intensifying from the middle of the 20th century on.

Profound changes began taking place after the year 2000. Whereas with time competencies of the Federal Government in the matter started to shift to the Federal States, the changes introduced with the *Zweckzuschuss-Novelle 2001* (BGBl. I Nr. 3/2001) included for the first time, climate policy objectives within the framework of housing subsidies (as well as a loosening of the intended purposes of the funds). However, environmental requirements for housing subsidies were specified only after the enactment of the *Vereinbarung gemäß Art. 15a B-VG zwischen dem Bund und den Ländern über gemeinsame Qualitätsstandards für die Förderung der Errichtung und Sanierung von Wohngebäuden zum Zweck der Reduktion des Ausstoßes an Treibhausgasen* in 2006 (BGBl. II Nr. 19/2006 Teil II). The competence on housing subsidies was ultimately fully transferred to the Federal States after the enactment of the *Finanzausgleichsgesetz 2008* (BGBl. I Nr. 103/2007), whereby the Federal States' expenditure' autonomy grew, with the Federal Government only retaining capabilities regarding the compliance with energy building performance standards and the redistribution of subsidies from new constructions to renovations (Fröhlich 2012). Finally, with the enactment in 2009 of the *Vereinbarung gemäß Art. 15a B-VG zwischen dem Bund und den Ländern über Maßnahmen im Gebäudesektor zum Zweck der Reduktion des Ausstoßes an Treibhausgasen* (which replaced the BGBl. II Nr. 19/2006) the Federal States agreed, when granting building subsidies, on implementing even tighter energy requirements in comparison to the ones set out by the *OIB-6* (BGBl. II Nr. 251/2009, article 3).

Presently, the framework under which Vienna finances the construction of new residential and office buildings as well as renovations, is the *Viennese housing promotion and dwelling renovation act (Wiener Wohnbauförderungs- und Wohnhaussanierungsgesetzes – WWFSG 1989 / Neubauverordnung 2007)* (LGBl. Nr. 18/1989, LGBl. Nr. 27/2007).

The parties involved in granting of building subsidies are:

- *Wohnfonds_wien*: a non-profit organization that acts as a coordination point between property developers, homeowners, and the municipal departments of the city of Vienna (in particular funding agencies).
- *MA50 – Housing subsidy and arbitration board for housing law matters (Wohnbauförderung und Schlichtungsstelle für wohnrechtliche Angelegenheiten)*: the government department responsible for matters related to funding law; and
- *MA25 – Technical urban renewal (Technische Stadterneuerung)*: the government department providing advice and help with technical questions (Stadt Wien 2020c, Wohnfonds_wien 2019).

The role of Wohnfonds_wien is relevant since the organization defines a set of objectives for residential buildings which have to be observed. These objectives influence building physics aspects since some of them are oriented directly at improving building energy performance. Others do so indirectly through sustainability requirements, such as improving climate conditions on site through more vegetation and greenery, sustainable mobility, flora and fauna protection, implementation of renewable sources of energy, planning and constructing according to the principle of less ecological life-cycle costs, etc.

The *WWFSG 1989* together with the *Neubauverordnung 2007* define a set of conditions required to be granted a subsidy, as well as call for new buildings to comply with heightened energy performance requirements. These building performance requirements were additionally summarized in 2011 in a document published by MA25, launched under the name *Guideline No. 1 of the MA 25 on increased thermal insulation requirements for subsidized apartment buildings according to the WWFSG 1989* (MA25a 2011). This document was valid at the time the building permits of the case study were processed. A detailed description of the content of this guideline in its 2011 form is also available in the appendix.

The requirements set for subsidized buildings were updated in the year 2018, as permissible materials or maximum heating demand values (MA25b 2018). A general analysis of the changes indicates that:

- A new residential building built with subsidies, for which building permits were granted through the end of 2016 had 30% better energy performance than buildings without subsidies in the same period.

- A new residential building to be built with subsidies, for which building permits are to be granted from 2021 on, will have a 10% better performance than buildings built with subsidies granted through the end of 2016.
- A new residential building to be built with subsidies, for which building permits are to be granted from 2021 on, will have the same energy performance as buildings to be built without subsidies in the same period. Thus, an improved, reduced heating demand is no longer a condition to be granted building subsidies from 2021.

3.3 Generic building physics tasks list

As explained in chapter *2 Method*, in order to set a first structure of analysis of building physics tasks in the building delivery process of the case study, this section offers a listing of building physics considerations that must or might be taken into account in each of the planning phases of a given project. Its rendering is based on the reviewed building legislation, interviews with the planning experts, and specialized literature that have a praxis-oriented approach to BP.

Building projects are traditionally executed following the so-called sequential planning model (Müller 2011). Following this model, the project process is conceptually divided into structured phases, which are differently defined. For example, the *ÖNORM B 1801-1 Bauprojekt-und Objektmanagement* (ASI 2015) identifies six sequential phases, whereas the *Federal Chamber of Civil Engineers* (Bundeskammer der ZiviltechnikerInnen 2016) divides the planning services of building physicists, although not sequentially, into nine phases. Authors such as Usemann (2005) also describe the project phases for designing efficient buildings using the previously mentioned model. Table 2 offers a comparison of these two models:

Table 2. Comparison of project phases

ÖNORM B 1801-1	Federal Chamber of Civil Engineers and specialized literature
Project development	LPH1 Project evaluation
Preparatory phase	LPH2 Preliminary design phase
Preliminary design phase	LPH3 Design phase
Design phase	LPH4 Building permit phase
Execution phase	LPH5 Execution planning
Commissioning phase	LPH6 Call for tender
	LPH7 Execution supervision
	LPH8 Object supervision
	LPH9 Object operation

This schematic division describes an ideal situation. It is not unusual that difficulties are encountered during the planning process in a given phase that require going back to a previous phase (Greiner et al. 2005), for example to rethink a detail that cannot be executed as originally planned.

In the first step of the methodology, the chosen delimitation of phases is grounded in the *ÖNORM B 1801-1* (ASI 2015) but adapted to the division of phases proposed in the specialized literature and in the interviews. The reason for this is not to alter the theoretical division of tasks proposed by these two sources, which are different from one another. In the case of tasks based on building legislation, which do not have a specific phase, these are attributed to the project phases according to their content and description. In some cases, these are repeated in different phases. This will be later contrasted to the factual division of phases in the building delivery process of the case study.

The division of project phases in the generic building physics tasks list is the following:

- P1 Development phase/preliminary design phase
- P2 Design phase
- P3 Building permit phase/call for tender phase
- P4 Execution phase
- P5 Building commissioning phase

It is important to mention that in some cases there are differences between the content in literature and in the interviews. Some aspects or tasks collected in the list based on the literature might be evaluated in later stages according to the interviews, be repeated in more than one stage or not be considered at all. To support the objective of this thesis, the generic list includes all identified building physics tasks from the three sources, as there may be differences with other projects regarding which building physics tasks are performed.

What is more, although tasks derived from legislation are, in fact mandatory, not all tasks derived from specialized literature are. As previously mentioned, many of the tasks emerging from literature point out to an effective design of energy-efficient buildings. These can, therefore, be described as recommendations, and should not be defined as objective tasks but rather aspects that have to be evaluated in the building delivery process. Therefore, I additionally classified the building physics tasks in the generic list in three types:

- Primary tasks (PT): these tasks can be performed in different phases of the planning but are mandatory and therefore unavoidable. These are normally the result of legislation and/or contract specifications. For example, the *OIB-Guideline 6* foresees the implementation of highly efficient alternative systems. This translates in the list in the form of a primary task-evaluation/implementation of highly efficient alternative systems (HEAS).
- Recommended tasks (RT): these are specific actions that influence the building thermal performance but are not necessarily mandatory. These emerge from building legislation as recommendations or from specialized literature. An example of this type of task is given in the *WWFSG 1989* in which Intermediate blower door measurements during the construction process are recommended.
- Intrinsic tasks (IT): these includes aspects that may or may not considered at all. They frequently emerge as input data, first or intermediate steps necessary to execute primary tasks. These tasks are often proposed in specialized literature, for example, the definition of operative temperatures in summer and in winter.

The final classification of building physics tasks according to the building project phases is shown in Table 3:

Table 3. Generic list of building physics tasks

BUILDING PHYSICS TASKS	**TASK TYPE**
P1 Development phase	
General analysis of building physics prerequisites and clarification of framework conditions	PT
Indoor environment design:	
Definition of operative temperatures in summer and in winter	IT
Definition of operative temperatures in transitional seasons	RT
Definition of indoor air quality	RT
Definition of required natural room illumination	PT
Definition of required artificial room illumination	PT
Building zoning:	
Definition of heated and non-heated rooms	IT
Building zoning considering building use, building construction, usage profiles, 4 K criteria, and technical building systems	IT
Technical building systems:	
Energy-supply concept: evaluation/implementation of highly efficient alternative systems (HEAS)	PT
Energy-supply concept: evaluation/implementation of renewable energy sources (solar thermal, photovoltaics, or heat recovery systems) if the implementation of HEAS is not possible	PT
Researching of available subsidies to implement renewable energy technologies in the project	RT
Summer heat protection:	
Evaluation if natural ventilation during the night is sufficient (considering security and privacy requirements, surrounding noise, insects, etc.)	RT
Calculation of the emission area-related effective storage mass for the most unfavorable rooms in residential buildings (summer heat protection)	PT
Calculation of the cooling requirements in non-residential buildings (summer heat protection)	PT
Assessment if shading devices are needed for the reduction of solar gains during day (summer heat protection)	PT
If mechanical cooling is needed, assessment of on-site energy production	RT
Elaboration of a building physics concept considering norms and regulations:	
Definition of which thermal performance level has to be achieved according to building legislation, subsidy regulations and project developer objectives	PT
Issuing of a catalogue of building components	PT

Issuing of the energy certificate (calculation of the U-values of transparent and opaque building components)	PT
Assessment of building physics aspects (thermal insulation, summer heat protection, moisture protection, airtightness, and wind tightness) in architecture plans, in consultation with the other project parties	PT
Preliminary negotiations with local authorities and other parties involved in the planning for clearing the approval capability of the project	PT
Assessment of passive solar energy through transparent components:	
Optimization of windows with south orientation	RT
Optimization of the facade to glass surface ratio	PT
Evaluation of windows parameters considering summer heat protection	PT
P2 Design phase	
Assessment of building plans, the building envelope and of building parts:	
Redefinition of the building thermal zones and of conditioned rooms, if necessary	IT
Concept to guarantee compliance with maximum values for air exchange rate n50 according to the *OIB-6* or to the requirements for building subsidies	IT
Selection of materials that do not hold greenhouse gasses if applying for building subsidies	PT
Issuing of a catalogue of building components	PT
Issuing of a details catalogue to guarantee a correct evaluation of week points and correct execution of these details later during the building execution phase	PT
Assessment of building physics aspects (thermal insulation, summer heat protection, moisture protection, airtightness, and wind tightness) in construction details, particularly of projecting components, parapets, terraces, component joints, geometric thermal bridges, etc.	PT
Assessment of building physics aspects (thermal insulation, summer heat protection, moisture protection, airtightness, and wind tightness) in architecture plans, in consultation with the other project parties	PT
Issuing of the energy certificate (or updating the input data), checking compliance with energy performance requirements (*OIB* or for building subsidies)	PT
Technical building systems:	
Selection of HVACR systems (heating, ventilation, air conditioning) for the building	PT
In case exhaust air systems are implemented, controlled air supply has to be guaranteed, if applying for building subsidies	PT
Air supply and air exhaustion systems (if built combined) equipped with a heat recovery device, if applying for building subsidies	PT
Installation plans that guarantee compliance with minimum requirements for the insulation of conducts	PT
Approval by MA25, MA50 and the property advisory board in case of design and component changes in the project	PT

Recommendations for energy-efficient buildings:	
Assessment of the compactness of the building design, without facade projections	RT
Building oriented to the south, with windows to the east, west and north not bigger than the minimum requirements for room illumination	RT
Avoiding overhanging building components, or thermally partition them	RT
Minimize surface area between heated and non-heated volumes	RT
Compare prices of thermal insulating materials with the same U-values that are to be applied in the building envelope before selecting them	RT
Heating and hot water pipes should be located inside the building envelope	RT
The length of supply pipes should be kept as short as possible	RT
P3 Building permit phase	
Issuing of the energy certificate (or updating the input data), checking compliance with energy performance requirements (*OIB* or for building subsidies)	PT
Evaluation of further possible measures to reduce energy consumption	RT
Evaluation of alternative concepts/materials to reduce building costs	PT
Selection of materials that do not hold greenhouse gasses if applying for building subsidies	PT
Implementation of life-cycle analysis	RT
Implementation of life-cycle cost analysis (maintenance, cleaning costs, etc.) for the recommendation of materials	RT
Assessment of building physics aspects (thermal insulation, summer heat protection, moisture protection, air- and wind tightness) in architecture plans, in consultation with the other project parties	PT
Assessment of building physics aspects (thermal insulation, summer heat protection, moisture protection, air and wind tightness) in construction details, particularly of projecting components, parapets, terraces, component joints, geometric thermal bridges, etc.	PT
Assessment of windows-, French windows- and exterior doors constructions, and building openings, regarding thermal performance	PT
Assessment, planning and dimensioning regarding the protection against wind-driving rain and joint permeability of windows, French windows, exterior doors and similar building openings	PT
Calculation of water vapor diffusion according to the Glaser method; recommendations in case additional vapor barriers are deem necessary	PT
Assessment of potential construction- and geometric thermal bridges; definition if additional thermal insulation measures are necessary	PT
Definition and dimensioning of sun protection measures and their location	PT
Assessment, planning and dimensioning of waterproof barriers on cold roofs (rear-ventilated constructions) and warm roofs, as well as on green roofs, terraces, balconies etc.	PT
Assessment, planning, and measures listing regarding wind-driving rain on rear-ventilated facades and EWIS facades	PT

Assessment if targeted material costs were achieved	PT
Issuing of building physics documentation for submission to the building authorities including:	
Evidence of compliance with thermal insulation requirements for opaque and transparent components	PT
Evidence of compliance with the required energy indicators (energy certificate)	PT
Evidence of compliance with summer heat protection requirements	PT
Submission of energy certificate records to the municipal authority (WUKSEA database)	PT
P4 Execution phase	
Assessment of building physics aspects (thermal insulation, summer heat protection, moisture protection, airtightness, and wind tightness) and final approval of construction plans from executing companies (window and portal details, locksmith plans, etc.)	PT
Assessment of building physics aspects (thermal insulation, summer heat protection, moisture protection, airtightness, and wind tightness) and final approval of polishing plans	PT
Assessment of building physics aspects (thermal insulation, summer heat protection, moisture protection, airtightness, and wind tightness) and final approval of construction details, particularly of projecting components, parapets, terraces, component joints, geometric thermal bridges, etc.	PT
Assessment of windows-, French windows- and exterior doors constructions, and building openings, regarding thermal performance	PT
Calculation of water vapor diffusion according to the Glaser method; recommendations in case additional vapor barriers are deem necessary	PT
Assessment of potential construction- and geometric thermal bridges; definition if additional thermal insulation measures are necessary	PT
Assessment, planning and dimensioning of waterproof barriers on cold roofs (rear-ventilated constructions) and warm roofs, as well as on green roofs, terraces, balconies etc.	PT
Updating of input data in the energy certificate and checking of compliance with energy performance requirements (*OIB* or for building subsidies)	PT
Clearing of building physics related questions in the building site in case specific issues emerge	PT
Planning of construction process workflow for prevention of unwanted moisture penetration	RT
Actions to accelerate the drying of building moisture	RT
Checking the quality of building components, materials, and assembly methods (correct execution of the building airtightness concept)	RT
Controlling whether the required U-values of insulation materials, wall materials, mortar and window glasses and frames match the values specified in the delivery receipt when materials are delivered in the construction site	RT
Airtightness test (blower door test), documenting and delivering of results to MA25 (for building subsidies)	PT
Intermediate measurements of the airtightness during construction process, as defined for building subsidies	RT
Compliance with minimum requirements for the insulation of conducts	PT

Documenting and delivering of:	
Building user manual for occupants	RT
Building user manual for operational managers	RT
Replacement plans: issuing and delivery of building physics documentation for the municipal authority	PT
Issuing of building physics documentation for the completion notification to the municipal authorities	PT
Submission of energy certificate records to the municipal authority (WUKSEA database)	PT
Publication of energy performance certificates for buyers or tenants	PT
Additional recommendations for energy-efficient buildings:	
Selecting thermal insulation materials than have similar thermal conductivity values, in case they are mixed-up during construction works	RT
Specify type and thermal conductivity values of insulating materials in all building plans	RT
Detail planning of all building component connections, no building details should be left open to be solved or decided by the construction workers during construction works	RT
Briefing the construction site manager by the building physicist or by the architect regarding potential problematic details that require particular attention by their execution	RT
Supervision and instruction of construction workers during execution works of the thermal insulation	RT
Supervision of the execution of moisture barriers and wind barriers, considering that it is extremely difficult to correct problems later	RT
P5 Building commissioning phase	
Presenting factual energy consumption of the building 3 years after the building completion, in each of those 3 years	PT
Implementation of a monitoring system to check minimum and maximum optimal values (heating, cooling, airtightness) achieved in the usage phase	RT
In case of large deviances between calculated and factual heating values:	
The correct performance of the technical building systems should be checked	RT
Additional recommendations or personal consultation should be offered to building users	RT
Construction defects should be identified	RT
Implementation of a building certification system (green building certificate)	RT
Reglementary control of boilers and air conditioning systems	PT

4 Case study

4.1 Object presentation

The residential housing project used as case study was built within the framework of a housing developer competition in the context of a master plan for a new urban development in the 21st district in the city of Vienna. The aim of these developer competitions is to secure the realization of socially sustainable, high quality, innovative and ecological residential buildings, also targeting their affordability (Wohnfonds_wien 2020). By participating in the competition, project developers had the possibility of buying the plot of land they applied for (if they won) in the future urbanization, to an affordable price. Candidates had to apply in an assembly consisting in a project developer, a landscape planner (LP), and an architecture office. At the end of the competition phase the judges assessed the projects according to the *four pillars of sustainability model* (economy, social sustainability, ecology, and architecture), recommending or discouraging the construction of the project. In the case of a successful outcome at the competition, the project developer had committed to build the project according to the architectural design, the concept of social sustainability, the maximum construction costs, and the ecological concept. These were all binding commitments and represent the business basis for the sale of the plot in question. Additionally, winners committed themselves to participate in the subsequent dialogue-oriented development process for the project area.

In Table 4 hard facts about the case study are presented:

Table 4. Case study basic data

Zoning and development plan	Building land – mixed building area GB, building class IV (max. 21 m), closed construction with the provisions 50%, BB 1,2,17.
Additional provisions	Plot areas that are not built or used as access, maneuvering areas or parking had to be designed as green areas; roof areas of more than 12 m² had to be designed as green roofs.
Plot size	2.335 m2
Usable area	Approx. 5.300 m² net floor area built in two buildings (5.013 m² net living area).
Construction costs	1.720 €/m²
Uses	80 apartments divided in two point-houses, one office, six shared residence units, one rental apartment, one communal room for the neighborhood, four communal facilities for residents, one vegetable garden, two communal loggias, two bikes and buggies storage rooms, cellar with storage compartments, one office container, one bike workshop container.
Building shape	Partially cubic point house pair, with bay windows (winter gardens) and loggias in the facade, two floors height communal loggias on the north facade, setback in the rooftops, setback on the ground floor. Six floors plus rooftop.

Figures 2 to 5 show the floor plans, section, and photos of the project:

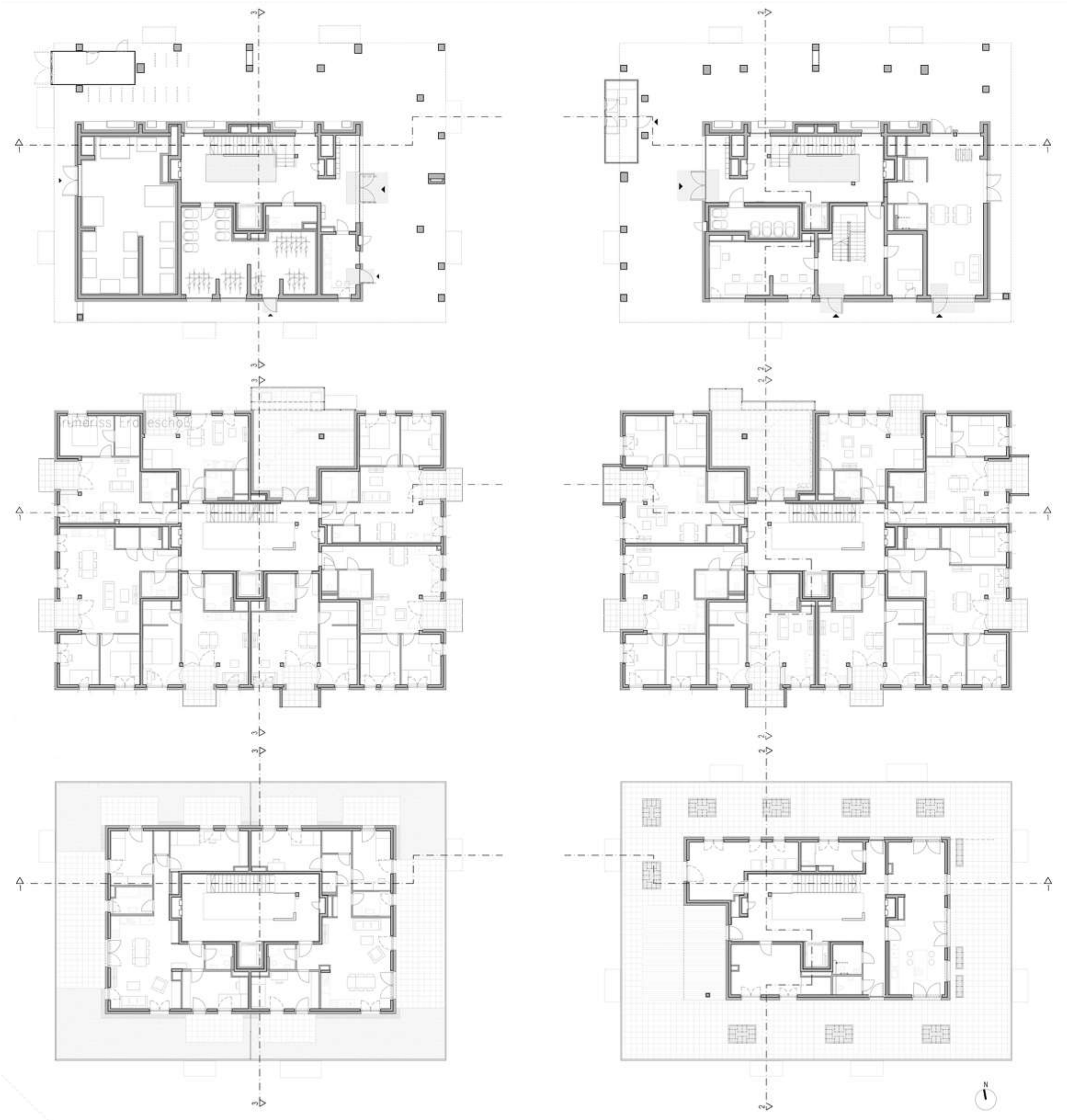

Figure 2. Ground-, third- and top floor plans (Architecture office 2020)

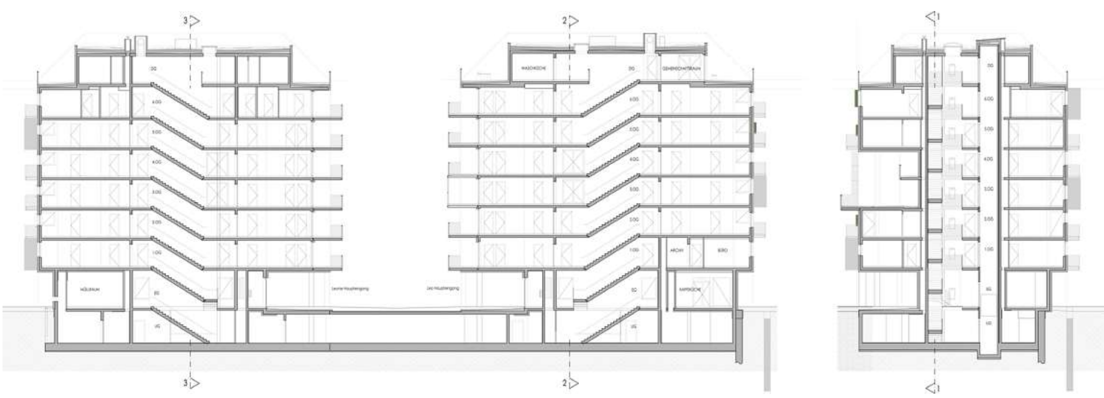

Figure 3. Longitudinal and cross sections (Architecture office 2020)

Figure 4. South facade (Hawelka 2020)

Figure 5. North facade (Hawelka 2020)

4.2 Project phases

The building delivery process of the case study is also divided in the project development phases as they were structured in the reality. This is defined in the corresponding contracts between the project developer and the experts, which are signed in the second phase after the architecture competition is awarded to the project developer.

Table 5 offers a comparison between the project phases in the building delivery process of the case study and the generic list of building physics tasks:

Table 5. Comparison of project phases

Generic building physics tasks list	Case study
P1 Project development/preliminary design phase	P1 Development phase (1st competition phase)
P2 Design phase	P2 Preliminary design phase (2nd competition phase)
P3 Building permit phase/call for tender phase	P3 Design and building permit phase
P4 Execution phase	P4 Call for tender phase
P5 Building commissioning phase	P5 Execution phase
	P6 Building commissioning phase

The structure is very similar, with the main difference in the P4 Call for tender phase which is addressed as a separated phase in the case study. This phase is also – temporarily – detached from the other phases. The P2 Preliminary phase is also considered as an individual phase and corresponds to the second phase of the developer competition, in which only the winners of each plot continued to participate. Finally, in the case study the P3 Building permit plans phase in the project was also merged with the design phase.

As explained in the methodology, this section offers an analysis and documentation of building physics aspects in the building delivery process of the case study. Here the generic list of building physics tasks is used as a guide to identify which of the tasks were in fact performed in the building delivery process of the case study.

Additionally, in the appendix section, supplementary project documentation is provided. In particular, the final architecture plans as they were delivered at the end of each project phase are presented, to offer a clearer idea of which level of detail is to be attained at the end of each project phase.

Figure 6 shows the timeframe of the planning and execution of the case study, divided in project phases:

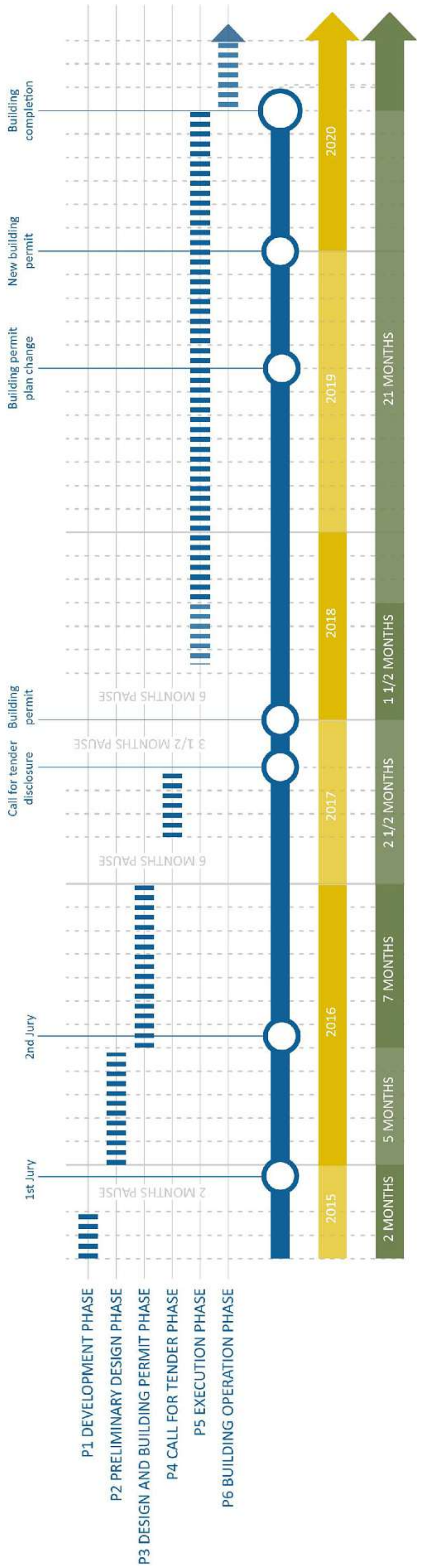

Figure 6. Project timeframe (own authorship)

4.2.1 P1 Development phase (1st competition phase)

Overview

In this section, the content of the descriptive categories *timeframe, tools, input, time effort* and *outcome,* correspondent to the P1 Development phase is summarized in Table 6:

Table 6. P1 Descriptive categories

TIMEFRAME	TOOLS
End of August 2015 - end of October 2015 (two months)	AutoCAD, SketchUp

INPUT	TIME EFFORT	
Documentation	**Hours**	**Consultant**
Application procedure for assemblies – tender text	412,25	ARC
Smart city Vienna framework strategy	0	BPt
STOP climate killer in the construction sector		

OUTCOME	
Concepts/Designs	**Consultant**
Project area mobility concept	All
Project area green spaces concept	All
Architectural concept, net m2 living area	ARC
Structural concept	SE
Documentation	
Landscape plan	LP
Architectural plans, sections, 3D-visualization, sketches	ARC

Project development

The main bases that define the objectives and characteristics of the projects that had to be addressed by architecture offices and project developers participating in the competition were laid down in the document called *Application procedure for assemblies – tender text* (Wohnfonds_wien 2015). This tender specification was developed by the awarding authority in cooperation with wohnfonds_wien. Some relevant characteristics of the project, namely ecological requirements, were set in the masterplan in the context of the *Smart city Vienna framework strategy* (Stadt Wien 2014), although the main aspect related to thermal performance was the green spaces that had to be planned.

During the first planning phase, only the architects, the landscape architect and the project developer took part in the planning process, except for one consultation with the structural engineer (SE) in which the building structure proposed by the planners was assessed.

Building physics was concentrated on the energy-supply concept, i.e., the implementation of district heating, and the insulation thickness of the thermal envelope. The assumptions for a realistic thickness for the insulation of outer walls directly impact the net living area of the project. This is important because in later stages of the planning process, the planners have to stick to this net living area, not only because of the maximum costs per m^2 defined by the *WWFSG 1989*, but also because a reduction would represent a financial loss for the investor.

As it was planned to build the project with building subsidies, there were additional energy performance requirements directed to guarantee a high of the building as stipulated in the *WWFSG 1989*, but these were at this stage not part of the planning whatsoever.

From the beginning it was also defined that the use of construction materials that hold greenhouse gasses was not permissible. Applicants were provided with a Greenpeace document called *STOP climate killer in the construction sector, alternatives to construction products with HCFC/HFC/SF6* (Greenpeace 2003). The document states that HCFCs have been banned for insulation materials in Austria since the year 2000 (also in the EU as well as imports from third countries). HFCs however are not forbidden neither in Austria nor in the EU, and the same applies to SF6 which is used in sound-damping windows. The information brochure from Greenpeace provides an overview of alternative, HFC-free products. Planners had to develop a strategy to comply with this requirement.

4.2.2 P2 Preliminary design phase (2nd competition phase)

Overview

The content of the descriptive categories *timeframe, tools, input, time effort* and *outcome,* correspondent to the P2 Preliminary design phase is summarized in Table 7:

Table 7. P2 Descriptive categories

TIMEFRAME	TOOLS
January 2016 - end of May 2016 (five months)	AutoCAD, SketchUp, Rhino, ArchiPHYSIK

INPUT	TIME EFFORT	
Documentation	**Hours**	**Consultant**
Standard catalogue of building parts for subsided projects	1457,25	ARC
Standard building specification and equipment description	40	BPt
Design parameters from the project developer		
Economic parameters and planning factors for subsidized residential construction projects in Vienna		

OUTCOME	
Concepts/Designs	**Consultant**
Deepened project area mobility concept	All
Deepened project area green spaces concept	All
Deepened architectural concept, facade design	ARC
Deepened structural concept	SE
Materialization of building components	All
Energy efficiency concept	BPt
Technical building systems concept	BSE
Documentation	
Architectural plans, sections, views, model, renders, sketches	ARC
Landscape plan	LP
Catalogue of building parts	BPt
Energy certificates	BPt
Technical building systems report	BSE

Project development

Energy supply and thermal performance requirements

There were dialogue-oriented workshops taking place in parallel to the project planning, in which alternative sources of energy for the whole project area were evaluated. These (both solar energy and gas from electricity) were rejected because it meant additional costs for the project developers. Regarding the heating and hot water preparation supply systems, it was explained that the infrastructure needed for the whole project area to implement district heating would be financed with the sale of the plots to the project developers. By implementing district heating, the §118 (3) of the *WBO* which requires the implementation of highly efficient alternative systems is fulfilled. Moreover, according to the *OIB-6* highly efficient alternative systems are considered as a source of renewable energy, for which the share of renewables in the project is also considered as fulfilled. In the workshops it was also decided that the building performance requirements set by the *OIB-6* and the *WWFSG 1989* were also considered sufficient.

The second competition phase marked the incorporation of the BPt and other consultants to the planning process as the structural engineer and the building systems engineer. The integration of other project consultants in the planning process resulted in a constant adaptation of the preliminary design. By detailing the different building components new problematic areas emerged, changing the configuration of the project on a regular basis.

Catalogue of building parts (first version)

The first document produced and delivered by the BPt was a generic catalogue of building parts called *Component structure catalog, building physics for subsided construction projects* (Building physicist 2016). At this point there was almost no definition about building materials, technical building systems, window areas, shading devices, etc. Overall, very few of the building components were fixed.

Consequently, the generation of the building parts catalogue required assumptions by the BPt to fill the gaps in the planning. Because an energy certificate was not yet issued, he used generic constructions that have heat transfer coefficients (U-values) which not exceeded the maximums defined by the *OIB-6* for conditioned rooms. The selection of constructions was rather based on experience since the catalogue was not tailored to the project. This generic catalogue of building parts, together with other project related assumptions, was expected to cover the mentioned increased energy performance requirements. It contained:

- Basic prerequisites: minimum thermal protection requirements in accordance with *OIB-6:2015*, maximum heating demand requirements according to the *WWFSG 1989*.
- Basic assumptions: window area proportion per orientation, ventilation through windows, insulation thickness in roofs.

This first building parts catalogue pursued different objectives. On one hand, it was an initial proposal for the materialization of the building components. On the other hand, the planners needed definitions about component constructions to check if with the proposed constructions their own architectural design ideas, building owner expectations, legal requirements, and constructional considerations from a structural, fire protection, and technical building systems perspective could be achieved.

To better understand the building configuration and to add more detail to the project this document also provided with details of typical building components in the basement and ground floor levels that usually require additional thermal insulation. Examples of these basement insulation details are illustrated in Figure 7:

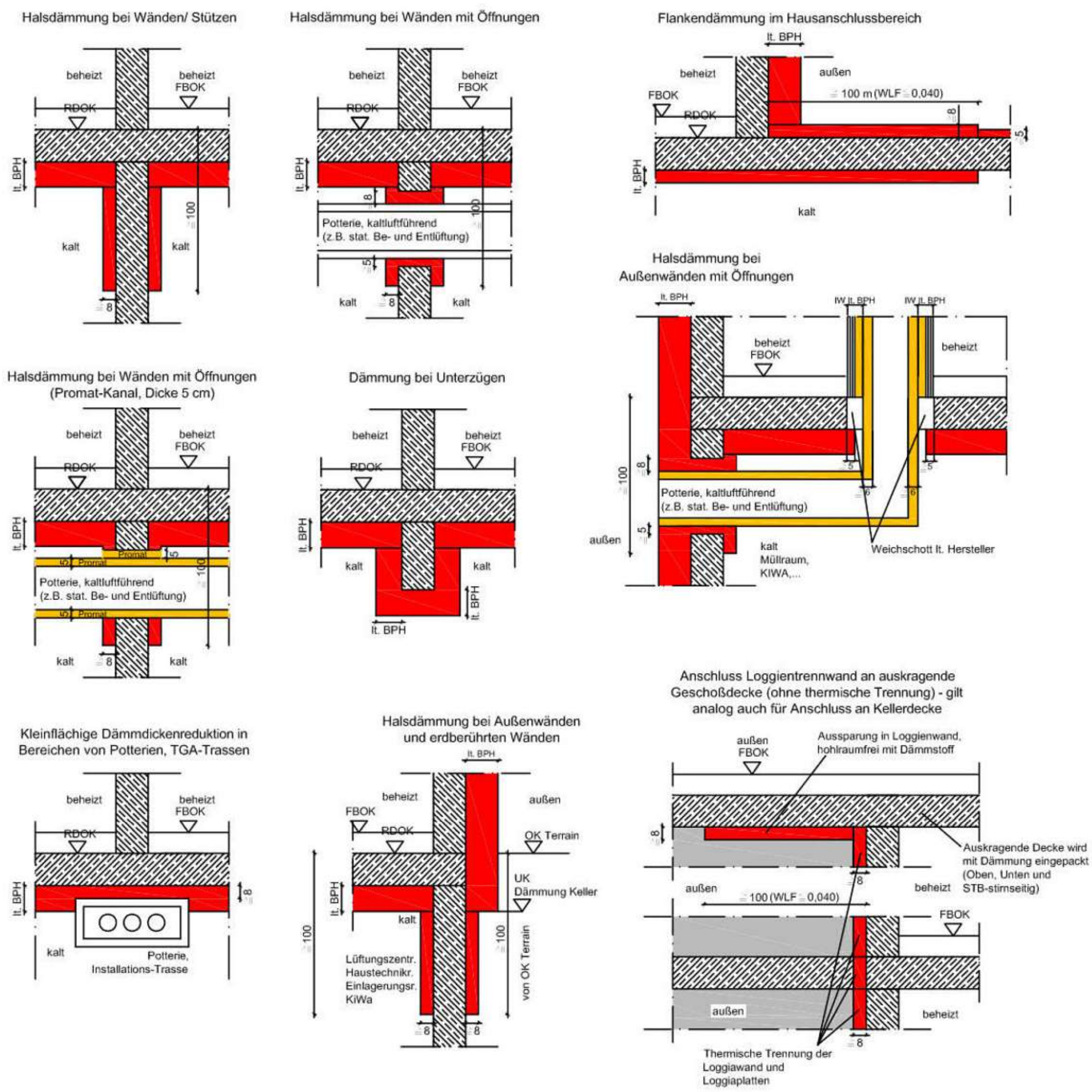

Figure 7. Standard basement insulation details (Building physicist 2016)

Energy certificate

For the handover of the final version of the preliminary architectural design, the BPt issued the first energy certificates for the project. The certificates were required as a part of the deliverables to the jury which is a particularity of projects that are built with subsidies. Four documents were issued: a certificate for building one, a certificate for building two, a certificate for the office inside building two, and a catalogue of building components for both buildings, which by this time was adapted to include the already defined building constructions.

The data used to generate the energy certificate emerged from three sources:

- The architectural plans.
- The technical building systems concept (*Technische Gebäude Ausrüstung – TGA Entwurf*).
- Assumptions made by the BPt.

Some of the assumptions that were made include heating and hot water distributors (radiators, floor heating and instantaneous water heaters), assumptions regarding insulation and length of pipes, lighting is calculated with benchmark values, ventilation is set through windows manual operation. Some of these assumptions will change in the building permit phase and once again in the execution phase.

Technical building systems

The technical building systems constitute a fundamental part in the planning process. A first concept for the technical building systems of the project (TBS) was established through the revision of the architectural plans per email. Up to that point, the architects had designed the cellar and floor plans of the project based on their experience, building legislation and meetings with the project developer. Through a cyclic process (drawing of architectural plans → BSE revision → adjustment of architectural plans) the TBS were incorporated into the project. The remarks in the architectural plans covered a wide range of topics: from size and positioning of technical shafts, dimensioning and positioning of plasterboard walls and technical installations, guide trenches in the floor slabs for pipes, ventilation systems for cellar rooms and for technical rooms, mechanical ventilation for the office, to the dimensioning of technical rooms in the cellar, etc.

By incorporating more detail to the project additional aspects had to be checked. For example, depending on their location plasterboard walls require additional thermal insulation; pipes that run through the floor construction have to be dimensioned in a way they are correctly insulated, the same for ventilation pipes, etc. All this information had to be added to the plans to be assessed by the BPt in later stages.

Technical building equipment concept – preliminary draft report

This document was issued at the end of the preliminary design phase and it contained a synthesis of the TBS planned for the project, including heating, ventilation, plumbing, electricity, and technical fire protection (Building systems engineer 2016). Because by the end of the preliminary phase there were still many elements that were not yet defined, for their completion the building systems engineer used a standard (not tailored) building specification and equipment description catalog provided by the project developer which describes the intended but not yet defined building components, acoustical and thermal insulation systems, facade systems, window and door types, sun protection measures, technical systems, etc (Project developer 2014). Additionally, the TBS report was based on additional input data as the architectural plans and the structural concept issued by the structural engineer.

Facade design

One of the most relevant aspects influencing the thermal performance of building is the facade design, which was first assessed during the preliminary design phase. Different options were evaluated and presented to the project developer. The two main aspects addressed through the facade design were color and greenery. Interestingly, in the first sketches there was an intention to design the facade considering shading optimization, as shown in Figure 8 and Figure 9. In the original idea, exterior steel sheet window-frames of different sizes were aleatory given to the apartments, each apartment having at least one. The frames worked as a holder for flowerpots, giving more greenery to the facade, whereas providing extra shading for the windows. The number of window-frames was reduced or increased according to the orientation.

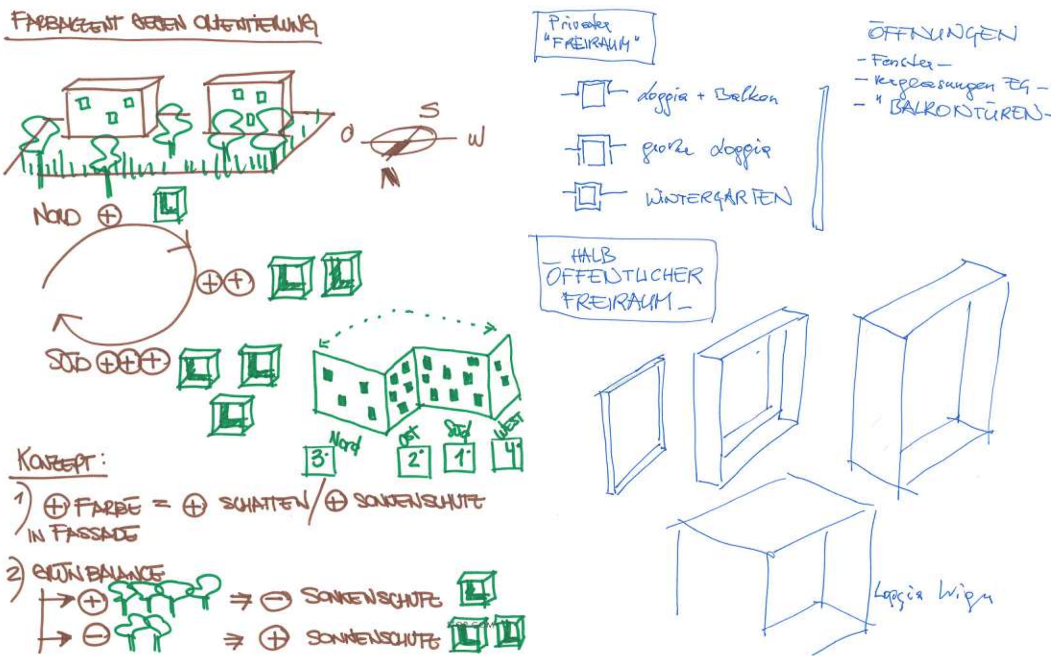

Figure 8. Facade design (Architecture office 2016)

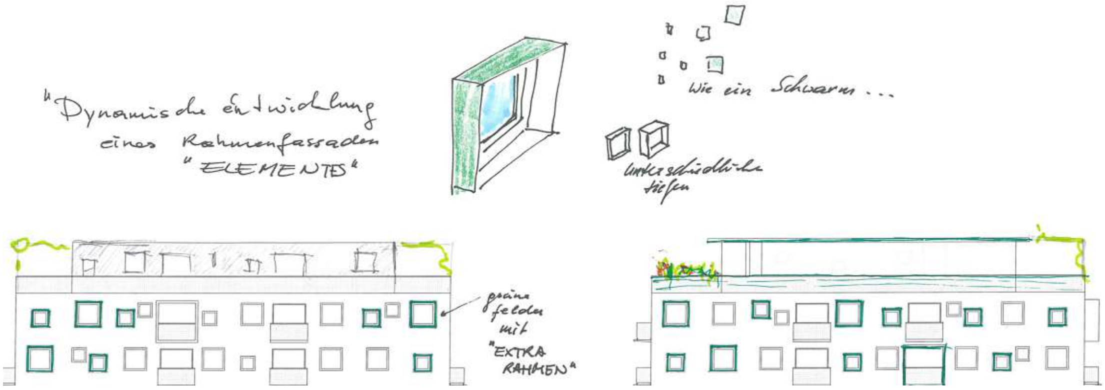

Figure 9. Facade design (Architecture office 2016)

Another compelling element of the facade design were the loggias, balconies, and winter gardens. Considering different users' preferences and climate conditions in Austria, loggias and winter gardens were added as individual outdoor spaces as an alternative to balconies. The different loggias and winter gardens configurations are shown in Figure 10. Because one of the themes of the competition was individuality, again the apartments were aleatory given one of these three elements. However, orientation was not taken into consideration for their arrangement (e.g., winter gardens for the apartments located to the cold north, balconies to the warm south, loggias to the west/east).

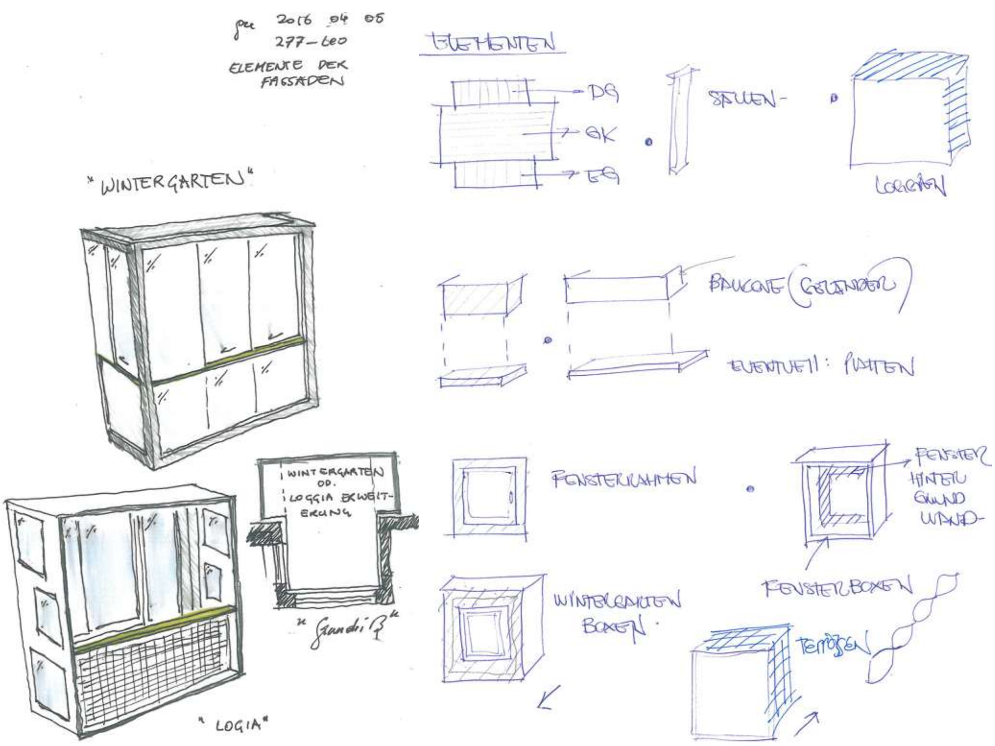

Figure 10. Loggias, winter gardens and balconies (Architecture office 2016)

Pergolas and grid walls were also added to the facade design, as shown in Figure 11. The pergolas, located in the rooftop, would provide shading to the outdoor terraces and living rooms whereas working as a support structure for climbing plants. Because of space limitations due to facade recess in the rooftop, living rooms in this level are located to the east and west. The pergolas have therefore also these orientations. Similarly, grid walls were also planned for the two floor-height community loggias. Although they do not provide shading protection due to the location of the loggias to the north, they work as a support structure for climbing plants and therefore contribute to added greenery to the project and improve the local climate.

Figure 11. Pergolas and grid walls (Architecture office 2016)

The last and most important of the facade design elements is the window and glass area. The size of windows and French windows was set by two conditions: the minimum illumination requirements defined by the *OIB-3* (OIB 2015a), and the so-called facade parameters. According to the document *Economic parameters and planning factors for subsidized residential construction projects in Vienna* (WKO 2015) produced by the Austrian Chamber of Commerce, for an efficient facade design there are four parameters that need to be observed. Of these four, two were used in the project: P8: Facade area/subsided area; and P9: Window and French window areas/subsided area.

These parameters had not been applied in the 1st phase of the competition, because there was no facade design at that point. In the 2nd phase of the competition, the parameters P8 and P9 were used together with other parameters provided by the project developer, which are part of the architecture services contract. The economic design parameters provided by the project developer are shown in Figure 12:

		Referenzbereich *) von - bis	Einheit
R1	Bruttogeschoßfläche / Nettogeschoßfläche	1,10 - 1,20	Faktor
R2	Nettogeschoßfläche / Wohnnutzfläche	1,30 - 1,60	Faktor
R3	Umbauter Raum / Wohnnutzfläche	4,80 - 5,30	Faktor
R4	Wohnnutzfläche / Anzahl Wohnungen 1)	75 - 90	Quadratmeter
R5	Anzahl Wohnungen / Stiegenhäuser	20 - 35	Stück
R6	Nettofläche Garage / Stellplätze	23,00 - 26,00	Quadratmeter
R7	Garage - Netto - Rauminhalt / Stellplätze	60,00 - 70,00	Kubikmeter
R8	Fassadenfläche / Wohnnutzfläche	0,55 - 0,75	Faktor
R9	Fassadenfläche / Umbauter Raum	0,10 - 0,15	Faktor
R10	Fenster, FeTüren, etc / Fassadenfläche	0,15 - 0,20	Faktor
R11	Fenster, FeTüren, etc / Wohnnutzfläche	0,10 - 0,15	Faktor
R12	Sonst. Außenabschlüsse / Fassadenfläche	0,03 - 0,07	Faktor

Figure 12. Economic design parameters (Project developer 2016a)

In the parameter list the parameters R8 - P8 and R11 - P9 are the same. Particularly the parameter R11 seems quite tight (0,10 – 0,15), since the *OIB-3* stipulates a window area of at least 12% (0,12) of the net living area of living-rooms and of sleeping-rooms. Other parameters relevant for the facade design are R9 (ratio facade area/building volume) and R10 (ratio window and French window areas/facade area). In an intermediate check instance, the design of the facade was not scoring well in the parameters related with facade design (R8, R9, R10 and R11).

That was not the case for the parameters that give an idea of the compactness of the building, efficient floor plan design, etc. Although these were positive rated, due to the rigidity of the floor plan design and the restrictions related to building legislation, there was not much room for changes in the building configuration. It can be affirmed that from this perspective the floor plan design was very efficient from the very beginning. Moreover, in the project the limit for the allowed net living area (5.000 m^2) was also used at its maximum.

4.2.3 P3 Design and building permit phase

Overview

The content of the descriptive categories *timeframe, tools, input, time effort* and *outcome,* correspondent to the P3 Design and building permit phase is summarized in Table 8:

Table 8. P3 Descriptive categories

TIMEFRAME	TOOLS
June 2016 - end of December 2016 (seven months)	AutoCAD, SketchUp, Rhino, ArchiPHYSIK

INPUT	TIME EFFORT	
Documentation	**Hours**	**Consultant**
Architecture services contract	2011,5	ARC
Design parameters from the project developer	60	BPt

OUTCOME	
Concepts/Designs	**Consultant**
Architectural design	ARC
Structural design	SE
Technical building systems design	BSE
Materialization of building components	All
Energy efficiency design	BPt
Sun protection measures per orientation	BPt
Building physics recommendations for the building execution	BPt
Building ecology recommendations	BPt
Documentation	
Architectural plans, sections, views	ARC
Landscape plan	LP
Building and equipment description report	PD
Catalogue of building parts	BP, ARC
Energy certificates	BPt
Windows parameters report	BPt
Building physics technical report	BPt
Summary of heat protection, sound protection and heat storage calculations	BPt
Technical building systems documentation	BSE

Project development

Building and equipment description report

In the P3 Design and building permit phase, the PD set up the *Building and equipment description report* (Project developer 2016b) basing its content in the standard one and in the catalog of building parts provided by the BPt (both provided in the P2 Preliminary design phase), but now tailoring it for the project. This report was generated in the early stages of the project phase and worked as a road map for the planning experts. The content of this report includes:

- The project description.

- Potential start of construction works and timeframes.
- Description of the materials and constructions of building components including foundations, exterior walls, interior walls, floor slabs, floor constructions, roof constructions, thermal insulation, facade systems, plumbing, windows and French windows, doors, sun protection devices, heating and hot water preparation systems, and ventilation systems.

First building physics assessment of architectural plans

This first building physics assessment consisted in the revision of all floor plans and the sections of the project. Most of the comments targeted the ground level, addressing issues such as the thermal enclosure around the staircase and ceiling insulation and sidewalls insulation in the basement, thermal insulation in floor constructions, insulation of technical shafts, insulation of ventilation systems, over-insulation around window openings, insulation of terrace floor constructions, planning of an inverted roof, etc.

Second building physics assessment of architectural plans

Shortly before the final delivery of the project to the building authorities, the BPt delivered a second revision of the building plans. In particular, the presence of a previously not known sealing wall some meters under the ground floor level (built to contain the contamination of the soil) derived in a replanning of the building structure and reconfiguration of the floor plans, specially of the ground floor, as well as of the views. This resulted in a repetition of the planning cycle.

This second assessment consisted in a newly run revision of the architecture plans and sections, with the difference that the plans had gained more detail and that there was one more transverse section, which is important to be able to assess in more detail critical constructions that otherwise might go unseen. This time the comments were directed to the issues: avoidance of thermal bridges, measures to guarantee an uninterrupted building envelope, ceiling insulation in the basement level because of the changes on the ground floor, remarks made in the first revision that were not added to the plans as insulation of technical shafts, insulation of ventilation pipes, etc.

The last intervention of the BPt is the delivery of the final building physics documentation of the project to the building authority, as required by §118a of the *WBO*. Among the documents are:

Final catalog of building parts

In the final version of the catalogue of building parts, several floor constructions were added to address changes in the roof top level and in ground floor and cellar levels. It includes the minimum U-values that have to be fulfilled by the building components. In some cases, the U-values of the building components are far better than the requirements set in the *OIB-6*. It can be speculated that this is due to the higher requirements set by the *WWFSG 1989* which as previously explained do not define maximum U-values but maximum values for the heating demand of the building (Building physicist 2017a).

Windows parameters report

This report contains specifications for the thermal (and acoustical) performance of transparent components and measures to avoid summer overheating (Building physicist 2017b). In the section dedicated to thermal requirements there are Uw-values provisions for four differentiated transparent components: for exterior windows in apartments and common rooms, for exterior windows in the office, for dome lights in staircases, and for the entrance portals in staircases.

The last section of the document is dedicated to summer heat protection. The recommendations are set differently for the office in building two and for all other rooms and apartments in building one and building two. The summer heat protection is calculated according to the *OIB-6:2015* through the simplified verification method described in the *ÖNORM B 8110-3* (ASI 2012) for residential buildings, and by observing a maximal acceptable external induced cooling demand for the office. The calculations were made with the program *ArchiPHYSIK* (Interview 2 2020).

The sun protection measures for the office are defined thorough g-values for windows and z-values for sun protection irrespectively of the orientation (here the z-value seems to be referring to the Fc-value), whereas for the apartments and common rooms one single g-value is assigned to all windows but different g-total values (thus different Fc-values) are given depending on the orientation, together with a recommendation for the type and positioning (inside/outside) of the shading device.

It should be pointed out that windows have to fulfill a set of different requirements. On one hand, to reduce heat losses from the inside to the outside, a high insulation performance of the windows (through a low Uw-value) is fundamental. On the other hand, this also results in less heat penetrating from the outside through the window which is a major disadvantage in winter. The other key value is the g-value (the solar heat gain coefficient), which quantifies the directly transmitted solar radiation as well as the secondary heat release that occurs from the glass to the inside. Windows with a low g-value provides good protection against overheating caused by excessive solar radiation, which is beneficial in summer but not in winter (Fensterbau Ratgeber 2020). Moreover, the g-value of the window influences directly how the window works together with the shading device regarding summer heat protection. The Fc-value (the so-called shading value), it is usually defined as the reduction factor of solar radiation attained by the shading device. The lower the value the less solar radiation goes through the device. However, the Fc-value is mostly derived from the simplified g-tot calculation according to the *ÖNORM EN ISO 52022-1* (ASI 2018) (Fc-value = g-tot x g-value) meaning that each Fc-value correlate to a specific glazing value and should not be used in combination with a different glazing, as shading devices do not have a specific Fc-value. This indicates that the resulting g-total value is of more use to describe the performance of both elements together (BVST 2019).

The levels of protection defined for the apartments through specific g-value, g-tot and Fc-value was divided as follows:

- Level 1: no additional sun protection measures.
- Level 2: interior blinds (*Innenjalousien*) or something better.
- Level 3: interior film blinds (*Folienrollos*) or something better.
- Level 4: external shutters (*Rollläden*) or something better.

The BPt provided a sketch describing for each building use (apartment, common room, office, etc.) and orientation which sun protection measure had to be fulfilled. For example, for the apartments in both buildings with orientation of north, no sun protection measures were required.

The report also included recommendations and assumptions regarding compulsory night ventilation, opening windows in different facades and in different levels at the same time (cross ventilation), observance of minimum required hygienic air exchange rate, etc. To guarantee that these recommendations are put into practice, according to the construction manager (Interview 3) these are included in the user's manual which is delivered to the building occupants.

Building physics technical report

This report includes not only a review of the building physics measures taken to comply with thermal performance requirements, but also describes additional building physics requirements and building physics recommendations for the execution works of the thermal envelope, moisture protection-, sun protection-, airtightness- and building ecology measures (Building physicist 2017c). The following aspects are addressed:

<u>Heat protection</u>

- Description of boundary conditions in the project: construction technologies, technical building systems, definition of heated and unheated rooms.
- Description of transparent components of the building thermal envelope, as exterior windows and doors (different requirements for apartments and for the office), requirements for doors that separate conditioned rooms from unconditioned rooms (staircase on the ground floor).
- Description of exemplary opaque components of the building thermal envelope (materials and thicknesses of the thermal insulation) as external walls, flat roofs over the last floor, terraces and loggias above apartments, ceilings above outside air, ceiling above garbage room, ceiling over basement rooms, thermal separation of loggias by means of Isokorb and gravel bed.

Additionally, the report defines requirements for the next planning phases: joints and window details are to be sent to the building physicist for approval before execution, windows are to be executed with a predefined perimetral over insulation, insulation of ventilation pipes in basement rooms, staircase thermally insulated from the basement, packed attics, thermal separations when using steel components that perforate the thermal envelope, entry openings of the pressure ventilation system (DBA) thermally insulated and airtight, etc.

The report also deals with:

<u>Moisture protection</u>

Recommendations for a correct execution of vapor barriers, windows- and doors sealings, avoidance of building residual moisture.

<u>Airtightness</u>

Correct execution of airtight windows, perforations and openings, requirements set by the *WWFSG 1989* have to be fulfilled, the values have to be tested through a blower door measurement according to *ÖNORM EN 13829* (ASI 2001), pipes perforating the thermal envelope have to be executed in conformity with the detail shown in Figure 13, ensuring that the distances between the pipes allow a sufficient insulation:

Figure 13. Insulation requirements for pipes (Building physicist 2017c)

<u>Building ecology</u>

Goals are to ensure a pollution-free indoor air, the improvement of workers protection and the minimization of environmental pollution. Additionally, as set by the *WWFSG 1989*, construction materials that hold greenhouse gasses and plastic windows are not to be used in the project. According to the interview with the project developer (Interview 4 2020), this will later concretize through complementary controls during the execution works, carried out by the company *BauXund* (BauXund 2021), who besides product management also carried out room-air measurements during execution works.

Summary of heat protection and heat storage calculations

This is the most extensive of the reports produced by the BPt and describes the calculations done as required by building legislation (Building physicist 2017d). In this document the BPt declares to have complied with all regulations regarding energy certification and thermal insulation. It also describes which norms and regulations were observed for the calculations.

The document is divided in the following parts:

<u>Catalog of building parts</u>

The catalog provides an overview of the component structures and their building physics parameters. It contains clarifications as simplifications in the structures carried out for the calculations, that only the most unfavorable component combinations are calculated (the thinner thicknesses), and that in case different materials are used, the calculations have to be repeated.

Summer heat protection

The calculations for summer heat protection measures for the residential part of the building are done according to the *OIB-6* and the *ÖNORM B 8110-3* (ASI 2012) (determination of the minimum storage-effective masses of the room based on the effective emission areas). The calculation is done for unfavorable sample rooms (two communal rooms and four living-rooms in apartments) which face the four orientations (the apartments face the west, northwest, northeast, southeast whereas the communal rooms face the north-east-south orientation). The result of the calculation defines the corresponding window parameters (g-values) and the sun protection devices for each orientation. The calculation for the office is done according to the *OIB-6* (cooling requirement (KB *) of ≤ 1 kWh/m³a) which also results in the corresponding g-values and z-values. The results are the ones already described in the *Windows parameters report.*

Proof of heat and energy demand

This section of the report includes the results of the calculations of the following parameters:

- Proof of compliance with the reference heating demand (HWBRef, RK) for the residential buildings and the office and with the externally induced cooling requirement (KB *) for the office.
- Proof of compliance with the heating energy requirement (HEB, RK), the final energy demand (EEB, RK), and the total energy efficiency factor (fGEE) for the residential buildings and for the office.
- Proof of compliance with the share of renewable source of energy. For the residential part of the buildings and for the office there will be a at least 5% reduction in the maximum permissible overall energy efficiency Factor (fGEE). Additionally, at least 50% of the requirements for space heating and hot water preparation will be covered by district heating from highly efficient cogeneration.

Recommendations

This section encompasses seven pages addressing the execution and configuration of components as floating screeds, ventilation of components that have thermal insulation, shafts and technical facilities, ventilation systems inside the apartments, building joints in exterior windows and doors, furniture near exterior walls, attics, thermal separation of overhanging components, thermal separation of steel components, basement ceiling insulation and flanking insulation.

The last part of the report includes the calculation of U-values for each individual building component, of the summer heat protection for the selected unfavorable rooms, and the energy certificates for both residential buildings and for the office separately.

Technical building systems

During the building permit phase, the concept for the technical building systems was deepened. The following aspects were discussed and added to the project through meetings and revisions of architectural floor plans and sections: basement design, design of the ventilation system for the office, ventilation openings requirements, rainwater and wastewater management and planning, design of the compression ventilation system for fire protection in the staircase (DBA).

The discovered underground sealing wall to contain the contamination of the ground resulted in a replanning of the building´s structure. This also resulted in replanning processes for the BSE and the BPt, as they had to revise the plans again.

Technical building systems documentation

The documents delivered at the end of the building permit phase by the BSE related to BP included the plans and dimensioning of the heating, water preparation and ventilation systems.

The room temperatures defined to calculate the heating operating capacity of the heating system (e.g., 22°C in living rooms and 26°C in bathrooms) are not related to the assumed comfort temperatures defined for the issuing of the energy certificate. The temperature in living rooms, sleeping rooms and offices during wintertime is set by Austrian standards to be at least 20°C. The topic of thermal comfort and human behavior was not particularly addressed as part of the planning process, and there were not special conditions or temperature requirements set for transitional seasons. The users would be given the possibility to regulate the room temperatures through thermostats located in each of the rooms.

The dimensioning and design of the ventilation systems included mechanical ventilation systems for the washroom and the office, mechanical ventilation for bathrooms, toilets, and garbage room, static ventilation of technical rooms and storage rooms in the basement, ventilation through door grilles (storage rooms, garbage rooms) and a compression ventilation system for fire protection in the staircase.

Technical building systems deliverables for the building authorities

One document that had to be delivered to the building authority was the proof that the implementation of highly efficient alternative energy supply (heating) systems was evaluated. In case they are not implemented this have to be accordingly justified and a prove have to be delivered. The deliverable consists in a form where the project developer or the building systems engineer declares which highly efficient alternative system is being implemented in the project, and if applies, which source of renewable energy (Stadt Wien 2015).

Structural concept

The discussions with the SE are also related to BP. For example, the definition of the form of the columns on the ground floor to accommodate the flanking insulation (an aesthetic adaptation) and the use of Isokorb elements to anchor overhanging parts (relevant to guarantee an even floor-level between the outside and the inside).

Facade design

The planning parameters related to the glass to facade ratio already described in the preliminary design phase had to be checked again. This was done at least in two different moments at the beginning of the design phase. It should be pointed out that aspects such as windows design have to be fixed by the end of the permit phase because otherwise a change of architecture plans have to be delivered to the building authority during the execution phase. At the same time, at the beginning of the execution phase the planners produce the commercial plans of the project (this is occasionally done by the project developer). This is in some cases problematic because these plans are part of the buying and renting contracts of the future residents of the building, which are often signed before the building execution in completed. Therefore, changes should not occur in the planning of the apartments (for instance changes in size or positions of windows, ceiling heights, etc.) after the contracts are signed.

4.2.4 P4 Call for tender phase

Overview

The content of the descriptive categories *timeframe, tools, input, time effort* and *outcome,* correspondent to the P4 Call for tender phase is summarized in Table 9:

Table 9. P4 Descriptive categories

TIMEFRAME	TOOLS
July 2017 - mid-September 2017 (two and half months)	AutoCAD, Rhino

INPUT	TIME EFFORT	
Documentation	**Hours**	**Consultant**
No additional reports or documents were provided	461	ARC
	10	BPt

OUTCOME	
Concepts	**Consultant**
Construction solutions	ARC, SE
Assessment of alternative construction methods	ARC, SE
Technical building systems design	BSE
Building physics recommendations for the execution of technical building systems	BSE
Materialization of building components	All
Documentation	
Architectural plans, sections, views	ARC
Catalogue of building details	ARC
Landscape and outdoor equipment plan	LP
Landscape and outdoor equipment details	LP
Technical building equipment report	BSE
Technical services description report	BSE
Static calculation	SE
Call for tender general contractor works	PD

Project development

In this phase the architects draw the details of the project that they considered more complex to execute during the construction works (Interview 1 2020). It is the first instance in the project when the planners assessed the execution methods of building components. Because there was not yet a detailed cost evaluation, it can be stated that these details only show possible solutions about how the project can be built, complying with building regulations. The process of drawing the details helped to assess potential problems in the execution of the components and opens the discussion for the evaluation of alternatives. The project parties involved in the process were the planners, the project developer, the structural engineer, and the building physicist.

Details

In total, the details catalog produced by the architects encompassed eighteen details, of which twelve details were addressing building physics aspects. The main building physics issues that had to be solved through the details were wind tightness, airtightness, correct execution of the thermal insulation, and moisture protection (Architecture office 2017). There were two revisions of the construction details done by the BPt. The SE also assessed them in two occasions. At the end of this phase the SE also produced a document called *Static calculation* which includes a description of the thermal insulated slabs through Isokorb elements (Structural engineer 2017).

Revision of architecture plans

Because there were almost no changes in the architectural plans between the P3 Design phase and the P4 Call for tender phase, the remarks made by the BPt were mainly pointing out to building physics aspects that were previously not included in the plans because that information is not required for building permits. This information would become relevant later in the execution phase (for example, interior insulation of shafts). In some cases, there were remarks or issues that were not solved during the previous phase and remained unclarified. Other set or remarks were directed to aspects that can only be taken into account later in the P5 Execution phase when products are defined (e.g., insulated flaps for the fire protection ducts).

Updated technical building equipment report

This document is the same as the one delivered at the end of the P2 Preliminary design phase, with some corrections that resulted during the P3 Design phase (Building systems engineer 2017a). It was previously mentioned that the basement and the ground floor had suffered changes because of a preexistent sealing wall in the plot. Additionally, a mechanical ventilation system was added for the office.

Technical services description report

This is an important document produced by the BSE because describes the execution of heating, ventilation, and plumbing works (Building systems engineer 2017b). Among the specifications are:

- Planning examination: the contractor receives the project with the tender documents for review and examination in technical terms and for completeness.

- Systems trial operation: all technical building systems are to be subjected to a full trial run for a continuous period of ten days before the finalization of the execution of the project.
- Airtightness: when penetrating the building envelope, ducts have to be executed airtight. To check the airtightness of the individual units, a blower door test must be carried out, for which all openings of the building envelope have to be hermetically sealed.
- Airflow measurements: these are to be carried out and documented individually in all apartments.
- Heating demand calculation: according to the final building physics values.
- Thermal insulation: to avoid heat losses and excessive room temperatures, all hot pipes and pipe fittings (valves etc.) are to be insulated. Joints must be overlapped tightly so that a continuous thermal protection is guaranteed. All cavities are to be filled with a sufficient insulation layer density. The material must be compressed within the permissible tolerances. The insulation thicknesses are to be implemented according to the state of the art (3/3 insulation of the nominal diameter). Thermal bridges must be avoided.
- Technical building systems: this part of the report is very extensive. It includes a description of ventilation, heating and hot water preparation systems among others, their distribution, including an additional description of the requirements for pipes and ducts insulation.

Call for tender general contractor works

After the construction details and all other technical reports were ready, they were included in the call for tender. It is through this document, named *Call for tender general contractor works* (Project developer 2017) that the project developer invited construction companies to make an offer for the execution of the project. The content of the call for tenders is based on the architectural plans, the technical plans, experts' reports, details, and any documentation delivered by the project consultants involved in the design of the project during and after the P3 Design phase. It includes a description of the works that are expected to be executed. To be able to produce such a document, extensive technical knowledge is required. In the case of this project, the document was written by the project developer itself, because the company have a technical department.

In the call for tender, building physics aspects were given particular attention. According to the interview with the BPt (Interview 2 2020) to guarantee the correctness of the document, the BPt performed a random check. The parts in the document addressing building physics aspects or the execution of building physics measures are the following:

- Technical description: a comprehensive description of the execution and/or material composition of the building components is provided. In some case there is a reference to the plans or other documents that have to be observed (details, architecture plans, reports). The description includes the description of foundations, basement, external masonry, ceilings, floor structures and floor coverings, roof construction (flat roof over basement and collector corridor and flat roof over apartments), sound and heat insulation measures, moisture protection measures (in walls in contact with the earth, in roofs, in screeds), facades, wall surfaces, balustrades, loggias/terraces/balconies, pergolas, outside buildings, windows, shading devices, entrance doors and interior doors, Heating systems, ventilation systems, hot water preparation systems, rainwater management, etc.
- Avoidance of problematic materials: construction products have to be eco-labeled. A chemicals and products management have to be carried out to observe an adequate building ecology and building biology criteria. An IBO ÖKOPASS (IBO 2021) certification, rating – good – is also required.
- It is particularly pointed out that the construction project has to be executed as a low-energy house. The requirements for sound and heat protection of the *WBO* and of the *OIB-Guidelines* have to be observed.
- Examination of the execution documents: the incompleteness of the construction specifications does not exempt the construction company of a comprehensive execution of the works. It is implied that the construction company is also responsible for complying with all building regulations, even if there is missing information in the documentation of the project.
- The contractor is liable for the work carried out by him, and by all professionals or subcontractors commissioned by him.
- Unless higher quality conditions have been agreed, for the execution of all services the minimum requirements set by the relevant ÖNORM´s are to be observed. These are considered binding and part of the contract. This mention could have repercussions in case that problems emerge after the project is executed, because

as previously explained, the ÖNORM´s that are not specifically mentioned in the *OIB-Guidelines* or in other building regulations are in theory not mandatory.

- Tests and reports: delivering a thermal insulation report with the external components executed by the contractor, photo thermographs, five airtightness measurements (blower door test), continuous reviews of the building materials before and during the execution of the construction works to ensure compliance with the relevant technical regulations, avoidance of thermal bridges.
- Performance description of the construction company: this part of the document goes deeper in the description of the execution of the building components. The accent is given to the execution of windows and French windows, doors, External wall insulation systems (EWIS), technical shafts, waterproof sealings on flat roofs/terraces/loggias and balconies, sun protection measures, etc.
- It is required to commission the services of a supervisor expert for controlling the execution of the facade (*SV* in German).

4.2.5 P5 Execution phase

Overview

The content of the descriptive categories *timeframe, tools, input, time effort* and *outcome,* correspondent to the P5 Execution phase is summarized in Table 10:

Table 10. P5 Descriptive categories

TIMEFRAME	TOOLS
Mid-July 2018 - July 2020 (almost two years)	AutoCAD, ArchiPHYSIK

INPUT	TIME EFFORT	
Documentation	**Hours**	**Consultant**
No additional reports or documents were provided	4248,5	ARC
	150	BPt

OUTCOME	
Concepts	**Consultant**
Retrenchment's listing	CSM, PD
Assessment of alternative construction methods and materials	All

OUTCOME	
Documentation/Tests	
Architectural plans, sections, views	ARC
Updated and extended catalogue of building details	ARC
Reinforcement and formwork plans	SE
Construction documentation from the executing companies	ExC
Blower door test	CSM, ExC
External wall insulation system expert´s report	CSM, ExC
Materials assessment and certification	CSM, ExC
Architectural plans, sections, views (intermediate building permit)	ARC
Energy certificate (intermediate building permit)	BPt
Final catalogue of building parts	BPt
Final energy certificates	BPt
Final windows parameters and summer heat protection measures report	BPt

Project development

The P5 Execution phase expanded in a period of almost two years. From this phase on there were new parties involved in it. Whereas in this case the architects, the building physicist, the landscape planner, and the structural engineer conserved their active role in the planning, there was a new company in charge of the planning and execution of the technical building systems. The construction company and its subcontractors were also integrated in the building delivery process.

Retrenchment's listing

It can be stated that the execution phase started with the definition of which elements described in the call for tender were going to be optimized or eliminated from the project. After one construction company was selected to execute the project, the project developer assessed the building costs presented by the construction company and choose which elements had to be economized in order not to exceeding the budget per m^2.

However, even after the elements that had to be eliminated from the project were set, later there were additional changes in the building components. The difference is that changes in the constructions done after the assessment of the retrenchment listing should not cause additional building costs for the project developer. Any changes happening after the list is decided had to be separately evaluated by the project parties. The reason for this is that the executing companies, their capabilities, and factual costs (this time costs for the construction company) were still not know because the works were still not assigned. This process takes place along the P5 Execution phase.

Moreover, another of the tasks the BPt is responsible for is to evaluate alternative solutions and materials that could be implemented to reduce building costs. According to the interview with the BPt (Interview 2 2020), in case the construction company preferred or found cheaper materials and products different to the ones listed in the catalog of building parts, these had to be evaluated and approved by the BPt, who would then document the changes and included them in the corresponding reports.

Planning, construction meetings and email communications

After the retrenchments listing was agreed upon, the execution planning meetings started. At this point the changes in the project that resulted from the costs optimization had to be reflected in the architectural plans. In this planning phase the architects added more information relevant to the execution of the project.

The planning meetings started before the objective construction works. The construction meetings are those taken place in parallel to the execution of the project. These meetings were documented in protocols.

The project parties present in the planning meetings were the architects, the project developer (from now on the project developer was being represented by an engineer from the technical department, who also overtook the role of the local construction supervisor, *ÖBA* in German), the structural engineer and the construction site manager. This fixture would remain the same along the whole phase. The BPt was not present in any of these meetings.

The construction meetings took place one a week at the beginning and twice a month in the last quarter of the execution works. During the construction meetings the different issues that emerge along the construction works were presented and discussed. The project parties participated in the meetings depending on the issues that had to be discussed. Normally the CSM communicated the project consultants if their presence was required, so that they could attend. The topics that were discussed are broad, from execution of details, products recommendations and sampling, changes in the planning, etc. The executing companies also participated in the meetings. They were involved in the discussion of potential problematic details, additional costs, etc. It was not unusual that issues had to be clarified during the week per mail or by phone because the involved consultant was not present or because additional details, calculations, etc. were needed. In that case the results were further discussed in the next construction meeting.

According to the protocols, the BPt was present in one out of 31 construction meetings. However, many building physics aspects were discussed during the meetings. During the 31 meetings, at least 90 times building physics issues were discussed. The issues related to BP that were given more attention were the positioning of French windows in loggias and the anchoring of handrails in the rooftop.

Approval of reinforcement and formwork plans

During the execution phase there were new documents produced by the project parties that addressed building physics aspects. These also had to be assessed and sent for approval to other project parties. In the case of the formwork plans produced by the SE, the building physics issues that had to be considered for their approval was very limited. However, because these plans are not revised by the BPt, this task is overtaken by the architects. The formwork plans are delivered by the SE in parallel to the execution of the structure in the building site, often no more than six weeks before the actual execution of the plan in question. This means that the planners have to anticipate which construction details need to be already discussed, agreed, and approved by the time they receive the formwork plans for their approval, as mistakes in the execution of the building structure are difficult to compensate. An example of this is the execution of balconies, loggias, and winter gardens. In these details, waterproof barriers, thermal insulation, and other building regulations and products (e.g., the rainwater infiltration system) have to be defined before the approval of the plan.

Approval of construction details

Although the details produced by the planners had been already assessed from a building physics perspective in the P4 Call for tender phase, many of them had to be redrawn as a result of the discussions held in the construction meetings. The architects also produced a total of three new catalogs of details (Architecture office 2018). The first catalog has details addressing the different rooftop situations. In the second catalog the different variations for the execution of balconies, winter gardens and loggias are illustrated. In the third catalog the different joints situations on roof components are drawn.

Only four out of seventeen details were sent for additional building physics approval. Nonetheless, at least seven of the details had been previously assessed in the P4 Call for bids phase, although in their anterior form. After the architects proposed possible solutions, the PD and the CSM assessed the correctness of the details.

Approval of architectural plans

The last of the assessments of building physics aspects in the documentation delivered by the architects in a one-time random evaluation of architectural plans by the BPt. The remarks pointed out to the night-time ventilation of the staircase (summer overheating), joints in openings in the thermal envelope (condensate formation), separation of furniture from the wall (condensate formation), heating storage-rooms in contact to exterior walls (condensate formation), thermal insulation in technical shafts (thermal bridges), continuous thermal envelope between thermal zones (condensate formation, thermal bridges), thermal insulation of ducts, thermal insulation of exterior columns, execution of ceiling insulation and perimetral insulation of walls in contact with the soil.

Approval of construction documentation from the executing companies

There were several building elements that required a more detailed planning before being executed in the building site. The executing companies in charge of them draw special plans for their execution, which had to be revised and approved by the project parties. The BPt was one of the planners in charge of the revision of the construction documentation delivered by the companies in charge of executing these building parts. These are in fact subcontractors and report to the construction company. The set of building parts that required the approval of architects and/or the building physicist were windows and French windows, portals, doors, sun protection devices and locksmith plans.

<u>Windows and French windows</u>

The windows manufacturer had to deliver a list of windows and French windows indicating their characteristics, position in the project and details of how their construction is going to be executed. In addition, as stated in the call for bids, the manufacturer has to provide a test report which proves the compliance of his windows and French windows regarding the calculation of U-values.

The windows manufacturer is incorporated in the planning process by taking part in the construction meetings. During these meetings, the execution of windows is discussed, after which the manufacturer produces the corresponding details that are later sent for approval to the PD and the architects.

In this project the execution of French windows was extensively discussed. On one hand, there was the issue of the additional costs for the construction company if the windows were to be positioned in the insulation layer as proposed by the architects; on the other hand, the U-form of the glazing required special attention to be paid to the thermal insulation. The first step in this process was therefore to illustrate which were the sensible aspects for the execution of the windows. This was done by the architects. These details were sent to the BPt for their approval, after the building physics assessment the details were sent to the manufacturer so that he could produce his own details.

In the window manufacturer details, building physics aspects as the execution of sun protection devices, over-insulation of windows and waterproof barriers were also drawn. However, these details were not sent for approval to the BPt, this task was carried out by the architects, who used their own details to assess the different building physics aspects. The manufacturer details were also revised by the PD. It has to pointed out that is not possible to track-out all communications between project partners because these are not always documented, for which additional discussions by phone cannot be discarded. Moreover, because the construction company is the one directly handling with the manufacturers, on some occasions the communications and approval of details and products runs directly over the CSM without the intervention of other project parties.

Portals

The approval process for the execution of exterior glass portals runs in a similar way that for the windows. The architects provided the plans and details of the portals to the manufacturer, who produced the details for their execution together with a specifications list and the positioning of the portals in the project. These details are sent back for the approval of the PD and the architects. It can be stated that because the design of the portals was more or less standard, it did not require as much assessment in comparison with the French windows. Nevertheless, the complying with building physics requirements and benchmark values fell in the hands of the PD, the CSM and the architects.

Doors

The building physics requirements set for doors related to energy performance are limited because opaque doors were located inside the thermal envelope. As previously mentioned, the BPt set these requirements at the end of the P3 Design phase in the building physics technical report. For example, doors on the ground floor separating two different thermal zones had higher thermal requirements. The complying with these requirements is controlled by the project developer and by the construction company.

Sun protection devices

The approval of sun protection measures consisted in the revision of a list in which the different sun protection devices and their position in the project are defined. The list had to be ratified only by the architects, but because this information in also an integral part of the architecture plans, the construction company has also to verify its correspondence.

Locksmith plans

A particularity of this project was the proliferation of locksmith elements because these were an integral part of its aesthetic and architectural configuration. The locksmith produced an extensive number of plans for the execution of these elements. The main reason why these plans are relevant to BP is because the anchoring of this kind of elements means that the thermal envelope had to be perforated.

The locksmith plans that were sent to the BPt for his approval were pergola plans, terrace handrails anchoring plan, steel sheet window-frames plan, lattice wall plan, balconies and loggias handrail anchoring plan, separating lattice wall plan.

Although the BPt assessed the locksmith construction documentation, the approval of these plans by the architect was also mandatory. The architects had to verify the plans to avoid collisions between constructive elements (e.g., between the pergola and the sun protection devices) and looked for potential problems by the execution of these elements.

On-site measurements and certifications

Other building physics related events happening during the building delivery process were those linked to on-site measurements and certifications. These events take place in the building site. The project parties responsible for them were mainly the CSM and the PD, the last one because as previously mentioned, took over the role of the local construction supervisor.

Blower door test

The measurement of the airtightness of the building is a legal requirement set by the *OIB-6* and by the *WWFSG 1989*. For this project, the higher requirements set by the *WWFSG 1989* apply (n50 <1.5 air exchange rate). The procedure was completed by an external building physics services company, hired directly by the CSM. To carry out the test, all air supply outlets in the building were sealed. According to the interview with the PD (Interview 4 2020), there were two instances in which the test was carried out, the first one after both the building shell (concrete structure) was executed and the windows assembled, and one after completion of the screed coverings and filling works. The measurements were carried out in five apartments, with different floor plans and exposed locations, chosen by the CSM and the PD together. As the CSM pointed out, in the first test the focus was in finding leakages in the building envelope and in the installations. It was important to find the weak points in the envelope and to solve them after the first measures, because to correct them after the second measured would have been very time-consuming (Interview 3 2020).

According to the CSM, the first steps to accomplish the higher airtightness values consist in a precise and clean way of working during the execution of the building shell. The site foreman is the person in charge of guaranteeing that. The other necessary step is to pay attention to details during the posterior expansion works, especially the execution of technical building systems and electrical works. In addition, the execution of joints in screeds and drywalls is always checked and documented. According to the PD, to assembly the windows in accordance with ÖNORM´s is also fundamental (Interview 4 2020).

Expert inspection for the execution of the external wall insulation system

The execution of the facade system was supervised by an external facade expert hired by the construction company to secure its correct execution. According to the CSM (Interview 3 2020), the expert supervised the construction works during the execution of the facade, briefing the foreman (the construction site controller from the construction company) about the works that had to be carried out and which required special attention by their execution. During these control rounds (there are at least three documented inspections) the expert filled a protocol, which is a standard form where relevant details are described. A part of the job consists in the expert observing the execution of these details and comparing them with the form. Additionally, the expert described and documented with photos the different execution works that needed improvement. At the end of the inspection the expert briefed the foreman at the building site about these details and sent the protocol to the foreman and to the executing company in charge of building the facade, which is a subcontractor from the construction company.

According to the protocols, some of the aspects that were supervised by the expert were the proper storage of system components (protected from rain and humidity), the surface evenness, at least 40% percent of adhesive contact area with the insulation, size, filling and sealing of insulation joints, exterior blinds boxes with three cm surface insulation and fifteen cm joint insulation, fire protection bars, windows sill connections, rendering thickness depending of the insulation system (measured and compared with a chart), moisture protection in the socle area, execution of the insulation around windows, French windows, attics, socle area, etc., evidence of on-site monitoring of the execution works is to be provided by the CSM, as well as evidence that the construction workers involved in the execution works were properly trained is to be provided.

Material assessment and certification

To address the prerequisites of building without using products that hold greenhouse gasses, the CSM hired the services of the company *BauXund* (BauXund 2021) to carry out the chemicals and product management of the construction materials used in the building.

The trades affected by chemicals and product management were the builders and installers, flooring works, windows, tile works, painting works, cleaning works, roof sealing works, EWIS facade and their subcontractors. The trades that took part in the assessment were those that had the highest reduction potential of environmentally and human harmful substances.

According to the interview with the CSM (Interview 3 2020), the process of assessing and certifying the materials went as follows:

- First meeting between the CSM and *BauXund* in which the mains aspects of the construction materials assessment process were explained. *BauXund* also provided the CSM with a catalogue of materials which are permissible.
- The CSM had to include a set of requirements defined by *BauXund* in their call for tender texts to award contracts to the subcontractors.
- Each of the products that was going to be used for constructing had to be approved by *BauXund*; in some cases, the CSM did not intervene in the communications between the materials manufacturers and *BauXund*.
- When the subcontractors started executing the works, the CSM had to check the materials.
- There were several spontaneous visits of *BauXund* to the construction site in which they controlled the executing companies, and their products were tested.
- During construction works the CSM carried out random controls and documented them.
- At the end *BauXund* delivered a certificate.

In addition to the previous mentioned points, there were other controls carried out during the building execution related to building physics aspects. One of them is the screed heating test in floor heating systems. The screed heating test is carried out by the BSE and pursues the goal of controlling the correct functioning of the heating system and the readiness for covering the screed layer. It also helps drying the screed to prevent moisture and mold damage, whereas by slowly raising the temperature during the heating process, it prevents cracks in the screed. The procedure for the test is normed in the *ÖNORM B 3732* (ASIa 2016). Briefly described, it consists in letting the screed dry for several days (depending on the type of screed) till the test is carried out. During the test, the heating system is turned on and the temperature of the system raises till reaching a defined temperature. The system runs at this temperature for several days and then is slowly lowered. A correct ventilation of the rooms is to be observed during the process. After the test is finished, the humidity content in the screed is measured and compared to predefined values.

There are also other recommended actions during the execution of the construction works intended for the prevention of moisture penetration. According to the CSM (Interview 3 2020) other measures taken was the heating of the apartments during winter months after the screed layer was finished, frequent ventilation, and covering building elements in case of bad weather.

Six weeks before the final handing over of the building there was one instance in which the PD and other project partners inspected the building together with the CSM. During this inspection, the partners rove over the building and pointed out to the defects in building elements that required to be improved. Because by this time most of the constructions were already covered, only the surface and the building envelope could be checked. Nevertheless, defects in elements as the thermal envelope and joints were assessed and later corrected.

Delivery of building physics documentation for the project completion

During the execution works there were two more documents that had to be issued and delivered by the BPt. In case changes are carried out in the project after the plans for building permits are delivered to the municipal authority, there is one intermediate instance in which is possible to present the municipal authority with new plans to obtain an updated construction permit. This had to be done in the project because at the beginning of the P5 Execution phase, the sixth level in building one was changed from a student residence to four student apartments. In this case, the BPt had to produce only the documentation necessary to show the specific changes and not the whole documentation of the project. Thus, the only documents that had to be delivered again were an updated energy certificate for building one and the proof of compliance with energy parameters, which had only minimally been changed because the modifications in the project did not affect the thermal envelope of the building.

After the completion of the building, it is also mandatory for the BPt to present the municipal authority once again with the building physics documentation of the project. This time, the documents that were delivered were:

- The updated catalog of building parts.
- The window parameters report including the requirements for summer heat protection.
- The updated energy certificates.

4.2.6 P6 Building commissioning phase

Overview

This phase of the project development is not divided according to the structure used in the phases P1 to P5 because there are no more planning activities directly involving the architects or the building physicist. Moreover, it is not possible yet to assess building physics aspects that are addressed during the operation phase of this project because the building has been dwelled only for some months. Moreover, in this phase the only project partner that stays active is the PD.

Nevertheless, from the legislation review and from the interviews, the following building physics aspects can be listed as occurring during this phase:

- User's manual: this manual was issued by the PD and the CSM together. Through it the new residents of the building are advised about building physics aspects that are to be observed during the building operation, such as avoiding perforating the building envelope, pay attention to a sufficient ventilation and the operation of inner blinds (Interview 3 2020, Interview 4 2020).
- Publication of energy certificates to tenants and buyers: this regulation was explained in the legislation review.
- Heating consumption record: also explained in the legislation review, the PD has to present the municipal authority with a three-year heating consumption record of the building.

5 Results and Discussion

5.1 Building physics tasks in the case study

The first research objective of this thesis consisted in finding which specific building physics tasks were performed during the building delivery process of a residential project serving as case study. It also looked at identifying which consultants were involved in their execution.

The first approach to the evaluation of these building physics tasks consisted in the generation of a generic building physics tasks list, which was presented in chapter *3.3 Generic building physics tasks list.* Through the analysis of the sample project presented in chapter *4 Case study* it was possible to evaluate which of these tasks were factually performed in the building delivery process of the case study.

The tasks are sorted out according to the proposed division of phases presented in the study case analysis. Each task is additionally classified using the same task types as in the generic list (primary, recommended, intrinsic). Finally, it is also indicated which consultant took part in the planning or execution of the tasks. The final list of building physics tasks in the building delivery process of the case study is shown in Table 11:

Table 11. Building physics tasks in the case study

BUILDING PHYSICS TASKS	TASK TYPE	PROJECT PARTICIPANT						
		BPt	ARC	BSE	SE	PD	CSM	ExC
P1 Development phase								
Energy-supply concept: evaluation and implementation of highly efficient alternative systems	PT					X		
Building configuration considering thermal insulation of the building envelope	IT		X					

BUILDING PHYSICS TASKS	TASK TYPE	PROJECT PARTICIPANT						
		BPt	ARC	BSE	SE	PD	CSM	ExC
P2 Preliminary design phase								
Energy-supply concept: evaluation of renewable energy sources (solar thermal, photovoltaics, or heat recovery systems)	PT			X		X		
Technical building systems: evaluation of heat emitters systems (radiators, floor heating, etc.) and hot water preparation systems (instantaneous water heaters, central heating, etc.)	PT			X				
Technical building systems: evaluation of ventilation systems (in apartments, office, communal rooms, bathrooms and toilets, garbage room, staircase, cellar rooms)	PT			X				
Technical building systems: evaluation of sanitary installations (drinking water supply system, terrace and garden irrigation system, sewage water disposal system, rainwater drainage and rainwater management)	PT			X				
Grossly graphic representation of technical building systems in architectural plans	IT		X					
Assessment of TBS aspects in architectural plans, in consultation with the other project parties	PT			X				
Issuing and delivery of a technical building equipment concept report including heating and hot water preparation systems, ventilation systems, sanitary installations, etc.	PT			X				
Grossly graphic representation of the thermal envelope in architectural plans	IT		X					
Facade design (transparent components, shading elements, overhanging components, pergolas, vertical gardens, etc.)	PT		X					
Definition of required natural room illumination and design of transparent components	PT		X					
Checking and optimization of economic and planning parameters (compactness of the building, facade parameters, etc.)	PT		X					
General analysis of building physics prerequisites and clarification of framework conditions (thermal performance level to be achieved according to building legislation, subsidies regulations, project developer	PT	X						

objectives, etc.)								
Issuing of a catalogue of building components (generic; including U-values calculation)	PT	X						
Issuing of a catalogue of basement insulation details	RT	X						
Initial estimation of required sun protection measures (summer heat protection)	PT	X						
Indoor environment design: definition of operative temperatures in summer and winter	IT	X						
Building zoning: definition of heated and non-heated rooms	IT	X						
Building zoning: considering building use, building construction, usage profiles, 4 K criteria, and technical building systems	IT	X						
Final deliverables: energy certificates (calculation of energy parameters)	PT	X						
Final deliverables: updated catalogue of building components (including U-values calculation)	PT	X						
Issuing of a building specification and equipment description report (generic)	PT					X		

BUILDING PHYSICS TASKS	**TASK TYPE**	**PROJECT PARTICIPANT**						
		BPt	ARC	BSE	SE	PD	CSM	ExC
P3 Design phase/building permit phase								
Preliminary negotiations with local authorities and other parties involved in the planning for clearing the approval capability of the project	PT	X						
Continuous assessment and adaptation of the technical building equipment's concept (heating and hot water preparation systems, ventilation systems, sanitary installations, etc.)	PT			X				
Assessment of TBS-aspects in architectural plans, in consultation with the other project parties	PT			X				
Continuous assessment and adaptation of the static concept (incorporating technical building systems and building physics aspects into the planning) and its assessment in architectural plans	PT		X		X			
Optimization of the facade design according to economic design parameters	PT		X					

Assessment of building physics aspects in architectural plans, in consultation with the other project parties (thermal insulation, summer heat protection, moisture protection, airtightness and wind tightness)	PT	X						
Calculation of the emission area-related effective storage mass for the most unfavorable rooms in residential buildings and definition of sun protection devices and their location (summer heat protection)	PT	X						
Calculation of the cooling requirements in non-residential buildings (summer heat protection)	PT	X						
Building physics assessment and approval of the updated building specification and equipment description report	PT	X						
Redefinition of the building thermal zones and of conditioned and unconditioned rooms according to the changes in the planning	IT	X						
Final deliverables: updated catalogue of building components (including U-values calculation)	PT	X						
Final deliverables: windows parameters report (thermal insulation of windows; sun protection devices)	PT	X						
Final deliverables: building physics technical report (description of the thermal envelope, boundary conditions, opaque and transparent components, technical building systems, details that require building physics approval, additional insulation requirements, moisture protection measures, summer heat protection measures, ventilation requirements, airtightness requirements, material management requirements)	PT	X						
Final deliverables: summary of heat protection calculations including proof of calculations of single components, proof of compliance with energy parameters, updated energy certificates	PT	X						
Final deliverables: summary of heat storage calculations including calculation of summer heat protection for unfavorable rooms and definition of the corresponding window parameters and the sun protection devices	PT	X						
Final deliverables: recommendations for the execution of building physics measures (ventilation of components, shafts, connection joints, attics, thermal	PT	X						

separations, etc.)								
Final deliverables: proof of evaluation regarding the implementation of highly efficient alternative systems and of renewable energy sources	PT			X		X		
Energy pass database: upload in WUKSEA	PT	X						

BUILDING PHYSICS TASKS	**TASK TYPE**	**PROJECT PARTICIPANT**						
		BPt	ARC	BSE	SE	PD	CSM	ExC
P4 Call for tender phase								
Issuing of a construction details catalogue to guarantee a correct evaluation of weak points and correct execution of these details during the building execution phase	PT		X					
Assessment of building physics aspects in architectural plans (thermal insulation, summer heat protection, moisture protection, air- and wind tightness)	PT	X						
Assessment of building physics aspects of plans and details produced by the landscape planner (thermal insulation, moisture protection)	PT	X						
Assessment of building physics aspects (thermal insulation, summer heat protection, moisture protection, air-, and wind tightness) in construction details, particularly of projecting components, parapets, terraces, component joints, geometric thermal bridges, etc.	PT	X						
Assessment of windows-, French windows- and exterior door constructions, and building openings regarding heat protection	PT	X						
Assessment regarding protection against wind-driving rain and of the joint permeability on windows, French windows, exterior doors and on similar building openings	PT	X						
Assessment regarding wind-driving rain on facade systems	PT	X						
Assessment of potential construction- and geometric thermal bridges; definition if additional thermal insulation measures are necessary	PT	X						

Assessment, planning and dimensioning of waterproof barriers on cold roofs (rear-ventilated constructions) and warm roofs, as well as on green roofs, terraces, balconies etc.	PT	X						
Calculation of water vapor diffusion according to the Glaser method; recommendations in case that additional vapor barriers deem necessary	PT	X						
Final deliverables: updated technical building equipment concept report	PT			X				
Final deliverables: technical services description report (description of the execution of heating, ventilation, and plumbing works, airtightness, airflow measurements, thermal insulation of pipes, etc.)	PT			X				
Final deliverables: call for tender general contractor works record (technical description of the execution and material composition of the building components, building ecology measures, building physics onsite-measurements, experts services for the execution of the facade, etc.)	PT					X		
Assessment of the call for tender general contractor works record	RT	X						

BUILDING PHYSICS TASKS	**TASK TYPE**	**PROJECT PARTICIPANT**						
		BPt	ARC	BSE	SE	PD	CSM	ExC
P5 Execution phase								
Assessment and delivery of a retrenchments listing	PT					X	X	
Evaluation and approval of alternative concepts/materials to reduce building costs	PT	X					X	
Approval by the MA25, the MA50 and the property advisory board in case of design and component changes in the project (shading elements, glass area, etc.)	PT		X			X		
Updating and issuing of new construction details	PT		X					
Assessment and approval of updated and new construction details (thermal insulation, summer heat protection, moisture protection, airtightness, and wind tightness)	PT	X				X	X	
Proof of correctness and completeness of construction details (thermal insulation, summer heat protection,	PT						X	

moisture protection, airtightness, and wind tightness)								
Assessment and approval of polishing plans (thermal insulation, summer heat protection, moisture protection, airtightness, and wind tightness)	PT	X						
Assessment and approval of building physics aspects (thermal insulation, summer heat protection, moisture protection, air and wind tightness) of construction plans from executing companies (window and portal details, locksmith plans, etc.)	PT	X	X		X	X	X	
Clearing of building physics issues at the building site	PT	X						
Briefing the construction site manager regarding potential problematic details that require particular attention by their execution	RT	X	X					
Execution and controlling of building physics related building components	PT					X	X	X
Planning of construction process workflow for prevention of unwanted moisture penetration	RT						X	
Actions to accelerate the drying of building moisture	RT						X	
Checking the quality of building components, materials, and assembly methods (correct execution of the building airtightness concept)	PT						X	X
Intermediate airtightness test (blower door test) during the construction process, as defined for building subsidies	RT					X	X	X
Final airtightness test (blower door test), documenting and delivering of results to the MA25, as defined for building subsidies	PT					X	X	X
Expert controlling for the execution of the facade system (supervision and instruction of construction workers)	RT						X	X
Compliance with minimum requirements for the insulation of conducts	PT			X				
Screed heating testing and documentation	PT			X				
Construction materials and products management: assessment and implementation control of selected building materials and chemicals	PT						X	X
Round inspection of the constructed project before finishing construction works, to correct eventual problems	PT		X			X	X	

Final deliverables: updated summary of heat protection calculations including the catalog of building parts and energy certificates	PT	X						
Final deliverables: updated calculation of summer heat protection and definition of the corresponding window parameters and sun protection devices	PT	X						
Energy pass database: upload in WUKSEA	PT	X						
Final deliverables: issuing and delivery of building physics documentation for the replacement plans (only calculations that changed such as energy certificates)	PT	X						

BUILDING PHYSICS TASKS	**TASK TYPE**	**PROJECT PARTICIPANT**						
		BPt	ARC	BSE	SE	PD	CSM	ExC
P6 Building commissioning phase								
Issuing of a building´s user manual for occupants	RT					X	X	
Publication of energy performance certificates for buyers or tenants	PT					X		
Presenting factual energy consumption of the building three years after the building completion (for each year)	PT					X		

5.2 Changes evaluation template in the case study

The second research objective of this thesis pursued the goal of identifying which were the changes in the building components that occurred along the building delivery process that generated planning modifications, with subsequent building physics implications.

Here building physics implications refers to changes in the building components that trigger additional building physics tasks (reassessing details, replanning building parts) or that might affect the thermal performance of the building.

The changes in the building components are listed based on the analysis and documentation of the case study presented in chapter 4 *Case study*. The results are shown in Table 12, which describes the building component that changed, the reason for the change, the final status, and the phase the change occurrence took place.

It has to be pointed out that during the P1 Development phase there are no credited changes in the building components. It is considered that a change occurs if in a previous phase the given building component was defined either in plans, reports, etc. This means that because the initial project documentation appears after the finalization of P1, no changes are possible in this phase. Similarly, during the P6 building commissioning phase there are no planning activities in which the project consultants are involved. Thus, changes after the project completion are not part of the findings. Moreover, those building elements that were not evaluated and defined at the end of the P1 Development phase are considered to have suffered later changes only if at the end of a previous phase these were accordingly documented in plans or reports from the planning experts. The planning process through which building elements gain detail (through discussions in meetings or per email) is consider as part of the natural project evolution and is therefore not listed as a change.

The changes evaluation template of the case study is presented in Table 12:

Table 12. Changes in building components in the case study

CHANGES IN BUILDING COMPONENTS										
COMPONENT INITIAL STATUS	**CHANGE OCURRANCE**		**CHANGE CAUSE /REMARKS**	**END STATUS**	**CHANGE OCCURANCE PHASE**					
	YES	**NO**			**P1**	**P2**	**P3**	**P4**	**P5**	**P6**
TBS										
District heating system for room heating and hot water preparation		X								
Use of photovoltaics and other renewable energy sources	X		Costs	Evaluated but not implemented		X				
Heating system: floor heating		X	Costs; temporary change to radiators	Floor heating implemented						
Heating and hot water preparation distribution through staircase shafts	X		Decided by the new BSE	Distribution through apartments shafts					X	
Technical shafts										
Technical shafts: type A (vertical sealing-off)	X		Limited size of bathrooms and toilets (accessibility design). Shafts type B require less thermal insulation	Technical shafts type B executed (horizontal sealing-off)			X			
Technical shafts: position	X		Changes in the TBS						X	

CHANGES IN BUILDING COMPONENTS										
COMPONENT INITIAL STATUS	CHANGE OCURRANCE		CHANGE CAUSE /REMARKS	END STATUS	CHANGE OCCURANCE PHASE					
	YES	NO			P1	P2	P3	P4	P5	P6
Sanitary systems										
Terrace and garden irrigation system		X								
Natural rainwater infiltration	X		Soil contaminated	Not implemented (rainwater shafts)			X			
Rainwater drainage system		X		Execution relevant for building physics planning						
Static sewage water disposal system	X		Connection to the public network too high	Sewage water disposal system with pumping station		X				
Ventilation										
Window sound-absorbing fans	X		Costs	Replaced with wall sound-absorbing fans					X	
Apartments and common areas: manual ventilation		X								
Bathrooms and toilets: mechanical ventilation		X								
Office: mechanical ventilation	X		Costs	Not implemented (manual ventilation)					X	
Cellar rooms and technical rooms: static ventilation		X	Changes in the room fixture/ configuration of the cellar floor plan							
Laundry room and garbage room: mechanical ventilation		X								
DBA compression ventilation system (fire protection)	X		Practicability	System inverted					X	
Electricity										
Artificial lighting fixture in communal areas apartments	X		Costs	Quantity reduced					X	
Artificial lighting fixture in apartments		X								

CHANGES IN BUILDING COMPONENTS										
COMPONENT INITIAL STATUS	CHANGE OCURRANCE		CHANGE CAUSE /REMARKS	END STATUS	CHANGE OCCURANCE PHASE					
	YES	NO			P1	P2	P3	P4	P5	P6
Sun protection measures										
External shutters in all windows and French windows in apartments and the office	X		Costs	Only empty wall-boxes in windows for posterior installation of shutters. Interior blinds in windows and French windows in all orientations but north					X	
External shutters in common rooms (except for the ground floor, there interior blinds)	X		Costs	Shutters only in the big communal room in the roof top. Interior blinds in all common rooms without exterior shutters, except for north orientation					X	
Building ecology										
Jackdaw nesting		X								
Facade/thermal envelope										
EWIS facade system		X								
Windows and French windows material: wood-aluminum	X		Costs	Replaced with plastic-aluminum					X	
Windows positioning: in the outer edge of the reinforced concrete		X								
French windows positioning: in the inner edge of the thermal insulation	X		Additional costs for the CSM	Moved to the outer edge of the reinforced concrete					X	
Windows glass area	X		Economic parameters	Area reduced		X				
French windows glass area	X		Consequence of moving them to the reinforced concrete outer edge	Minimally reduced					X	
Entrance portal material: transom/ mullion construction	X		Costs	Replaced with an aluminum-portal					X	

Communal rooms portal material: Aluminum-portals		X								
Aluminum-portals glass area	X		Costs	Reduction of portals to 50-75%					X	
Dome lights in the staircase	X		Change in the fire protection system; another product was preferred by the CSM	Different size; different product					X	
Opaque components (separating thermal zones)		X								
Exterior steel sheet window-frames	X		Costs	Quantity reduced to 75%; other material chose by the CSM					X	
Winter gardens	X		Costs	Quantity reduced to 50%					X	
Pergolas	X		Costs	Quantity reduced to 50%					X	
Grid walls (vertical gardens)		X								
Ground floor columns perimetral insulation material: Heraklith	X		Costs	Executed with mineral wool					X	
Basement ceiling insulation	X		Costs	Executed with Paroc Fixrock					X	

CHANGES IN BUILDING COMPONENTS										
COMPONENT INITIAL STATUS	**CHANGE OCURRANCE**		**CHANGE CAUSE /REMARKS**	**END STATUS**	**CHANGE OCCURANCE PHASE**					
	YES	**NO**			**P1**	**P2**	**P3**	**P4**	**P5**	**P6**
Building constructions										
Roof uplift wrapped up with thermal insulation	X		Another solution was preferred	Executed with the product Overtec				X		
Vegetable garden concrete pots	X		Another solution was preferred	Executed with prefabricated blocks					X	
Roof top floor construction: inverted roof	X		Thermal bridge	The detail was adapted; change to a warm roof where to handrail is anchored					X	
Exterior side-buildings (size, construction on-site)	X		Costs, practicability of the construction method	Prefabricated containers					X	

Building structure										
Static design of the ground floor and basement levels	X		Soil contaminated	Ground floor and basement had to be redesigned			X			
Communal balcony slabs wrapped up with thermal insulation	X		Practicability	Balcony slabs executed with Isokorb				X		
Ground floor columns configuration	X		Perimetral insulation	Form adapted to include thermal insulation			X			
Rooftop reinforced concrete slab	X		Thickness of the floor construction due to thermal insulation; accessibility design	Concrete slab was lowered			X			
Ground floor reinforced concrete slab	X		Thickness of the floor construction due to thermal insulation and rainwater infiltration	Concrete slab was lowered			X			

5.3 Discussion

This section discusses the results shown in Table 11 and Table 12, and the analysis presented in chapter 4 *Case study*. Looking at answering the research questions in chapter 6 *Conclusion*, the discussion is thematically structured in subtopics.

5.3.1 Building physics tasks and project requirements

By comparing the case study building physics list with the generic building physics list, it appears that most of the tasks not occurring in the project are those related to additional recommendations for the design of energy-efficient buildings and with the implementation of alternative sources of energy.

The proposed classification of Building physics task types proposed in the methodology (primary, intrinsic, and recommended) pursued in part the objective of identifying which of them were driven by legislation requirements. In the final building physics tasks list, the vast majority of these are identified as primary (69) whereas only eight tasks are identified as recommended. Six are intrinsic tasks. The distribution of task types is shown in Figure 14:

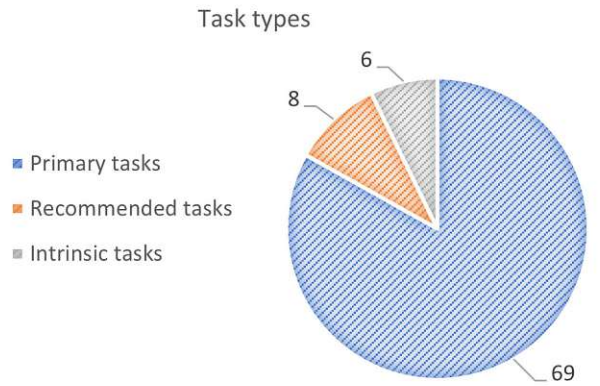

Figure 14. Task types

This implies that little is done beyond what is required by building legislation and contractual specifications, since primary tasks amount for 83% of the total tasks, and only 9,6% are recommended tasks.

A further analysis of the tasks shows that recommended tasks also occurred in their majority in the P5 Execution phase, as briefing the construction site manager regarding potential problematic details that require particular attention by their execution, expert controlling for the execution of the facade system, intermediate airtightness test (blower door test) during the construction process, etc.

Regarding the project requirements, from the analysis of the case study emerges that energy performance and airtightness requirements were reduced to its legal minimum. The fact that the project received financing from the city of Vienna tightened the energy efficiency, thermal performance and building ecology constraints, this is however also dictated by the corresponding building legislation. The same happened with technical building systems (the availability of district heating meant that other sources of renewables were discarded because of costs reasons) and mechanical ventilation systems, which were also cut out. It has to be pointed out that costs were particularly relevant in this project because the upper limit for subsidies is very restrictive.

Moreover, the descriptive category *Tools*, shows that the use of software tools during the planning was limited to the utilization of traditional computer-aided design and drafting applications as *AutoCAD* (Autodesk 2021), *SketchUp* (Trimble Inc. 2021) and *Rhino* (McNeel 2021), whereas *ArchiPHYSIK* (A-Null 2021) was the only software used for the energy modelling. Other tools for thermal performance assessment were not implemented.

Nevertheless, project requirements as extensive green areas, fauna protection, mobility concept, and materials certifications, (which address building ecology aspects except for the inclusion of green areas, which influence the local climate and therefore reduce temperatures) were dictated by the promotors of the project area, which could be considered as an indirect legal requirement.

Other design elements which affect the thermal performance of the building that were included in the project came from the architects, as the steel sheet window-frames, the grid walls (vertical gardens) and the pergolas, whereas the empty wall-boxes in windows to enable a posterior installation of shutters came from the project developer.

5.3.2 Experts' involvement

Concerning the distribution of building physics tasks among project participants, the building physicist participates in the big majority of them, performing 42 tasks. The second place is occupied by the project developer, the architects, the construction site manager and the building systems engineer which were involved in a similar number of tasks (sixteen, fifteen, fourteen and twelve respectively). The executing companies are identified as executing six tasks, whereas at the bottom of the list is the structural engineer with only two tasks. The distribution of tasks among project consultants is shown in Figure 15:

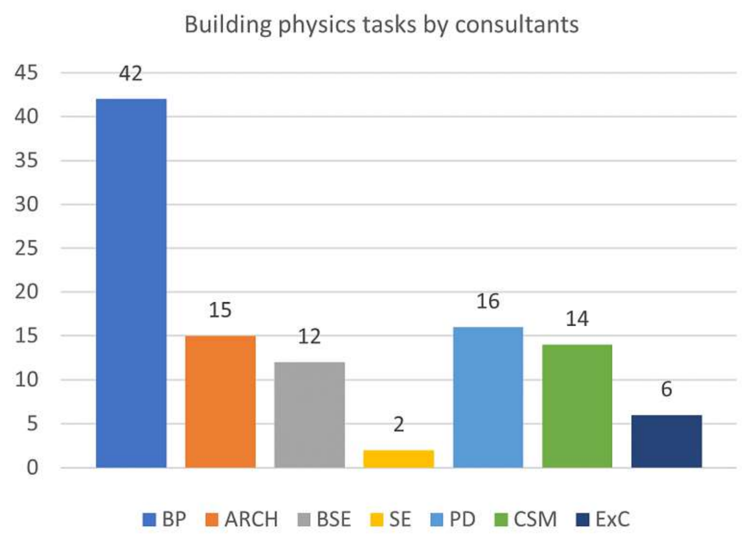

Figure 15. Building physics tasks by consultants

The conception and drawing of the construction details is a task of the architects, who also decided which were the critical details that required special attention. The selection was however confirmed by the project developer and the building physicist (Interview 1 2020). This was done first during the P4 Call for tender phase. The building physicist had the responsibility of assessing these details for its correctness. This also included the details drawn by the landscape planner, who produced its own details.

Construction details are part of the *Call for tender general contractor works* produced by the project developer, which also included a description of the works that were expected to be executed, including execution of building physics measures. This document was also randomly checked by the building physicist. Moreover, in this document it was explicitly formulated that the construction company is comprehensively responsible for the correct execution of the works, even if construction specifications and details are incomplete or contain mistakes. Additionally, the deliverables of the BPt at the end of the P3 Design phase included descriptions for the correct execution of critical building components.

The construction details were again extensively discussed with the executing companies and construction site manager during the construction meetings in the P5 Execution phase. Only at this point the costs and difficulties or impracticability of their execution was assessed. The building physicist was almost never present during these discussions. However, after the details were readapted some of these were sent back to him for approval.

The recurrency in the discussion of certain details during construction meetings and the fact that they had to be redrawn also give an idea of their specificity. At least 58% of the original details needed to be changed. This also indicates that details had to be assessed by different project parties, which brought specific knowledge to the table, each questioning different aspects. The most discussed details were those dealing with the execution of U- and L-French windows in loggias (eleven), the anchoring of the handrail in the rooftop (six), positioning of portals (four), the execution of the thermal insulation in terraces and communal loggias (four), and the insulation of exterior columns (four). This assessment coincides with the observations of the project developer (Interview 4 2020). Additionally, the construction site manager named the execution of loggias (Interview 3 2020). Reasoning from this, it can be inferred that the building physics aspect that requires more clarification efforts during the building delivery process is thermal insulation. Taking all this into account, it could be argued that although the details address known problematics as the execution of the thermal envelope, these still require adaptations to express the reality of the project, and to fulfil the requirements of the construction site manager and the executing companies once they are incorporated to the project.

As a response to the discussions emerging in the construction site, the architects also provided supplementary construction details addressing building physics aspects. Almost the same number of new details in comparison with P4 Call for tender phase had to be drawn in P5 Execution phase. Considering both adaptations of previous details and new details, only 25% of them were sent for approval to the building physicist. This also shows that the responsibility about the correctness of building physics related details relays not only in the building physicist but also in the project developer and in the construction company, which did revise the new details.

The windows- and portal manufacturer, the executing companies, and the facade expert also produced their own details. These were approved by the building physicist together with the architects and the project developer.

With respect to the execution of construction details, their correct execution is guaranteed partially through the implementation of on-site measurements as the blower door test, and screed heating test, although this is stipulated by building legislation. Other tool as photo thermographs was initially contemplated but discarded because of costs. Regarding the evaluation of thermal bridges and mold formation, it was stated by the building physicist that normally only in case of doubt these are additionally modelled, which was not the case in this project (Interview 2 2020). Finally, although initially discarded, the construction company did hire the services of a facade expert for the supervision of the facade execution although this is not mandatory (Interview 3 2020).

In case of doubts, the project developer checked the correspondence of defined building components with the specified in the construction details, although normally he visited the construction site only every second week (Interview 4 2020). Whenever possible, the construction company also supervised the work of the executing companies, which are also additionally instructed to observe building physics requirements. These are also certified companies that provide a certification of the correct execution of the building components. However, it was acknowledged that in the case of execution of moisture-, air- and wind barriers these are not getting the necessary attention during execution works. In this issue the construction company relays in the qualifications of the executing companies, which is suggested to be arbitrary. In addition, the existence of sub-contractors of the sub-contractor companies is pointed out as also being problematic (Interview 3 2020).

5.3.3 Building physics planning efforts

In Table 11 there is a total of 83 identified building physics tasks, including tasks that repeat themselves in different stages. Their distribution in the project phases is shown in Figure 16:

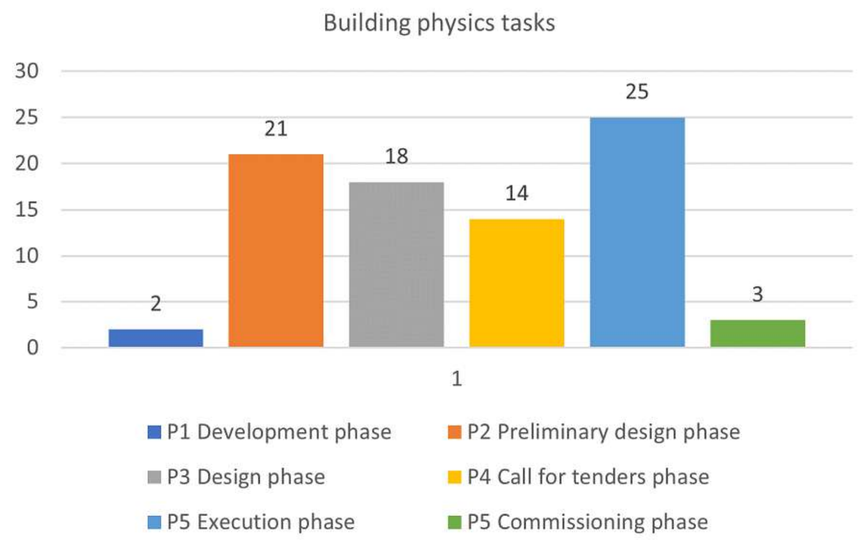

Figure 16. Phase distribution of building physics tasks

Most tasks are concentrated in P5 Execution phase. There are almost no building physics tasks in the P1 Development phase at the beginning of the building delivery process.

In the analysis of the case study, tables were provided describing the number of hours worked by both architects and building physicist (category *time effort*) and the duration of each planning phase (category *timeframe*). To evaluate the planning efforts made in each phase, it is useful to compare the content of the Tables 6 to 10.

Figure 17 shows the duration of each phase in months, additionally discriminating the percentual duration in relation to the full planning and execution process:

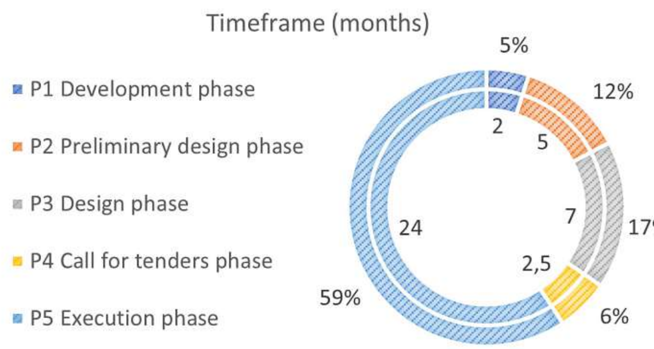

Figure 17. Monthly and percentual duration of the planning phases

Besides the P5 Execution phase, which is by far the longest phase, the second extended one is the P3 Design phase, followed by the P2 Preliminary design phase. Both P1 Development phase and P4 Call for tender have almost the same duration, being this a third of the design phase. However, the duration of the phase per se does not mean they required more planning efforts, since planning interruptions (as occurred in the design phase due to soil contamination) and other factors as long decision-making waiting times cannot be evaluated without a detailed documentation of working hours.

Figure 18 provides a comparison of the working hours invested by the architects and by the building physicist in each phase:

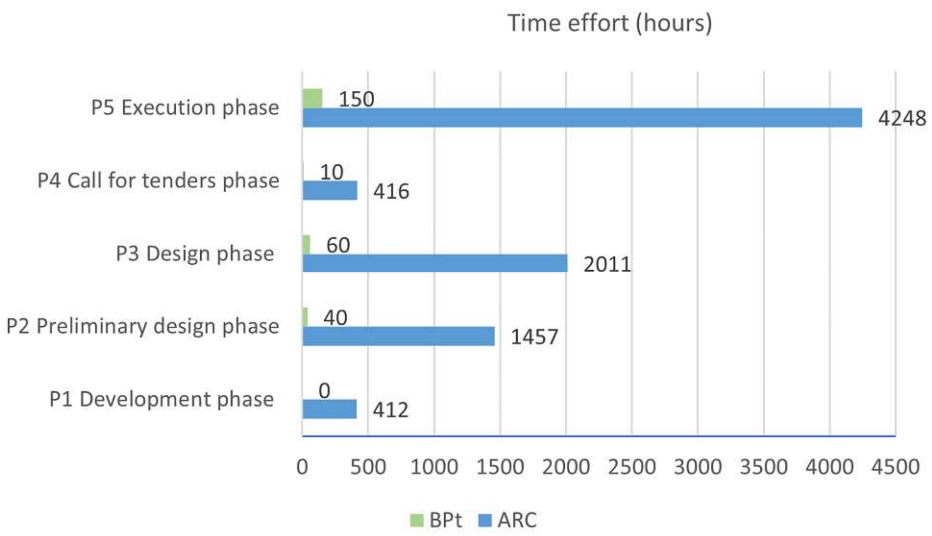

Figure 18. Invested planning hours

There is a correlation in the duration of the phases and the number of hours worked by the architects, being the P5 Execution phase the most time-consuming, followed again by the P3 design phase and the P2 Preliminary design phase. However, although the duration of the P5 Execution phase is three times longer, the number of hours worked only double the hours invested in the P3 Design phase. This can be interpreted as the design phase requiring more planning efforts in a shorten period.

By looking at the invested hours by the building physicist a similar correlation can be observed, except for the hours invested in P4 Call for tender which was the less time consuming. The BPt was not involved in the P1 Development phase.

To analyze the issue in more detail, Figure 19 offers a weighted comparison of the invested worked hours per month in each planning phase by the architects and by the building physicist:

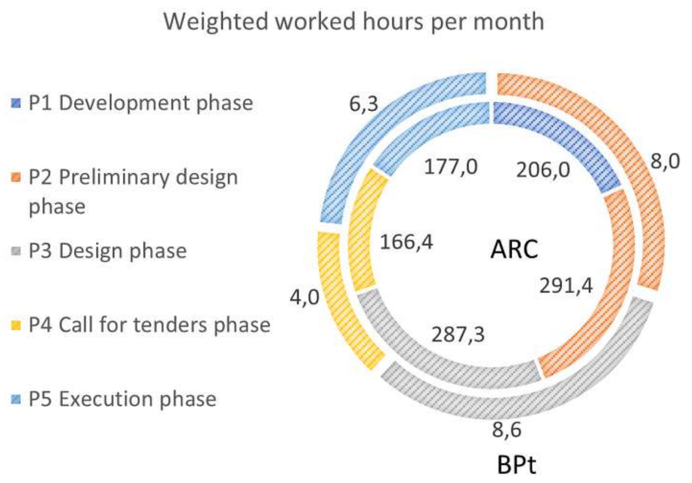

Figure 19. Weighted worked hours per month

If the duration of the phase in considered, for the architects the P5 Execution phase is not the most effort-consuming, but the P2 Preliminary design phase, closely followed by the P3 Design phase. The P5 Execution phase is in the fourth place, with the number of hours invested per month relatively similar to those worked in the P4 Call for tender phase. However, the call for tender has a duration of 10% of the execution phase.

This also shows that for the building physicists the most effort-consuming phase is, comparably to the architects, the P3 Design phase followed by the P2 Preliminary design phase. The third most effort consuming phase for the BPt does not correlate with the architects, as for him the P5 Execution phase required more effort, whereas for the architects in third place is the P1 Development phase.

What stands out in Figure 18 is the huge difference in the number of hours invested by the architects and by the building physicist, with the total time-investment by the BPt representing 3,5% of the hours worked by the architects. However, this percentage by itself does not say anything about how many hours are investing architects to deal with building physics aspects. On one side, besides architecture planning the architects assume the role of coordinators of the other planning experts, and on the other side, as it can be deduced from the building physics tasks list, building physics specific tasks executed by planners are hard to single.

Turning now to the descriptive category *outcomes,* if the number of documents and reports produced during a phase is considered to measure how much effort is invested in building physics tasks, it emerges that the P5 Execution phase is the one producing more material results followed by P3 Design phase, the P4 Call for tender phase, the P2 Preliminary design phase and last the P1 Development phase. The distribution of documents and reports per phase is shown in Figure 20:

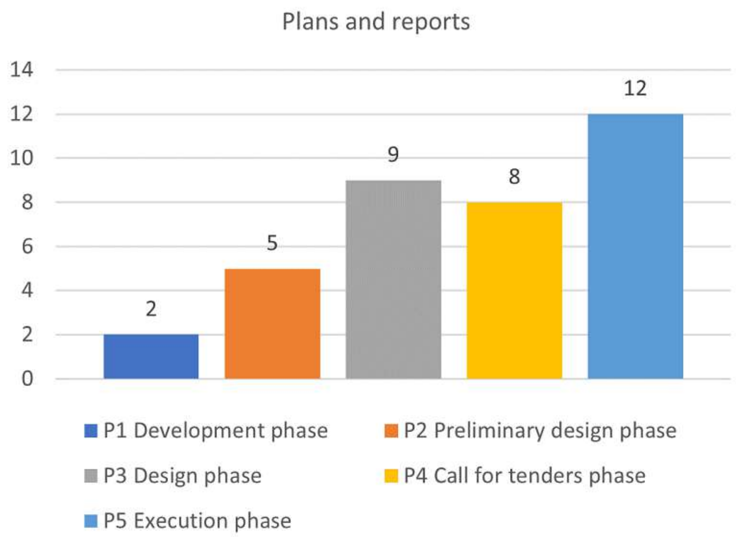

Figure 20. Plans and reports per phase

This correlates with the duration of the project phases except for P4 Call for tender. If the building physics tasks distribution is considered (shown already in Figure 16), there is another correlation. The Figure shows that the phases with more single steps are the P5 Execution phase (25), the P2 Preliminary design phase (21), the P3 Design phase (eighteen), the P4 Call for tender (fourteen), and the P1 Development phase (two). The longest phase is therefore producing more materials results and the one with more single building physics tasks. This also can be partially driven by the larger number of consultants involved in the planning. Besides, it correlates with the number of hours worked by the architects or the building physicist.

5.3.4 Building components definition

In Table 12 the building components that suffered changes along the building delivery process were shown. A further analysis of this table shows that out of 34 change occurrences in the project, seventeen originate in the necessity of reducing building costs, fourteen because of planning related issues, two are the result of unexpected circumstances (as the contamination of the soil). One change was caused by other reasons. That is, 50% the changes in building components are due to costs, with planning changes slightly behind. The motives for changes in the project planning are illustrated in Figure 21:

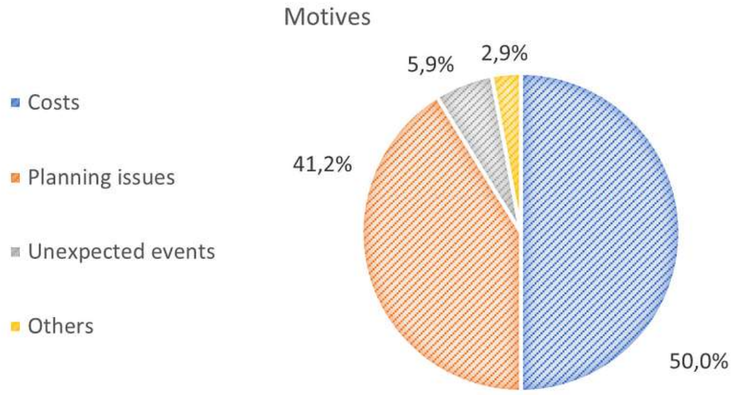

Figure 21. Motives for project changes

In addition, at least ten out of the seventeen changes caused by the need of reducing costs can be identified as influencing the thermal and energy performance of the building (i.e., glass area, exterior sheet window frames, exterior shutters, ventilation system, lighting, etc.). However, not all of this data was utilized to issue the energy certificates.

A vast majority of the 34 changes occurred in the P5 Execution phase, amounting for 64,7% of the changes (22), followed by 20,6% (seven) during the P3 Design phase. The distribution of occurrence changes in the different project phases is shown in Figure 22:

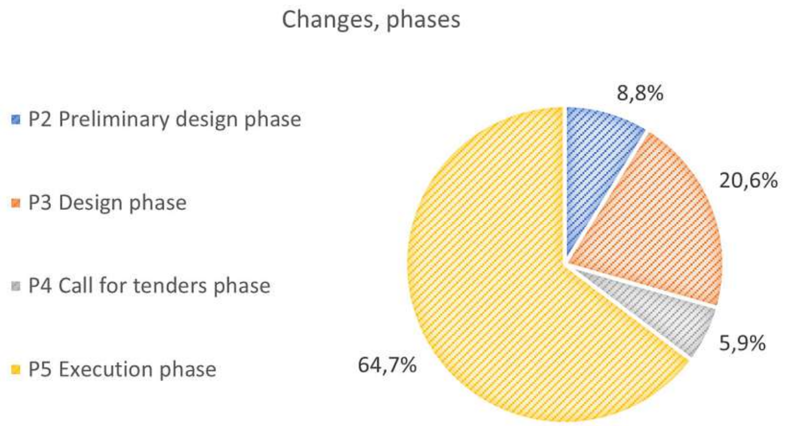

Figure 22. Phase of the change occurrence

This is particularly relevant in the case of the changes originated by costs, with 88,2% of the changes occurring during the P5 Execution phase. This correlates with the fact that the retrenchment listing was provided at the beginning of the P5 Execution phase when the specific costs of the project were first known. Interestingly, the other two changes caused by costs happened during the P2 Preliminary design phase, in the early stages. As previously mentioned in chapter *4 Case study,* the facade design was first sketched during this phase and subjected to a checking instance with the economic parameters provided by the project developer. This means that changes due to costs occurred either at the beginning of the planning process or at the very end.

Regarding the changes occurred due to planning aspects, the motivations behind differ raging from changes introduced by the BSE, changes to comply with building regulations, new project data, changes in products, the practicability of construction solutions, and changes originated in the adaptation of the building design to the requirements of the thermal envelope. As in the costs case, the big majority of planning changes occurred in the P5 Execution phase amounting 42,8% but closed followed with 35,7% in the P3 Design phase. P4 Call for tender follows with 14,2% and the P2 Preliminary phase with 7,1%. This indicates that although not evenly distributed, planning changes are not so concentrated as changes caused by costs. Figure 23 illustrates the motives of the changes and the phase they took place:

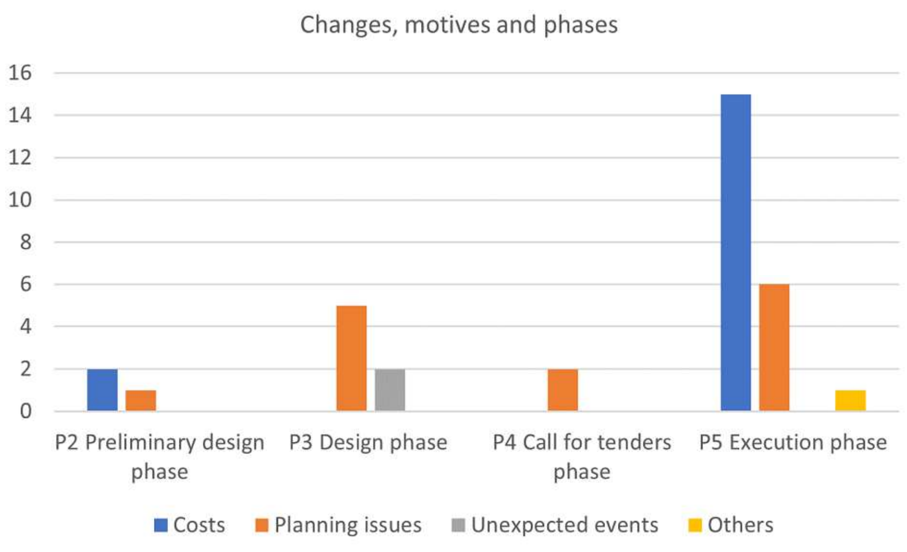

Figure 23. Changes motives distribution

A possible explanation for planning changes occurring in the P5 Execution phase is the mentioned incorporation of new agents in the planning process, as the company in charge of executing TBS, the construction site manager, and the executing companies. It could be argued that the involvement of the executing companies in the planning process makes changes in the execution phase unavoidable. Additionally, the availability and delivering times of manufacturing companies proving products and materials also play a part. Moreover, there are other triggers as overlooked building regulations, not enough planning experience or not enough detail gained in early stages of the project which also might cause changes in the planning.

A further analysis of the building components is provided in Table 13. Premised on the changes template provided in 5.2 and on the evaluation of the case study provided in chapter 4, Table 13 shows specifically a summary of the main building components and design parameters influencing the energy and thermal performance of buildings and the phase they were fixed in the project:

Table 13. Phase definition of energy-relevant building components

BUILDING COMPONENTS relevant for energy performance			
Development phase P1	**Preliminary design phase P2**	**Design phase P3**	**Execution phase P5**
Energy supply system	Additional renewable energy sources	Artificial lighting Fixture (apartments)	Heating system
Thermal envelope (facade system)	Manual ventilation (apartments)		Heating and hot water distribution system
Net living area (m^2)	Windows and portals (arrangement)		Mechanical ventilation systems
Building form	Windows and portals (building physics requirements)		Artificial lighting fixture (common areas)
Building orientation	Opaque components (separating thermal zones, requirements)		Exterior shading devices
			Interior shading devices
			Glass area
			Dome lights (size and product)
			Exterior steel sheet window-frames (shading, greenery)
			Winter gardens (puffer zone)
			Pergolas (shading, greenery)
			Grid walls (vertical gardens)

From the analysis of Table 13, it emerges that more than a half (twelve) of the building components relevant for thermal and energy design are only defined at the end of the building delivery process, during the P5 Execution phase. The other half of the components are defined almost equally during the P1 Development phase (four) and the P2 Preliminary design phase (five). In the P3 Design phase only one element is defined. The phase definition of these building components is shown in Figure 24:

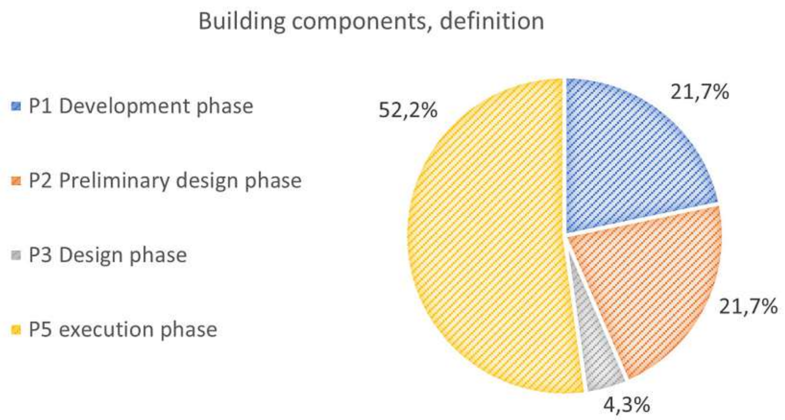

Figure 24. Phase definition of energy-relevant building components

The results in this section seem to indicate that whereas some building components essential to assess the energy and thermal performance of the building are defined at the very beginning of the planning (net living area, building form, building orientation), a substantial majority of building components suffer changes till the very end of the planning process.

6 Conclusion

6.1 Answers to the research questions

- **RQ1: Are building physics related tasks and requirements in the project driven only by building legislation?**

The types of tasks identified in the building physics tasks list of the case study suggest that most of them are performed to comply with building regulations or contractual specifications, and only a minority of the tasks are identified as recommended tasks. Furthermore, among those identified as recommended, the majority are tasks with a focus in securing the correct execution of building physics measures in the building components. The fact that most of the recommended tasks are also performed in the P5 Execution phase at the end of the building delivery process indicates that the efforts put in building physics tasks tend to concentrate in the correct planning and execution of construction details and not in an efficient building energy design, as otherwise proposed in the reviewed specialized literature.

It general, therefore, it seems that if not supported by building legislation there is a lack of motivation to assess the energy and thermal performance of buildings. Software tools used by both architects and building physicists remain being the traditional computer-aided design and drafting applications, as *AutoCAD* (Autodesk 2021), and *ArchiPHYSIK* (A-Null 2021). No other building performance assessment tools were used. This however needs to be interpreted with caution, since a reason for not implementing other instruments as green certifications is found to be that the market of subsided rental apartments does not necessitate them to make the apartments attractive, which could also explain the lack of incentive to implement other assessments tools.

Nevertheless, although their impact in the building performance was not studied, requirements set in the context of the master plan, although indirect obligations, raised the project quality. Moreover, even if costs were restraining the design possibilities, the analysis shows that there is still some room for implementing passive design strategies as it was the case of the facade design, which was an initiative of the architects.

- **RQ2: Which consultants are responsible for securing the correct planning and execution of building physics related construction details?**

The responsibility for the correct planning of construction details is found to be distributed among the architects, the landscape planner, the building physicist, the project developer, the construction site manager and to some extent the executing companies.

Although thermal insulation continued to be the most discussed topic during the P5 Execution phase, evaluation methods as thermal bridges modelling was not implemented. This is left to the criteria of the building physicist, who decided if they deemed necessary.

All in all, the findings show that the correct execution of construction details during the building delivery process is mostly but not completely covered. In this case, the responsibility lays by the project developer, the construction site manager, and the executing companies. Here there seems to be room for improvements. The lack of thermal bridges modelling was not compensated with photo thermographs, which were considered but not implemented because of their cost, hence a thermal bridges-free construction cannot be guaranteed. Monitoring systems during the commissioning phase will not be implemented, therefore potential problems such as heat leakages through the thermal insulation will probably stay unnoticed. Nevertheless, although not mandatory, the construction company did hire the services of an expert for inspecting the execution of the external wall insulation system. Besides, it was pointed out by the project developer that only one in ten buildings experience problems related to incorrect building components execution works.

The last link in the execution chain are the executing companies. It was suggested that although these are certified companies, also instructed about the correct execution of building physics relevant measures as moisture-, air- and wind barriers, their qualification was put into questioning. The fact that in the construction site some of the executing companies are sub-contractors of the sub-contractors was also mentioned as problematic. Finally, their work is only randomly supervised by either the construction site manager or by the project developer.

- **RQ3: Do the invested working hours in each planning phases correlate with the building physics related planning efforts?**

As previously stated, the resulting building physics tasks list of the case study indicates that most of the tasks are concentrated in the P5 Execution phase, this phase being the longest one and with more expert's participation. Moreover, in the execution phase both architects and building physicist invested more working hours, although the architects performed other tasks not related to building physics. In this phase, more documents and plans addressing building physics aspects are produced. The tasks also concentrate around the correct planning and execution of construction details. However, a note of caution is due here. When the duration of each phase is considered together with the number of hours worked, it emerges that the architects made more planning efforts (more hours worked per month) during the P2 Preliminary design phase, whereas for the building physicist it was the P3 Design phase. This can be interpreted as more materials results having to be delivered in a shorten period, which correlates with the delivery of the quasi-final project documentation to the municipal authority, which occurs at the end of the design phase. Beyond this point, modifications in the project can only be made if they do not substantially change the building configuration and prescribed legal requirements.

It is also asserted that although the building physicist is by far the one involved in more building physics tasks, performing three times more tasks, other planners as the project developer, the architects, the construction site manager, and the building systems engineer are also equally responsible for executing them. This is in line with the changes in the building delivery process dynamic suggested in the introduction.

- **RQ4: At which point of the building delivery process are the building components defined in a level of detail that can be considered as influencing the (final) thermal and energy performance?**

The changes evaluation template shows that a half of the change occurrences in the case study derive from a reduction of the building costs, with the other half of the changes caused by diverse planning motives. There are no indications that changes caused by planning affect building performance aspects. These rather caused reprocesses as the redrawing and reassessment of construction details which leads to more working hours.

In contrast, more than a half of the modifications originated because of costs can be described as influencing the thermal and energy performance of the building. As in the case of the building physics tasks, most of the changes caused by costs also occurred during the P5 Execution phase. This means that to some extension the final fixture of the building remains undefined till the very end of the building delivery process.

In connection with this, the findings indicate that whereas a little less than a half of the building components relevant for energy analysis are defined by the end of the P2 Preliminary design phase, a substantial majority of building components suffer changes till the very end of the planning process. This could limit the usefulness of predictive energy performance tools if these are not repeated in each phase when more detail is added to the project.

6.2 Conclusion

The aim of this thesis was to propose an evaluation method to examine how building physics aspects are incorporated to the planning stages of the building delivery process, focusing on thermal protection and energy efficiency, although some building ecology features were also tackled. Through the documentation and analysis of a residential building built with subsidies in the city of Vienna it was possible on one hand to identify which are the specific building physics tasks carried out during its planning and execution process, and which planning experts are involved in their execution. On the other hand, it was possible to identify changes in the building components occurred during the building delivery process that prompt additional building physics planning modifications. The question of at which point in time are building components relevant for energy analysis defined in the planning process was also explored.

The main findings indicate that most of the tasks related to building physics concentrate around the correct planning and execution of building physics aspects in construction details in the last project phases, in contraposition to potential tasks to assess or improve the thermal performance of the building in early stages. Still, there might be room for improvements in relation to the modelling and evaluation of construction details, on-site testing, and supervision of their execution at the building site. As for the qualifications of the executing companies, the increasing number of building sites in the city of Vienna and the consequent shortage of specialized work force might have repercussions regarding this point.

Concerning the project requirements, although most building physics tasks are performed to comply with building regulations related to the energy and thermal performance of the building as defined in the *WBO*, the *WWFSG 1989* and the *OIB-6*, there were some recommended tasks done which support passive design strategies, even though construction costs were restrictive. These came as initiative from the planners and in the context of the requirements set for the masterplan of the project area. However, the impact of these passive design strategies was not measured. The relevant data was not used for issuing the energy certificates and no other simulation tools were implemented. The fact that passive design strategies were implemented even if the project had a reduced budget because it received building subsidies opens the door to the possibility of using these strategies to improve the performance of buildings in private financed projects. Yet, building costs can vary from project to project depending on many factors, for which a generalization cannot be made.

The downside of the analysis appears in relation to the configuration of the facade glass area. The restrictive economic parameters from the project developer meant that only the minimum requirements set by the *OIB-3* for illumination were implemented. This leaves almost no room for improvements if the facade design is not evaluated together with the building form, building orientation and floor plan configuration already in the first stages of the project planning, because later changes are not possible.

In this line, although at the beginning of the building delivery process little was done in relation to building physics tasks or to assess the thermal performance of the building, a little less than a half of the building components relevant for energy analysis were defined in the early stages of the planning process. This can be promising if energy performance simulation tools are used to assess the initial building configuration. Energy analysis should however be repeated along the building delivery process since the analysis also shows that most changes in building components occurred in the execution phase at the end of the building delivery process. Particularly, the fact that costs are only known late in the planning might prove problematic when trying to predict energy consumption in early phases.

Overall, the building delivery process showed distributed building physics tasks in all project phases except for the initial development phase and the commissioning phase. The tasks were performed in their majority by the building physicist, however, there was an even distribution of tasks among other experts, which reinforce the idea that the dealing with building physics aspects increasingly involves other areas of expertise. The current building legislation, which is now putting the emphasis on the implementation of highly efficient alternative systems and building automation and control systems, is likely to continue this trend.

Although most tasks are performed towards the end of the building delivery process when more experts are involved, the number of tasks performed in the preliminary- and design phases together and the proportion of hours worked in shorten periods in these phases show that many efforts are made to deliver a building design which complies without major problems with the energy and thermal performance requirements set in building legislation.

Interestingly, the four experts interviewed in this thesis agreed that the building delivery process of the case study can be described as representative of other planning processes. Among other aspects, the architects mentioned the framework conditions, project requirements and the approval process of construction details as comparable to other projects. The construction site manager pointed out to the expeditive delivery and approval process of construction details, identifying this as being particularly eventful. Finally, of the aspects examined in this thesis, the building physicist identified the work structure, the tasks performed in each phase and the workload as being representative. It was also suggested that the complexity and size of a given architecture project are main determents of how the planning process unfolds. This indicates that the tasks per se might not differ much in other projects, but the amount of planning efforts invested.

By and large, the findings in this study support the idea that the growing complexities experienced in the planning and execution of architecture projects also reflect on building physics planning aspects. Consistent with the interviews, the changes experienced in the last twenty years in the building delivery process dynamic in relation to the building physics field point out to higher legislation restrains and quality standards, further developments and possibilities in materials and technologies, challenging coordination efforts between planners, while also more sensibility to building physics aspects from the side of the building occupants.

6.3 Limitations of this study and further research

The broad scope of the building physics tasks proposed in this thesis meant that the single steps within each task could not be developed in detail. Further research could concentrate in deepening these single steps in intermediate steps. Weighting the relevance of each of the tasks in the overall building delivery process seems also advisable.

Moreover, it would be beneficial to analyze the impact of the changes in building components which affect the energy performance of the building caused by costs. At which point in the building delivery process would be useful to have them defined? It is possible to evaluate definite costs in early stages of the planning process? If not, are predictive tools useful at all?

Likewise, it could be further studied if a more efficient planning with less changes occurring along the building delivery process could lead to an increment of the available time-resources for planners to invest in analyzing the thermal and energy performance of buildings.

Although findings suggest that much effort is made to secure the correct planning of construction details, further work needs to be done using statistical data to establish whether more actions are required to improve the quality of their execution.

Finally, further studies need to be carried out to validate the observations made in this master thesis. Since the current study provided with the analysis of one object, comparisons are not yet possible and therefore needed in the future. A feasible approach could be comparing both the generic and the project-specific building physics tasks list to the building delivery process of other residential buildings, looking at finding matches and inconsistencies.

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Abbreviations

ARC	Architects
ASI	Austrian Standards International
BP	Building physics
BPt	Building physicist
BSE	Building systems engineer
CO_2	Carbon dioxide
CSM	Construction site manager
DBA	Druckbelüftungsanlage
DIN	Deutsches Institut für Normung
EADBV	Energieausweisdatenbank-Verordnung
EAVG	Energieausweis-Vorlage-Gesetz
EEB	Endenergiebedarf
EPBD	Energy performance of buildings directive
EU	European Union
EWIS	External wall insulation systems
ExC	Executing companies
fGEE	Faktor für die Gesamtenergieeffizienz des Gebäudes
GWR	Wohnungregister-Gesetz
MA	Magistratabteilung
LP	Landscape planner
OIB	Österreichisches Institut für Bautechnik
ÖBA	Örtliche Bauaufsicht
HEAS	Highly efficient alternative systems
HEB	Heizenergiebedarf
HWB	Heizwärmebedarf
IT	Intrinsic tasks
ISO	International Standardization Organization
KB	Kühlungsbedarf
PEB	Primärenergiebedarf
PD	Project developer
PT	Primary tasks
RK	Referenzklima

RO	Research objectives
RQ	Research question
RT	Recommended tasks
SE	Structural engineer
TBS	Technical building systems
TGA	Technische Gebäude Ausrüstung
WG	Wohngebäude
WBO	Wiener Bauordnung
WBTV	Wiener Bautechnikverordnung
WFLKG	Wiener Feuerpolizei-, Luftreinhalte- und Klimaanlagengesetz
WHKG	Wiener Heizungs- und Klimaanlagengesetz
WUKSEA	Wiener unabhängiges Kontrollsystem für Energieausweise

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Appendix

A. Interviews with planning experts

Interview 1: the architecture office

1. ***Können Sie einige Angaben zu Ihrer Ausbildung machen und wie viele Jahre Erfahrung Sie als Architekt haben.***

Ich habe von 1985-1994 studiert (TU Innsbruck, TU Wien, University of Michigan, Ann Arbor U.S.) und beschäftige mich seit 1996 durchgehend mit Architektur.

Seit ca. 2003 CEO von (name of the company), seit 2020 CEO von (name of the company)

2. ***Können Sie den Ablauf beschreiben, wie Ihre Firma an der Realisierung dieses Projektes involviert wurde.***

(Name of the company) wurde von einem Bauträger in Wien eingeladen gemeinsam an einem Bauträgerwettbewerb teilzunehmen. Dieser zweistufige Bauträgerwettbewerb konnte gewonnen werden und daraufolgend wurde (name of the company) mit den Planungsleistungen Architektur beauftragt.

3. ***Was ist das Interesse Ihrer Firma an geförderten Wohnbauprojekten?***

Es gehört grundsätzlich zu den klassischen Planungsaufgaben eines Architekturbüros. Darüberhinaus spielt der soziale Aspekt – etwas Positives für die Gesellschaft beizutragen - auch einen wichtigen Aspekt der Motivation. Wir haben im Zuge der Beschäftigung unsere Kompetenz hinsichtlich sozialer Aspekte, wirtschaftlicher und auch ökologischer Aspekte erweitert.

4. ***Hat ihre Firma ein besonderes Interesse bei diesem Projekt Aspekte der Nachaltigkeit zu fördern? Wenn ja, welche?***

Soziale Aspekte (eine gute friedliche und kooperative Hausgemeinschaft) können auch durch Architektur in Gang gesetzt werden (Spielbereiche, Gemeinschaftsbereiche, Werkstatt) – diese fördern die nachhaltig gute Nutzung des Gebäudes. Darüberhinaus ermöglicht die Mischung von Funktionen (Büros, Wohnungen, Gästewohnung, Aussenbereiche, Dachnutzungen) ein nachhaltlig gut genutztes Gebäude. Last but not least stellt auch Ästhetik einen Nachhaltigkeitsfaktor dar, weil schöne Gebäude langfristig mehr geschätzt und erhalten werden.

5. ***Bitte beschreiben Sie generell, welche Anforderungen Sie in dem Projekt beachten mussten (z.B. Zielvorgaben für die Gebäudeoptimierung, Budget, usw.).***

Gemeinsam mit dem Auftraggeber wurde der Kostenrahmen immer strikt beachtet bzw. vor allem vor Baubeginn mussten Abstriche hinsichtlich Belichtungsflächen (Fenster) sowie bei der Qualität der Oberflächen erfolgen.

Die obligatorischen Ziele hinsichtlich Energiekennzahl wurde vor allem durch den Bauphysiker geprüft und kontrolliert.

Der Zuschnitt und die nutzbaren Flächen unterliegen im sozialen Wohnbau in Wien genauer Regeln welche eingehalten werden mussten.

6. ***Welche Aspekte der Bauphysik waren Ihrer Meinung nach für die Planung und Ausführung besonders wichtig?***

Vermeidung von Schimmelbildung durch Konsenat ist in Wien ein heikles Thema (Hygiene) und wird von Bauphysiker und Haustechniker gemeinsam hintangehalten (Kältebrückenvermeiden z.B.beim Einbau der Fenster), keine kalten Stellen im Bereich von Schränken u.ä. innerhalb der Wohnungen bei Außenwänden.

7. ***Wie wird in der Planung entschieden, welche die kritischen Details sind, die gezeichnet werden müssen? Zu welchem Zeitpunkt wurden diese kritischen Details gezeichnet? Wie erfolgt die Abstimmung mit anderen Konsulenten?***

Entscheidung fällt gemeinsam (Auftraggeber, Architekten, Bauphysiker) manchmal auch allein durch den Architekten.

Ein Teil wird bereits bei der Erstellung der Kostenermittlungsgrundlagen (Ausschreibung) erstellt, ein Großteil im Zuge der Ausführungsplanung (im Zuge der Polier- bzw. Rohbauplanung tauchen die relevanten Themen auf)

8. ***Haben bauphysikalische Maßnahmen Ihrer Meinung nach die ursprünglich geplante Architektur beeinflusst? Wenn ja, welche und inwiefern?***

Da der Entwurf relativ robust und einfach war, haben bauphsikalische Aspekte die Architektur kaum beeinflusst.

9. ***Welche Aspekte wurden für die Gestaltung von Fassaden und Fenstern evaluiert? Wurden die Himmelsrichtungen und die Glasflächen besorders betrachtet?***

Die Beschattungssituation wurde präzise untersucht. Die Ausrichtung des Hauses hatte im Entwurf keinen Einfluss auf die Fassaden und Fenster. Lediglich Aussenbereiche (wie zweigeschossige Gemeinschaftsloggien) wurden nach Norden orientiert, allerdings ist durch auch ein attraktiver Ausblick.

10. ***Sind Sie der Meinung, dass die Architekten in den ersten Phasen der Projektentwicklung Gebäudesimulationen durchführen sollten, um die Performance des Gebäudes zu optimieren? Wieso?***

Inwieweit diese Gebäudesimulationen die Konzeption bei einem Wohnbau beeinflussen könnten ist schwer zu sagen, als Ergänzung bzw. um Fehler zu vermeiden wären Gebäudesimulationen sicherlich begrüssenswert.

11. ***Wie hat sich Ihre Meinung nach die Baubranche in den letzten 20 Jahren aufgrund der Bauphysik verändert?***

- Erhöhung der Möglichkeiten (z.B. durch Vakuumdämmung)
- Trägt zur Erhöhung der Qualität von Gebäuden bei (Energieoptimierung, Wärmedämmung, keine Schimmelbildungen mehr)

12. ***Haben Sie Vorschläge, wie der Ablauf/Zusammenarbeit zw. Konsulenten, Planer und die GU verbessert werden könnte?***

- Telefon bzw. Videokonferenzen
- BIM Planung (zumindest prinzipielle dreidimensionale Planung)

13. ***Wie viele Arbeitsstunden haben Sie für das Projekt ca. aufgewendet?***

WET: 412

VOR: 1457

ENT: 2011

AUS: 416

POL: 4248

14. ***Basierend auf Ihrer Erfahrung, erachten Sie den Ablauf des Planungs- und Bauprozesses vom Projekt LEO als repräsentativ im Vergleich zu anderen Planungs- und Ausführungsprozessen?***

Abgeleitet aus der Erfahrung der letzten 20 Jahre im Bereich des großvolumigen Wohnbaues, kann das Bauvorhaben „Leo & Leonie“ aus meiner Sicht als repräsentativ hinsichtlich folgender Aspekte betrachtet werden:

-) Energiekennzahlen der beiden Baukörper „Leo & Leonie“ entsprechen dem „state of art“ hinsichtlich der Anforderungen im Bereich geförderter Wohnbau in Wien

-) Die geforderte Wärme- und Energieeffizienz wurde im Zuge des Entwurfs- bzw. baubehördlichen Einreichsprozedere festgelegt und bis zur Fertigstellung des Bauvorhabens eingehalten und realisiert.

-) Sämtliche geplanten Baudetails wurden ebenso ausgeführt und entsprechen den erprobten Standards umgesetzt. Es wurden keine Sonderdetails entwickelt, welche nicht auf bewährten Produkten aus der Bauindustrie beruhen.

-) Die Interaktion der Projektpartner (sowohl auf der Planerseite als auch auf der Aufführendenseite) entsprachen sowohl hinsichtlich der Prozesse (Detailabstimmung und Freigabeprozedere) den üblichen Gepflogenheiten unter Experten, auch von Seite der Zeitschiene gab es weder nennenswerte Verzögerungen noch Forcierungsmaßnahmen.

Interview 2: the building physicist

1. ***Können Sie einige Angaben zu Ihrer Ausbildung machen und wie viele Jahre Erfahrung Sie als Bauphysiker haben.***

(BPt1):

- HTL St. Pölten: Abteilung Informationstechnologie – Technische Informatik
- FH Technikum Wien: Bachelor-Studiengang Urbane erneuerbare Energietechnologien
- Berufsanstellungen bei IBO GmbH (2011 bis 2012) und (name of the company) (seit 2012) - seit 2015 als Bauphysiker tätig.

(BPt2):

- HTL-Hochbau, Linz
- Architekturstudium TU-Wien

2. ***Können Sie den Ablauf beschreiben, wie Sie für das konkrete Projekt beauftragt wurden.***

Einladung von (name of the company) zur Teilnahme beim Wettbewerb, nach gewonnenem Wettbewerb erhielten wir einen Auftrag zur technischen Generalplanung (TGA, Statik, Bauphysik, Plan- und Baustellenkoordination)

3. ***Bitte beschreiben Sie für welche Leistungen Sie in jeder Phase beauftragt wurden.***

Bauphysikalische Bearbeitung

(1) Bauphysikalischer Entwurf und Nachweise für die Einreichungen

(2) Energieausweis

(3) Detailbearbeitung

zu (1) Bauphysikalischer Entwurf und Nachweise für die Baueinreichung

- Analyse der Grundlagen und Klären der Rahmenbedingungen.
- Ausarbeiten eines bauphysikalischen Entwurfes unter Berücksichtigung der Forderungen der Wiener Bauordnung sowie der ÖNORMEN B 8110 und B 8115.
- Berechnung der Wärmedurchgangskoeffizienten für die einzelnen Bauteile sowie des mittleren Wärmedurchgangskoeffizienten der einzelnen Außenbauteile.
- Berechnung der bewerteten Schalldämmmaße der Außenbauteile unter Berücksichtigung des Umgebungsgeräuschpegels, der bewerteten Normschallpegeldifferenz zwischen den Wohneinheiten und des Normtrittschallpegels zwischen den Geschoßen.
- Berechnung der immissionsflächenbezogenen speicherwirksamen Masse für den ungünstigsten Raum.
- Mitwirken bei Vorverhandlungen mit Behörden und anderen an der Planung fachlich Beteiligten über die Genehmigungsfähigkeit.

zu (2) Erstellung Energieausweis

- Erstellung des Energieausweises für das jeweilige Bundesland gemäß ÖNORM H 5055 sowie Richtlinie 2002/91/EG zur Einreichung bei Ämtern und Behörden sowie einmalige Überarbeitung und Neuausstellung aufgrund des Bestandes.

zu (3) Detailbearbeitung

- Überprüfen der bauphysikalischen Funktion von Planungsdetails wie auskragende Bauteile, Attiken, Terrassen, Bauteilfugen, geometrische Wärmebrücken etc.
- Planung und Beurteilung von Fenster- und Türkonstruktionen sowie ähnlicher Gebäudeöffnungen bezüglich Wärme- und Schallschutz.
- Nachweisberechnung der Wasserdampfdiffusion inkl. Festlegung ev. erforderlicher Dampfbremsen nach Glaserverfahren.
- Festlegung der erforderlichen wärmeschutztechnischen Maßnahmen bei konstruktionsbedingten und geometrischen Wärmebrücken.

- Ausarbeitung der erforderlichen Maßnahmen zur ausreichenden Herabsetzung der Schall-Längsleitung im Bereich der Trennwände und Geschoßdecken, sodass die Erreichung der geforderten Schalldämmwerte gewährleistet ist. Ausarbeitung der erforderlichen Maßnahmen im Bereich der Stiegenhäuser und Gänge zur Einhaltung der maximal zulässigen Normtrittschallpegel.
- Berechnung der resultierenden Schalldämmung bei zusammengesetzten Flächen (z.B. Wände mit Fenstern und Türen).
- Ausführungsvorschläge entsprechend den schallschutztechnischen Erfordernissen.
- Erstellung eines schallschutztechnischen Maßnahmenkataloges für die haustechnischen Anlagen (Wasser, Heizung, Lüftung, Aufzüge) zur Einhaltung der maximal zulässigen Störgeräusche in den jeweiligen benachbarten Bereichen (Installationswände, Rohrleitungshalterungen, Wand- und Deckendurchbrüche, Schachtabmauerungen, Ausführung von Etagierungen bei Abwasserrohren).
- Dimensionierung von erforderlichen Sonnenschutzmaßnahmen und Bekanntgabe der genauen Lage.
- Abdichtungstechnische Planung und Bemessung von Kaltdächern (hinterlüfteten Konstruktionen) und Warmdächern (auch Gründächern, Terrassen, Balkonen etc.).
- Planung und Festlegung von Maßnahmen bezüglich Schlagregen von Kaltfassaden (hinterlüfteten Konstruktionen) und Warmfassaden.
- Planung und Bemessung bezüglich Schlagregensicherheit und Fugendurchlässigkeit von Fenstern, Fenstertüren, Außentüren und ähnlichen Gebäudeöffnungen.

4. ***Bitte beschreiben Sie welche Aspekte der Nachaltigkeit Sie in dem Projekt beachten mussten.***

   keine speziellen Anfoderungen gegeben, ökologische Nachhaltigkeit sind bereits in OIB-RL6 implementiert

5. ***Bitte beschreiben Sie generell, welche Anforderungen Sie in dem Projekt beachten mussten (z.B. Zielvorgaben für die Gebäudeoptimierung, Budget, usw.).***

   - Technisch: Bauordnung, Förderrichtlinien und Normen
   - Ökonomisch: Erreichung der Ziel-Baukosten

6. ***Bitte beschreiben Sie den Arbeitsablauf der Bauphysiker im Laufe der verschiedenen Phasen des Projektes (z.B. Erstellung der Energiezertifizierung, Erstellung des Bauteilkataloges, Entwicklung von Details, Prüfung von GR, SCH, AN, bauphysikalische Beratung, usw.).***

WET: Erstellung der BPH-Studie für den Bauträgerwettbewerb (Energieausweise, Bauteilaufbautenliste, Datenblatt)

VOR: Durchsicht der Architekturpläne – Abstimmung mit den weiteren Projektbeteiligten

ENT: Durchsicht der Architekturpläne – Abstimmung mit den weiteren Projektbeteiligten

EIN: Erstellung der Bauphysik-Unterlage für die Baubehördliche Einreichung. Inhalt

- Nachweise der Einhaltung von Wärmeschutzanforderungen opaker und transparenter Bauteile
- Nachweise der Einhaltung von Schallschutzanforderungen opaker Bauteile (z.B.: Berechnung des erforderlichen Fenster-Schalldämmmaßes)
- Nachweise der Einhaltung der geforderten Energiekennzahlen (Energieausweis)
- Nachweise der Einhaltung des sommerlichen Wärmeschutzes (Berechnung der „Sonnenschutz-Maßnahmen“)
- Nachweis zur Einhaltung von Anforderungen an den Trittschallschutz und die Schallpegeldifferenz zwischen Wohneinheiten, Wohnung/Stiegenhaus, etc.
- Energieausweis-Datenbank: upload WUKSEA

Ausschreibungsphase:

- Durchsicht/Überprüfung der Arch-Leitdetails, Plandurchsichten
- Ggf. Überprüfung alternativer Konzepte/Materialien zwecks Einsparungsmöglichkeiten

AUS:

- Durchsicht und Freigabe von Unterlagen der Ausführenden (z.B.: Fenster-/Portalbauer, Werksplanung von z.B.: Schlosser)
- Durchsicht und Freigabe der Polierpläne
- Durchsicht und Freigabe von Detailplanungen

- Ggf. Erstellung von erforderliche BPH-Unterlagen für eine behördliche Auswechslung bzw. bauliche Abänderung
- Abschluss = Erstellung der BPH-Unterlage für die Fertigstellungsanzeige
- Energieausweis-Datenbank: upload WUKSEA

INB: keine

7. ***In welcher Phase des Projektes wurde die Energiezertifizierung erstellt? Wurde die Energiezertifizierung in jeder Phase wiederholt? Wie geht man mit Änderungen in der Plannung um?***

- Ersterstellung in der Wettbewerbsphase (BPH-Studie für den Bauträgerwettbewerb)
- Vollumfassende Nachführung in der Einreichphase
- Weiterführung bzw. Durchführung von Änderungen in der AUS

Bei Änderungen werden die Auswirkungen überprüft. Bei wesentlichen nagativen Auswirkungen werden erforderliche Kompensationsmaßnahmen definiert und bekannt gegeben.

8. ***Wie wurden der sommerliche Überwärmungsschutz sowie die Luft- und Winddichte evaluiert?***

- Der sommerliche Wärmeschutz wurde gem. OIB-Richtlinie 6 berechnet bzw. nachgewiesen
- vereinfachter Nachweis der Vermeidung sommerlicher Überwärmung wurde gem. ÖN B 8110-3 durch ausreichende Speichermassen sowie Luftvolumenstrom geführt
- Die Berechnungen erfolgten mit dem Programm Archiphysik

Hinweis: Der Begriff „sommerlicher Überwärmungsschutz“ ist an dieser Stelle nicht zutreffend, da dieser für eine detaillierte Nachweisführung gem. ÖNORM B 8110-3 steht.

zu Luftdiche: da gefördert, gilt als Vorgabe: n50 ≤ 1,5/h, dieser Wert wurde in Energieausweisen berücksichtigt

Winddichte: nur im Zuge von Details (Bauanschlussfugen, Detailplanungen) berücksichtigt

9. ***Wie wurde das Risiko, bezüglich Kondensation und Schimmelbildung tatsächlich evaluiert?***

Bei einzelnen kritischen Ausführungen wurden mit dem Programm FlixoPro Berechnungen durchgeführt. Zum Großteil kann eine Beurteilung gem. Erfahrungsschatz erfolgen und Maßnahmen zur Vermeidung unzulässiger Wärmebrücken formuliert werden.

10. ***Wie wurde im Projekt die Einsetzbarkeit von alternativen Energie-Systemen evaluiert?***

Da die von Beginn an gewünschte Wärme-/Warmwasserbereitstellung durch Anschluss an das Netz der Fernwärme Wien als „hocheffizientes, alternatives Energiesystem“ gem. OIB-Richtlinie 6 anzusehen ist, wurden diesbezüglich keine alternativen Energiesysteme geprüft.

11. ***Ihrer Meinung nach, haben die Ergebnisse der Gebäudesimulation/ der Energiezertifizierung/ der Gebäudezertifizierung, die ursprünglich geplante Architektur beeinflusst? Wenn ja, inwiefern?***

wohl nur der außenliegende Sonnenschutz in Teilbereichen und die von außen sichtbaren Schalldämmlüfter in der Außenwand

12. ***Ihrer Meinung nach, welche Aspekte der Bauphysik haben das Projekt am meisten beeinflusst?***

Wärmeschutz

13. ***Sind Sie der Meinung, dass die Architekten in der ersten Phase der Projektentwicklung Gebäudesimulationen durchführen sollten, um die Performance des Gebäudes zu optimieren? Oder sollte das die Aufgabe des Bauphysikers sein?***

Zwingend vom Bauphysiker durchzuführen.

Ganz im Sinne der interdisziplinären Planung sollte es ein Zusammenwirken der unterschiedlichen Fachplanungen geben. Ideal wäre es, wenn der ARCH dem BP ein reduziertes 3D-Modell in verwertbarer digitaler Form übermittelt, um die Gebäudesimulation nach bauphysikalischen Parametern gem. aktueller Anforderungen durchführen zu können.

14. ***In den Ausschreibungsunterlagen des BH sind viele technische Beschreibungen bezüglich Wärmedämmung, Abdichtungen, Wind- und Luftdichtigkeit usw. angefürt. Wird für die Freigabe der Auschreibungsunterlagen Ihre Zustimmung benötigt? Wie wird entschieden, welche Details ausgeschrieben werden müssen?***

Wir stellen dem BH unsere Bauphysik-Unterlagen zur Verfügung. Diese müssen Teil der Ausschreibungsunterlagen sein. In manchen Fällen erhalten wir die gesamten Ausschreibungsunterlagen, die wir mit Fokus auf Bauphysik stichprobenartig prüfen.

Die Leitdetailmappe des ARCH ist immer eine wesentliche Ausschreibungsgrundlage, die seitens BP jedenfalls zu prüfen und freizugeben sind. Den Umfang der Leitdetailmappe bestimmt aber der Architekt.

15. ***Haben Ihrer Meinung nach, die Planer ausreichende Details für die Ausführung von wichtigen Konstruktionen/Gebäudeteilen übermittelt? Wenn nicht, welche Details wären noch hilfreich gewesen?***

    Grundsätzlich ausreichend, der Vertikalschnitt bei der Wohnungseingangstüre, also Übergang Treppenhaus zu Wohnung fehlte.

16. ***Wie läuft die Arbeit der BP in der Ausführungsphase ab? Besuchen Sie die Baustelle in jener Phase?***

    Baustellenbesuch werden nur bei Erfordernis (z.B.: Abstimmung hinsichtlich einer bestimmten Fragestellung) durchgeführt, weil kein Auftrag für die örtliche Bauaufsicht in der Bauphysik

17. ***Wie wurden Varianten und alternative Materialien untersucht? In welchen Urterlagen wurden aufgrund der Untersuchung angefertigt?***

    Wenn die Baufirma sich Einsparungspotenziale durch alternative Produkte/Materialien verspricht, so müssen diese ggf. seitens BPH dahingehend überprüft werden, ob diese die vorgegebenen Materialspezifikationen (z.B.: Wärmeleitfähigkeit eines Dämmprodukts) einhalten und somit als „gleichwertig“ einzustufen sind.

    Dabei erfolgt seitens Bauphysik nur eine Rückmeldung („Ja“ / „Nein“ / „Unter bestimmten Auflagen“ / etc.). Wenn einem Produktwechsel nichts mehr im Wege steht, dann werden die beschlossenen Änderungen in den Dokumenten nachgeführt.

18. ***Verwenden Sie ein Monitoringsystem für die Kontrolle der erreichenden Mindest- und Maximalwerte in der Nutzungsphase?***

    In der Regel nicht.

19. ***Sind Sie involviert in der Erstellung der Informationsmedien für Nutzerinnen und Nutzer?***

    Im Grunde nicht, ggf. erfolgt eine kurze Abstimmung bei bestimmten Themen mit dem Bauherrn.

15. ***Haben Sie Vorschläge, wie der Ablauf/ die Zusammenarbeit zw. Konsulenten, Planer und dem GU verbessert werden könnte?***

    Änderungen in einem Projekt sind immer besonders herausfordernd. Also Änderungen auf ein Minimum zu beschränken bedeutet, mehr Vorlaufzeit und Abstimmungen in der Planungsphase bis zur baubehördlichen Einreichung.

    Wichtige Entscheidungen des BH sollten klar eingefordert und dokumentiert werden.

16. ***Wie hat sich in den letzten 20 Jahren der Bereich Bauphysik entwickelt?***

Vor 20 Jahren haben nur noch sehr bauphysikaffine Architekten die Bauphysik selbst gemacht, weil mit U-Wert-Berechnungen noch vergleichsweise einfach und unaufwändig. Die Gebäudehülle wurde mit einem spezifischen Transmissionswärmeverlust auf einer A4-Seite ausreichend dargestellt. Schimmelfälle und Kondensatbildungen waren im Jahr 2000 noch häufige Begleiterscheinungen. Der mindesterforderliche Sonnenschutz wurde häufig nicht gerechnet oder eingespart. Gebäudezertifizierungen und Qualitätssicherungsmaßnahmen gab es damals kaum.

Mit Umsetzung der EU-Gebäuderichtlinien wurden die Anforderungen höher bzw. verbindlicher. Aus dem EU-Gebäudepass lassen sich heutige Energieausweise ableiten, die seit Beginn der OIB-Richtlinien stets mit noch mehr haustechnischen Parametern zu füllen sind.

Heute sind in der Planungsphase intensive Abstimmungen zwischen den Konsulenten unerlässlich. In der Ausführungsphase wiederum gilt es, das Geplante sach- und fachgerecht baulich umzusetzen.

17. ***Wie viele Arbeitsstunden haben Sie für das Projekt ca. aufgewendet?***

WET: 20

VOR: 20

ENT: 60

AUS: 10

POL: 150

18. ***Basierend auf Ihrer Erfahrung, erachten Sie den Ablauf des Planungs- und Bauprozesses vom Projekt LEO als repräsentativ im Vergleich zu anderen Planungs- und Ausführungsprozessen?***

Auf Grundlage meiner bisherigen Erfahrungen meine ich, dass der Planungs- und der Bauprozess – so wie er beim Projekt LEO erfolgt ist – im Grunde auch bei anderen Bauvorhaben/Projekten in ähnlicher Art und Weise erfolgt.

Die Projektphasen und die erforderlichen Tätigkeiten sind ansich gleich, aber der Arbeitsaufwand ist unterschiedlich und gegebenfals muss man Änderungen bei den baurechtlichen/normativen Vorgaben beachten.

Wichtig ist, dass möglichst früh die Bauherrenvorgaben bzw. „Rahmenbedingungen" für ein Bauvorhaben klar sind => je nach Komplexität des Bauvorhaben (Anforderungen, Sonderthemen) gibt es dann Themen die mal leichter/schneller, mal schwieriger/langwieriger zu lösen sind.

Die Art der Interaktion ist unterschiedlich und hängt ebenfalls von der Komplexität des Bauvorhaben ab - Je komplexer und größer das Bauvorhaben ist, desto öfter wird es bereits in der Entwurfsphase in regelmäßigen Abständen Besprechungen in größerer Runde geben.

Interview 3: the construction site manager

1. ***Können Sie einige Angaben zu Ihrer Ausbildung machen und wie viele Jahre Erfahrung Sie als Bauleiterin haben.***

   Ich maturierte an der Handelsakademie mit Schwerpunkt Controlling in Mistelbach, anschließend absolvierte ich an der FH Campus Wien den Bachelor- und Masterstudiengang Bauingenieurwesen mit Schwerpunkt Nachhaltigkeit. 2012 begann ich als Bautechnikerin zu arbeiten, 2014 folgte die Diplomprüfung und seit 2017 bin ich nun als Bauleiterin für Baustellen verantwortlich.

2. ***Welche Kriterien waren entscheidend dafür, welche Firmen für die Projektausführung ausgewählt wurden?***

   Natürlich ist es größtenteils ein Preisthema, es wird aber auch immer darauf geachtet, ob es bereits Erfahrungen mit dieser Firma gibt und ob Referenzen und natürlich auch genügend Ressourcen vorliegen.

3. ***Von einer bauphysikalischen Perspektive aus gesehen, welche Abschnitte / Details im Projekt waren Ihrer Meinung nach die schwierigsten / problematischsten?***

   Beim (Project LEO) waren aus meiner Sicht die Loggien, Fensteranschlüsse und die Geländerausbildung im Dachgeschoss eine bauphysikalische Herausforderung.

4. ***Wie wird auf der Baustelle die korrekte Ausführung von bauphysikalischen Maßnahmen geprüft (Wärmeschutz, Feuchteschutz, Luftdichtigkeit, kritische Details)?***

   Grundsätzlich wird schon bei der Ausschreibung und Vergabe auf die erforderlichen Anforderungen geachtet. Spätestens bei Bestellung/Abruf der Leistung werden nochmals bauphysikalische Freigaben eingeholt und vor Ort dann auch nochmals, soweit als möglich, selbst überprüft.

5. ***Die korrekte Ausführung von Fenstern und Portalen wird generell als sehr wichtig betrachtet (vgl. Feuchteschutz, Luft- und Winddichtigkeit). Bitte beschreiben Sie die Vorgehensweise der Ausführung.***

   Schon im Freigabeprozess wird von allen Beteiligten auf die Einhaltung der bauphysikalischen Vorgaben geachtet. Die ausführenden Firmen werden dann auch vor Ort nochmals kontrolliert, sind aber generell zertifizierte Unternehmen, die im Rahmen der Baudoku dann auch Bestätigungen und Zertifikate für den ordnungsgemäßen Einbau erstellen.

6. ***Wurden Sie generell von dem Bauphysiker/ den Architekten über mögliche problematische Details, die bei der Ausführung besondere Aufmerksamkeit erfordern, informiert/ darauf hingewießen?***

   Ja, im Zuge der Baubesprechungen wurden heikle Themen immer wieder angesprochen.

7. ***Haben Sie vom Planer/Bauphysiker ausreichend Details für die Ausführung von wichtigen Konstruktionen/Gebäudeteilen erhalten? Wenn nicht, welche Details hätten Sie noch gebraucht?***

   Ja, waren vorhanden. Vor allem vom Planer kamen immer ausreichend Details, auch wenn wir sie kurzfristig anforderten.

8. ***Haben bauphysikalische Maßnahmen Ihrer Meinung nach die ursprünglich geplante Architektur beeinflusst? Wenn ja, welche und inwiefern?***

   Meiner Meinung nach nicht, da man als Bautechniker nicht so auf kleine, optische Veränderungen achtet. Ich denke aber, dass es aus Sicht von Architekten anders aussieht.

9. ***Wurden Bauarbeiter während der Ausführung zu Wärmedämmungsarbeiten beaufsichtigt und instruiert?***

   Beaufsichtigt in gewissem Maße ja, durch unser Personal (Polier, Bauleitung, Techniker) vor Ort, und zusätzlich auch durch einen von uns beauftragten, externen Sachverständigen, der mehrmals Begehungen und Abnahmen der Wärmedämmungsarbeiten vornahm.

10. ***Es wird generell bei der Ausführung von Feuchtigkeits-, Luft- und Windbarrieren eine strenge Überwachung empfohlen, da es äußerst schwierig ist, später Probleme zu beheben. Wie wird dies tatsächlich gemacht? Wie wird die korrekte Ausführung dieser spezifischen Arbeiten sichergestellt?***

    Generell ein heikles Thema, dem bestimmt mehr Bedeutung bedarf, als tatsächlich vor Ort gehandhabt wird. Es wird auf die notwendigen Qualifikationen der ausführenden Firmen und deren Mitarbeiter gehofft und teilweise, wie zB bei den WDVS-Arbeiten, mit externen Überprüfungen zusätzliche Maßnahmen gesetzt.

11. Sind Ihrer Meinung nach Gewerke für die Ausführung von kritischen Details genügend qualifiziert?

Bestimmt nicht alle Firmen, kritisch ist es vor allem, wenn leider immer mehr SUB-SUB-Unternehmen beauftragt werden.

12. Wie wurde generell im Projekt garantiert, dass die erhöhte Luftdichtigkeit-Anforderung (n50 ≤ 1,5/h) lt. Wohnbauförderungsgesetz erreicht wurde?

Die ersten Maßnahmen diesbezüglich sind schon im Rohbau zu setzten, also in einer genauen und sauberen Arbeitsweise, für die auf jeden Fall der Polier vor Ort verantwortlich ist. Wichtig ist es dann auch im Ausbau auf viele Kleinigkeiten und Details zu achten, vor allem auch durch die Haustechnik- und Elektroarbeiten. Anschlussarbeiten von Estrich und Trockenbau werden auf jeden Fall auch konsequent kontrolliert und dokumentiert.

13. Welche von diesen Maßnahmen wurden im Laufe des Betriebs durchgführt? Bitte beschreiben Sie die Vorgehensweise der Messungen (Anzahl der Messungen, ausgewählte Räume, Zeitplan, usw.).

- Wärmeschutzgutachten: wurde nicht ausgeführt
- Blower door Test: 1x Rohbaumessung in 5 Wohnungen, mit unterschiedlichen Grundrissen und exponierten Lagen, die gemeinsam mit dem Bauherrn ausgewählt wurden. Die Messungen erfolgten nach dem Fenstereinbau und die Ergebnisse waren allesamt positiv. Hauptsächlich geht es hier um die Fehlerfeststellung in der Gebäudehülle und bei den Installationsarbeiten. Nach erfolgter Fertigstellung des Estrichbelags und der Spachtelungsarbeiten wurde die 5 Wohnungen ein zweites Mal gemessen, um den endgültigen Wert festzustellen. Hier wäre es sehr aufwändig, schwere Mängel nachträglich zu beheben, daher wurden die erforderlichen Maßnahmen bereits nach der Rohbaumessung getroffen. Auch hier wurde bei allen Messungen die Werte deutlich eingehalten.
- Luftschallmessungen: Nach Fertigstellung der Bodenbeläge wurde in 6 unterschiedlichen Wohnungen je 3 Luft- und 3 Trittschallmessungen durchgeführt. Hier wurden folgende Messungen vorgenommen: horizontal von Wohnung zu Wohnung, vertikal von übereinanderliegenden Wohnungen und zwischen Wohnungen und Gang über die Wohnungseingangstüre. Diese Ergebnisse hielten die vorgegebenen Werte der Bauphysik ein.

- Thermofotografien: wurde nicht ausgeführt
- Überprüfungen der Baustoffe: BauXund Zertifizierung

14. Wie läuft die zusammenarbeit zw. GU und BauXund?

Erklärung zum Ablauf BauXund:

- Erstgespräch und Erklärung durch BauXund
- Beachtung und Einfügung Textbausteine bei Ausschreibungen und Auftragsvergabe betroffener SUB-Firmen
- Freigabe BauXund der Produkte – Kommunikation SUB-Firmen mit BauXund direkt
- Arbeitsbeginn Firmen, Erstkontrolle Produkte durch uns
- Spontanbesuche BauXund mit Kontrolle aller anwesenden, zu prüfenden Firmen und Produkte
- Immer wieder Stichprobenüberprüfung und Protokollführung durch GU
- Schlusszertifikat

15. Wird bei der Planung des Bauprozesses der Workflow zur Verhinderung des Eindringens unerwünschter Feuchtigkeit berücksichtig?

Ja, soweit es die Jahreszeiten und Wettereinflüsse zulassen.

16. Wurden Maßnahmen zur Beschleunigung des Trocknens von Gebäudefeuchtigkeit vorgenommen?

Es wurden über die Wintermonate die Wohnungen mit bereits eingebauten Estrich ausgeheizt.
Ansonsten regelmäßiges, richtiges Lüften und evtl. Abdeckungs- und Verschalungsarbeiten, bei schlechten Witterungen.

17. Wurde im Bauprozess die Qualität der Bauteile, Materialien und Montagemethoden geprüft? Wenn ja, wann finden diese statt? Wie wurden diese durchgeführt?

Ja, teilweise. Beim (Project LEO) wurden Betonprobewürfel ab der Fundamentplatte erstellt, aber nie im Labor getestet. Sonst hatten wir noch vom Systemhersteller des WDVS Überprüfungen des Materials und deren Haftzugswerte. Montagemethoden wurden teilweise auch durch die Statiker überprüft, zB Schlossergeländer.

18. ***Wurde geprüft, ob die erforderlichen U-Werte für Dämmstoffe, Wandmaterialien, Mörtel, Fenstergläser und Rahmen mit den im Lieferschein angegebenen Werten übereinstimmen, als die Materialien auf die Baustelle geliefert wurden?***

    Die U-Werte wurden nicht nochmal neu berechnet bzw. geprüft, es wurde eben nur auf Übereinstimmung der Unterlagen mit den Materialien und auf Plausibilität geprüft. Zertifizierungen und Berechnungen wurden von den Firmen zusätzlich übermittelt.

19. ***Laut Ausschreibungsunterlagen waren Arbeiten eines Sachverständigen für die Wärmedämmverbundsystemfassaden vorgesehen. Das wurde laut Einsparungsliste eingespart. Wurde diese Arbeit von der Baufirma übernommen oder wurde sie komplett weggelassen?***

    Genau, wie oben beschrieben, haben wir diese Kosten übernommen, um eine gute Qualität der Arbeiten garantieren zu können.

20. ***Wie läuft die zusammenarbeit zw. GU und WDVS-Sachverständigen?***

    - Beauftragung unabhängingen SV
    - Mehrere Kontrolltermine vor Ort (verschiedene Arbeitsschritte: Dämmung kleben, Spachtelung, Abrieb, etc)
    - Hinweise und Erklärungen durch SV vor Ort an Polier und SUB
    - Protokoll zur Umsetzung und Weitergabe an SUB
    - Keine Zertifikate oder Schlussprotokolle

21. ***In den Ausschreibungsunterlagen steht, dass Wärmebrücken vermieden werden müssen. Wie beurteilt dies die Baufirma?***

    In der Angebotsphase wird dies nicht gesondert behandelt, da es mittlerweile Stand der Technik sein sollte, wärmebrückenfrei zu bauen.

22. ***Sind Sie in der Erstellung der Informationsmedien für Nutzer involviert? Werden in diesen Informationsmedien Aspekte der BP besonders betrachtet?***

    Ja, wurden wir involviert und in gewissen Punkte wurde die Bauhpysik auf jeden Fall berücksichtigt. Beispiel Sonnenschutz oder auch die erforderliche Lüftung der Wohnräume.

23. ***Ist ein Benutzerhandbuch für Betriebsleiter hergestellt worden?***

    nein

24. ***Wie hoch waren insgesamt die Baukosten pro m2? Können Sie eine Einschätzung machen, wieviel davon ca. für bauphysikalische Maßnahmen (Wärmeschutz, Feuchteschutz, Luftdichtigkeit) investiert wird?***

    Bei einer Nutzfläche von ca. 5.300m² waren es 1.720€/m². Eine Einschätzung ist sehr schwierig, aber als Annahme, Arbeiten die quasi zusätzlich zum erforderlichen technischen Standard ausgeführt wurden, sind es in etwa 10-12€/m² NFL.

25. ***Wie hat sich Ihrer Meinung nach die Baubranche in den letzten 20 Jahren aufgrund der Bauphysik verändert?***

    Es wurden auf jeden Fall mehr Auflagen die einzuhalten sind. Mir persönlich fällt immer wieder auf, dass die Vorgaben und Auflagen von Baustelle zu Baustelle sehr unterschiedlich sind, was natürlich auch immer mit der Bewertung und Förderung des Bauvorhabens zu tun hat. Generell sind die Maßnahmen natürlich größtenteils sinnvoll und zeigen in vielen Punkten auch ihre langfristige Wirkung.

26. ***Was hat Verspätungen in der Planung und Ausführung des Projekts verursacht?***

    Einerseits sicher Unstimmigkeiten in der Beauftragung, aber auch äußere Einflüsse, wie Witterung oder nicht vorhersehbare Ereignisse wie COVID-19.

27. ***Haben Sie Vorschläge, wie der Ablauf/ die Zusammenarbeit zw. den Konsulenten, den Planern und der GU verbessert werden könnte?***

    Hilfreich ist es bestimmt, wenn Konsulenten mehr Zeit vor Ort einplanen und vor Baubeginn gewisse Grundsätze gemeinsam festgelegt werden, dies ist jedoch auch immer ein Zeitthema.

28. ***Basierend auf Ihrer Erfahrung, erachten Sie den Ablauf des Planungs- und Bauprozesses vom Projekt LEO als repräsentativ im Vergleich zu anderen Planungs- und Ausführungsprozessen?***

    Auf jeden Fall, würde ich den Ablauf als repräsentativ für weitere Projekte sehen. Ein Hauptpunkt, den ich persönlich noch selten so gut erlebt habe, war die Detailplanung. Baudetails standen uns nahezu immer zeitnah und inhaltlich richtig zur Verfügung – ohne großartig darum zu Bitten. Auch die Abstimmung der Bauphysikalischen Anforderungen erfolgte zumeist ohne großartige Hinweise unsererseits, was für uns eine Arbeitserleichterung darstellte. Abschließend würde ich sagen, dass die Kommunikation und Abstimmung zwischen allen Projektpartnern sehr gut funktioniert hat, und von meiner Seite für alle weiteren Baustellen wünschenswert wäre.

Interview 4: the project developer

1. ***Können Sie einige Angaben zu Ihrer Ausbildung machen und wie viele Jahre Erfahrung Sie als Bauherr haben.***

   HTL Innenausbau, FH Joanneum Architektur & Baumanagement, fast 6 Jahre (name of the company)

2. ***Hat ihre Firma ein besonderes Interesse bei diesem Projekt Aspekte der Nachaltigkeit zu fördern? Wenn ja, welche?***

   Nicht mehr als vorgeschrieben (außer BauXund = Vermeidung von Schadstoffen)

3. ***Wie wurde für das Projekt entschieden, welches Modell für die Vergabe von Aufträgen an Konsulenten und Planer besser war?***

   Wir holen immer jeweils 3 Angebote für die jeweiligen Konsulentenleistungen ein und vergeben die Aufträge zumeist an den Billigstbieter. Wenn uns die Zusammenarbeit mit einem speziellen Planer jedoch für ein Projekt wichtig erscheint, kommt es vor, dass wir diesen beauftragen auch wenn er nicht der billigste ist. Die Gründe dafür können sein: besonders gute Zusammenarbeit, oder aber im haustechnischen Bereich ein besonderes Konzept für eine alternative Energieversorgung.

4. ***Welche Details/Konstruktionen waren von einer bauphysikalischen Perspektive ausgesehen Ihrer Meinung nach die schwierigsten/ am problematischsten?***

   Geländer der Dachterrassen, Fenster

5. ***Haben bauphysikalische Maßnahmen Ihrer Meinung nach die ursprünglich geplante Architektur beeinflusst? Wenn ja, welche und inwiefern?***

   Nein.

6. ***Wurde die Anwendung eines Gebäudezertifizierungssystemes (BREEAM, LEED, DGNB, klima:aktiv, TQB, usw.) für das Projekt evaluiert? Falls nicht, was hat dagegen gesprochen?***

   Nur BauXund. Ich denke die Kosten, geförderte Mietwohnungen werden auch ohne weitere Zertifizierung problemlos vermarktet.

7. ***Während der Wettbewerbsphase wurde eine „Umweltfreundliche Baustellenabwicklung" als sehr wichtig betrachtet, wie wurde das konkret umgesetzt?***

   Bauplatzübergreifende Maßnahmen durch Wiener Netze, z.B. regelmäßige Straßenreinigung, Ersatzquartiere für div. Tierarten.

8. ***Wie hoch waren insgesamt die Baukosten pro m2? Können Sie eine Einschätzung machen, wieviel davon für bauphysikalische Maßnahmen (Wärmeschutz, Feuchteschutz, Luftdichttigkeit) ca. Invistiert wurden?***

   Reine Baukosten > 1.650,- /m² WNFL. Schätzung nicht möglich.

9. ***Welche bauphysikalische Maßnahmen wurden aus Kostengründen eingespart?***

   Sonnenschutz nur dort, wo bauphysikalisch erforderlich.

10. ***Wie wurde im Projekt die Einsetzbarkeit von erneubaren Energietechnologien (WRG-Systeme, PV, Geothermie, usw.) evaluiert? In welcher Phase wurde die Entscheidung getroffen? Wurden nach verfügbaren Subventionen geforscht (Klimafonds, usw.)?***

    Meines Wissens war der Anschluss an die Fernwärme schon im Wettbewerb vorgeschrieben…? Zusätzliche Systeme sind bei geförderten Mietwohnungen wirtschaftlich nicht umsetzbar.

11. ***Wie wurde entschieden, welche Klimatechnik (Heizung, Klimaanlage, Lüftung) im Projekt angewendet werden sollte?***

    Standard-Ausstattung FWB: Fußboden- oder Deckenheizung, Einzellüfter in Bad + WC, Klimaanlagen meist nur bei Eigentumswohnungen.

12. ***Wie wurde generell im Projekt garantiert, dass die erhöhte Luftdichtigkeit-Anforderung ($n50 \leq 1,5/h$) lt. Wohnbauförderungsgesetz erreicht wurde?***

    Normgemäßer Fenstereinbau, Blower-Door-Tests

13. ***Laut Wohnbauförderungsgesetz gibt es einen Zuschuss für erhöhte Anforderungen an Energiekennzahlen und für kontrollierte Wohnraumlüftung mit Wärmerückgewinnung. Wieso wurde dies nicht in Anspruch genommen?***

    Das ist im Grunde eine Kostenfrage. Da das Projekt ohnehin an der obersten Grenze der Förderbarkeit lag, hatten wir keinen Spielraum, da noch etwas zu verbessern. Die kontrollierte WRL sehen wir nicht mehr als die beste und nachhaltigste Lösung an, aber auch das ist letztlich eine Kostenfrage. Da wir beides nicht erfüllen, konnten wir auch keine Förderung in Anspruch nehmen.

14. Als örtliche Bauaufsicht, wie oft haben Sie die Baustelle während der Ausführungsphase besucht?

Alle 14 Tage, nach Bedarf öfter

15. Generell, wie wird an der Baustelle die korrekte Ausführung von bauphysikalischen Maßnahmen geprüft (Wärmeschutz, Feuchteschutz, Luftdichtigkeit, kritische Details)?

Prüfung auf Übereinstimmung mit Planung im Anlassfall

16. In den Ausschreibungsunterlagen steht folgendes: Von einer staatlich autorisierten Prüfanstalt sind jedenfalls kostenlos beizubringen:

- Schall- u. Wärmeschutzgutachten über die vom Auftragnehmer ausgeführten Außenbauteile,
- Fünf Luftschall- und fünf Trittschallmessungen je Stiege,
- Thermofotografien sowie
- Mind. fünf Luftdichtheitsmessungen gemäß OIB (Blower-Door-Messungen) an den von der örtlichen Bauaufsicht bezeichneten Stellen.

Vor und während der Ausführung der Arbeiten sind auf der Baustelle auf Kosten des Auftragnehmers fortlaufend Überprüfungen der zur Verwendung kommenden Baustoffe und der daraus hergestellten Werkstücke vornehmen zu lassen, um die Übereinstimmung mit den einschlägigen technischen Vorschriften festzustellen.

Welche von diesen Maßnahmen wurden im Laufe des Betriebs durchgführt? Bitte beschreiben Sie die Vorgehensweise der Messungen (Anzahl der Messungen, ausgewählte Räume, Zeitplan, usw.).

Wärmeschutzgutachten: wurde nicht erstellt

Blower door Test: Vorauswahl der Wohnungen durch GU und Bestätigung durch ÖBA, 1x nach Rohbau dicht (Fenstereinbau), 1x nach Ausbau

Luftschallmessungen: Vorauswahl der Räume durch GU und Bestätigung durch ÖBA (horizontal, vertikal, Stgh-Wohnung), eingespart auf je 3 Messungen je Stiege, frühestens wenn alle raumumschließenden Bauteile fertiggestellt sind (meist abhängig von Wohnungseingangstüren), auf Estrich oder fertigem Belag möglich.

Thermofotografien: wurden nicht erstellt

Überprüfungen der Baustoffe: Überprüfung (von Datenblättern) im Anlassfall, Begleitende Kontrolle der WDVS-Arbeiten durch einen SV

17. ***Sind Sie in der Erstellung der Informationsmedien für Nutzer involviert? Werden in diesen Informationsmedien Aspekte der BP besonders betrachtet?***

Nutzerhandbuch wurde durch ÖBA erstellt, inkl. besondere Hinweise betreffend Raumklima bzw. Lüften.

18. ***Sind Sie der Meinung, dass die Architekten in den ersten Phasen der Projektentwicklung Gebäudesimulationen durchführen sollten, um die Performance des Gebäudes zu optimieren? Wieso?***

Eine Gebäudesimulation ist meiner Einschätzung in der ersten Phase nicht notwendig. Es sollte nur ein günstiges A/V-Verhältnis beachtet werden.

19. ***Sind Sie der Meinung, dass Green Konsulenten im Projekt miteinbezogen werden sollten, um mehr Raum für die ökologische Optimierung des Projektes zu ermöglichen? Wieso?***

Bei geförderten Mietwohnungen sind geringe Kosten das wichtigste Kriterium – für höhere Anforderungen als gefordert ist wenig Spielraum vorhanden. Ich denke, dass eine ökologische Optimierung bei der Entscheidung der Kunden für eine bestimmte Wohnung nur eine untergeordnete Rolle spielt.

20. ***Sehen Sie Vorteile an gefördeten Wohnbauprojekten gegenüber Freifinanzierten?***

Für Bewohner: günstigere Mieten bzw. Finanzierungsbeiträge, bei Wettbewerben ggf. qualitativ hochwertige Planung mit vielen gemeinschaftlich nutzbaren Angeboten

Für Bauträger: einfachere Kundenbetreuung während Bau- und Gewährleistungsphase

21. ***Wie lange ist der Gewährleistungszeitraum? Sind schon Probleme aufgetaucht, die durch nicht-korrekte Umseztungen/Ausführungen von Details verursacht haben? Wenn nicht, wie oft kommt dies in anderen Projekten vor?***

- Gesamtbauwerk, Jahre: 3
- Feuchtigkeitsabdichtungen, Jahre: 5
- Vollwärmeschutzfassade, Jahre: 5
- Kanal, Fenster, Abdichtungen und Isolierungen, Schutz gegen Holzerkrankungen: 5
- Bauphysikalische Probleme sind eher selten, ca. bei 1 von 10 Projekten?

22. ***Wie hat sich Ihre Meinung nach die Baubranche in den letzten 20 Jahren aufgrund der Bauphysik verändert?***

Ich denke die Anforderungen sind stark gestiegen, alle Beteiligten (inkl. Bewohner) sind vielleicht sensibler für bauphysikalische Themen geworden. Die meisten Bauteile sind dicker + vielschichtiger, um allen Anforderungen gerecht zu werden.

23. ***Basierend auf Ihrer Erfahrung, erachten Sie den Ablauf des Planungs- und Bauprozesses vom Projekt LEO als repräsentativ im Vergleich zu anderen Planungs- und Ausführungsprozessen?***

Ja, ich würde den Ablauf durchaus als vergleichbar mit (unseren) anderen Wohnbauprojekten ansehen.

B. The OIB-6:2015 Guideline

In the wake of the extension, complexity, and detail of the guideline, it is not possible to summarize it completely. However, the following summary should offer an overview of the main points that are in direct relation to this thesis:

The sections 1.1 till 1.3 specify which buildings are excluded of the obligation of handing over energy certificates.

The section 3 defines building categories. The are 2 main groups, residential and not residential. The classification is based on the predominant building use, if the area of a secondary building use does not surpass 250m2. If it does, the building is to be divided in two different categories, which might have different predefined energy requirements.

The section 4 is the one of more relevance in the guideline. It listens the requirements for energy performance of buildings. The subsection 4.1 clarifies that energy requirements to be complied with apply for the specific reference climate, and that it can be chosen to provide evidence of its compliance either via the final energy demand or via the overall energy efficiency factor. In the subsection 4.2 the maximal values at which buildings have to be energetically performing are specified. For new buildings, whose construction permits were obtained till 31.12.2016 the following reference values and calculations are to be applied:

For residential and non-residential buildings, if complying through the HEB the maximum heating demand (HWB Ref,RK) is obtained by applying the calculation:

- $16 \times (1 + 3{,}0 / \ell c)$, not surpassing 54,4 kWh/m²a;
- together with maximal reference values for HEB (HEB max,WG,RK) and final energy demand (EEB max,WG,RK).

For residential and non-residential buildings, if complying through the total energy efficiency factor (fGEE) the maximum heating demand (HWB Ref,RK) is obtained by applying the calculation:

- $16 \times (1 + 3{,}0 / \ell c)$, not surpassing 54,4 kWh/m²a;
- together with a maximal total energy efficiency factor not bigger than 0,90 (fGEE max).

Is interesting to note that in this edition of the *OIB-6*, the energy parameters requirements for new residential and new non-residential buildings are the same (apart of the colling requirements). Moreover, the energy parameters requirements in the *OIB-6:2015* for buildings with construction permits authorized till the end of 2016 stayed the same as in the *OIB-6:2011*.

The subsection 4.3 deals with requirements related to renewable energy. It specifies which sources of energy are consider as renewables (wind, sun, geothermal, hydrothermal energy, hydropower, biomass, biogas, waste heat, etc.). Next, it clarifies that if energy from highly efficient alternative systems is used in the building, this energy is consider as renewable. The main point of the section describes through which measures the share on renewables is considered as covered by the building. For it, one of the following systems have to be implemented:

A) If the renewable source is located outside the building system limits:

- at least 50% of the heating demand for space heating and hot water has to be covered by biomass;
- at least 50% of the heating demand for space heating and hot water has to be by a heat pump;
- at least 50% of the heating demand for space heating and hot water has to be through district heating from a heating plant grounded on renewable energy sources;
- at least 50% of the heating demand for space heating and hot water has to be through district heating from highly efficient cogeneration and/or waste heat;

B) If the renewable source is generated on site or nearby:

- at least 10% of the net final energy consumption for hot water has to be generated through solar thermal systems at the location or in the vicinity;
- at least 10% of the net final energy consumption for domestic or operational electricity has to be generated through photovoltaics systems at the location or in the vicinity;
- at least 10% of the net final energy consumption for space heating has to be generated through heat recovery systems at the location or in the vicinity;
- reduction of the maximum final energy consumption or the maximum total energy efficiency factor by at least 5% through any combination of solar thermal, photovoltaic, heat recovery or increment of the system´s efficiency.

The subsection 4.4 outlines the maximum values for heat transfer coefficients (U-values) of building components (walls, slabs, windows, doors, floors and special transparent components) in conditioned rooms, in relation to the conditions on the other side of the building element (outdoor air, conditioned or not conditioned rooms, in contact with soil, etc.). The required U-value per component is illustrated in Table 14:

Table 14. Minimum U-values requirements (OIB 2015b)

	Building component	**U-value** [W.m^{-2}.K^{-1}]
1	WALLS against outside air	0.35
2	WALLS against unheated or not equipped attics	0.35
3	WALLS to unheated, frost-free-held parts of buildings (Attics) as well as against garages	0.60
4	WALLS in the ground	0.40
5	WALLS (partition) between residential or business units or conditioned Stairwells	0.90
6	WALLS against other buildings	0.50
7	WALLS small area against outside, the 2% of the walls of the not exceed the entire building against outside air	0.70
8	WALLS (partitions) within residential and commercial	-
9	WINDOWS, French doors, glazed doors respectively in residential buildings against outside air	1.40
10	WINDOWS, French doors, glazed doors respectively in non-residential premises against outside air	1.70
11	other transparent components vertically against outside	1.70
12	other transparent components horizontally or slants against outside air	2.00
13	other transparent components vertically against unheated parts of buildings	2.50
14	skylights against outside air	1.70
15	DOORS unglazed, against outside air	1.70
16	DOORS unglazed, unheated parts of buildings	2.50
17	gates, Rolling doors against outside air	2.50
18	INTERIOR DOORS	-
19	CEILINGS and roof pitches each against outside air and against roof spaces	0.20
20	CEILING unheated parts of buildings	0.40
21	CEILING against separate living and operating units	0.90
22	CEILING within residential and commercial units	-
23	CEILING over outdoor air (e.g., crossings, parking)	0.20
24	CEILING against Garages	0.30
25	FLOORS on the ground	0.40

The subsection 4.7 refers to the *ÖNORM B 8110-2* (ASI 2003), on avoiding condensation on the inner component´s surface or in their interior. It indicates that negative effects of thermal bridges must be reduced. This norm defines several building constructions in which, under defined framework conditions, the risk of condensation is considered avoided. In case the building components of the corresponding project do not correspond with these ones, the ÖNORM defines two procedures (one detailed and one simplified) for the calculation and assessment of the corresponding building components.

The subsection 4.8 deals with summer heat protection. For residential buildings, it is considered observed if sufficient storage mass is available, according to the simplified verification method described in the *ÖNORM B 8110-3* (ASI 2012). As explained in this norm, the simplified verification method is based on the determination of the storage area-related masses of the room and their comparison with the available hourly air volume flow related to the emission area. Its application is only possible for locations with daily average temperature of 23°C (although the *OIB-6* allows 130 days of exceedance in 10 years), and only if windows can be kept open at night (VÖZ 2018, ÖNORM B 8110-3). For non-residential buildings, this method does not apply. Instead, the *OIB-6* stipulates a maximal acceptable external induced cooling demand of KB max,RK = 1 kWh/m³a to consider summer overheating protection as observed.

It is worth to mention that the *ÖNORM B 8110-3* (ASI 2012) requires operative temperatures calculated through the diurnal variation method (the alternative method to the simplified verification method, which applies for either residential and non-residential buildings) to be less than 27°C in main rooms and less than 25°C in sleeping rooms during nighttime. These requirements changed after the introduction of the *OIB-6:2019*.

In the subsection 4.9 requirements for airtightness and wind tightness are described. It is compulsory in new buildings that the building envelope has to be airtight and windproof, for which the air exchange rate n50 (measured at 50 Pascal pressure difference between inside and outside, averaged over negative and positive pressure, and with closed exhaust air and supply air openings) should not exceed:

- in buildings without ventilation systems, n50 <3.0 air exchange rate per hour
- in buildings with mechanically operated ventilation systems with or without heat recovery, n50 <1.5 air exchange rate per hour

The measuring of this value has to be done according to the so-called *Procedure 1 (Verfahren 1)*, which is defined in the *ÖNORM EN ISO 9972* (ASIb 2016), although the norm is not directly mentioned in the *OIB-6*.

For residential buildings with a gross floor area of more than 400 m² these values have to be tested for each apartment. Averaging the individual apartments is not permitted. The value must also be observed for stairwells that lie within the conditioned building envelope. In the case of non-residential buildings, the requirement relates to each fire section.

Section 5 deals with technical building systems. In the subsection 5.1 it is stated that newly built air supply and air exhaustion systems (if built combined) have to be equipped with a heat recovery device. The subsection 5.2 is dedicated to the adoption of highly efficient alternative systems (as stated in the Viennese building code in §118). According to the guideline, their technical, ecological, and economic implementation feasibility has to be taken into account and documented. If one of the systems, to cover the building´s share of renewables mentioned in the section 4) A is already implemented, the requirement of implementation of highly efficient alternative systems is considered as satisfied. This point seems interesting, since in the *WBO* there was no mention (that changed in 2019) of the possibility to recur to renewable energy systems in the case that highly efficient systems were not feasible, with no alternatives named. As previously mentioned, the 4 systems identified as highly efficient in the *OIB-6* and in the *WBO* are: decentralized energy supply systems based on energy from renewable sources, cogeneration, district/local heating or district / local cooling, in particular if it is based wholly or in part on energy from renewable sources or comes from highly efficient combined heat and power plants, and heat pumps.

The subsection 5.4 defines minimum requirements for the insulation of conducts that are part of the heat transport system for space heating, as shown in Table 15:

Table 15. Minimum insulation of conducts (OIB 2015b)

Pipe types	Minimum insulation thicknesses (λ = 0.035 W/mK)
Lines in non-conditioned rooms	2/3 of the pipe diameter, but no more than 100 mm
for lines in wall and ceiling openings, in the crossing area of lines, for central line network distributors	1/3 of the pipe diameter, but not more than 50 mm
Lines in conditioned rooms	1/3 of the pipe diameter, but not more than 50 mm
Lines in the floor structure	6 mm (can be omitted when laying in the impact sound insulation for ceilings against conditioned rooms, of course without reducing the impact sound insulation)
Stub lines	no requirements

Section 6 and 7 describe the content that has to be included in energy certificates. Energy certificates comprehend two pages (the layout is included in the guideline), plus an attachment. It must be filled in completely, whereas in the attachment the following information has to be included:

- which norms and guidelines were used;
- which norm-compliance simplifications were applied;
- which other aids or calculations methods were used;
- comprehensible identification of the geometry, building physics and building technology input data of the building.

Moreover, in the first page the following energy indicators (related to the local climate) have to be listed:

- Specific reference heating demand (HWB);
- Primary energy demand (PEB);
- Carbon dioxide emissions (CO_2); and
- Total energy efficiency factor (fGEE).

In addition, other specific location-related and geometrical values for residential and non-residential buildings that have to be included are also listed, as well as an energy efficiency scale for heating demand, primary energy demand, carbon dioxide emissions, and for the total energy efficiency factor that serves as reference to evaluate the performance of the building.

In section 8 conversion factors for determining the PEB, the non-renewable part of the PEB, the renewable part of the PEB and CO_2 are given, whereas section 9 deals with input data for technical building systems. In general, it can be affirmed that the previously mentioned overall energy efficiency factor is the only energy performance requirement established for technical building systems. Consequently, these 2 sections are not explained in detail as are not directly covered by this thesis.

Along with the *Energy saving and heat protection* guideline, the *OIB* launched the *Guideline for energy performance of buildings (Energietechnisches Verhalten von Gebäuden),* a technical attachment that explains which ÖNORM´s have to be applied to calculate a variety of indicators that have a part in the energy performance of buildings, as well as information about procedures and input data for their calculation.

Of particular relevance in the guideline is the subsection 2.8 Zoning. In this section, the criteria for the division of the building in different thermal zones is explained. In order to calculate the energy demand of the building, it might be necessary to subdivide it into different calculation zones. The respective calculation zones depend primarily on the building use (divided in 2 main categories, residential and non-residential), more specifically according to the uses defined in the *ÖNORM B 8110-5* (ASI 2011).

In general, the building zoning can be defined according to the following criteria:

- different building uses with the same interior temperature (residential, office, hotel, etc.)
- different construction techniques (heavy, middle, light construction)
- different supply building systems: it includes parts of the building that are supplied by the same technical building systems (heating, hot water, ventilation, cooling or lighting). A supply area can extend over several zones, and a zone can also include several (different) supply areas.
- different building legal regulations

Gains and losses due to technical building systems have to be calculated for each of the defined building zones. The total energy requirement of the building results from the sum of the energy requirements of all building zones.

In the subsection 2.8.1 the criteria to identify the conditioned and the non-conditioned rooms (zones) in the building is explained. A zone encompasses the rooms or floor space which are characterized by uniform usage requirements (temperature, ventilation, and lighting) with similar boundary conditions. As soon as a zone has conditioning requirements (heating, cooling, humidification, ventilation) it has to be designated and calculated as a conditioned room. Unconditioned rooms or areas are only considered in the calculation due to their influence on neighboring zones through transmissional heat flow.

The subsection 2.8.3 gives more detail about the zoning criteria. The zoning of a building takes place in two steps. There is a first zoning for the calculation of the useful energy demand. Secondly, it may be necessary to define a second zoning for the calculation of the final energy demand, which might not match the first zoning. The main criteria are uniform supply systems (heating, cooling, lighting, drinking water and ventilation).

The zoning criteria for the calculation of the useful energy demand if the following:

a) General criteria. The allocation is based on the predominant use and construction techniques of the building (section 3 of *OIB-6*). If the limits do not coincide, the individual zones must be assigned to the different conditions of use and construction techniques methods according to criteria b) to d).

b) Construction technique. If individual sections of a building have different construction methods, the respective sections are to be calculated as a separate zone.

c) Usage profiles. The conditions of use within the building have to be taken into account, defining different zones if they do not coincide. The conditions of use to evaluate are:

- Heat dissipation from people, devices, lighting
- Air exchange rates
- Lighting assumptions
- Times of use (uses schedules)

d) Criteria 4 K. It is the limit value for calculating the heat flows between two adjacent zones. If the room temperature of two adjacent zones differs from one another by more than 4 K, these have to be calculated in separated zones.

The zoning criteria for the calculation of the final energy demand considers the different supply building systems, as follows:

1) Ventilation systems. If more than 80% of the building (gross floor area) is supplied by the same ventilation system, no further zoning of the conditioned rooms is required. Additionally, zones are grouped according to the requirements regarding the functions of heating, cooling, humidifying, and dehumidifying.

2) Heating and hot water systems. Zones that are supplied by different systems must be calculated separately (multiple systems). If more than 80% of the building (gross floor area) is supplied by the same heating system, no further zoning of the conditioned rooms is necessary. If the heating or hot water is not provided together (differences in heat distribution, storage, and provision), the heating and hot water systems must be considered separately. The zoning criterion applies to each individual system.

3) Cooling system. Zones that are supplied by different systems must be calculated separately. If more than 80% of the building (gross floor area) is supplied by the same cooling system, no further zoning of the conditioned rooms is necessary.

4) Lighting system. If more than 80% of the building (gross floor area) is supplied by the same lighting system, no further division of the conditioned rooms is necessary.

The bulk of ÖNORM´s and regulations that had to be observed (by 2015), and that are considered technical requirements defined by the *OIB* (level 2 and 3) are listed in the attachment 1 *Quoted standards and other technical regulations* of the *Wienerbautechnikverordnung 2015* (LGBl. Nr. 35/2015). Among them, the ones directly related to the building performance of buildings are mostly englobed in two subgroups, which is summarized in Table 16:

The subgroup 1: *ÖNORM´s B 8110-x*, Thermal insulation in building construction (*Wärmeschutz im Hochbau*), which deal with applicable regulations in thermal insulation structures and thermal protection measures; and

The subgroup 2: *ÖNORM H 505x*, Energy performance of buildings (*Gesamtenergieeffizienz von Gebäuden*), which deal with building technology regulations as part of the energy performance certificate.

Table 16. Legally binding norms in the WBTV (LGBl. Nr. 35/2015)

ÖNORM
In the guideline Energy saving and heat protection:
ÖNORM B 8110-2 Wärmeschutz im Hochbau – Teil 2: Wasserdampfdiffusion und Kondensationsschutz 2003-07-01
ÖNORM B 8110-3 Wärmeschutz im Hochbau – Teil 3: Vermeidung sommerlicher Überwärmung 2012-03-15
In the Guideline for energy performance of buildings:
ÖNORM B 1800 Ermittlung von Flächen und Rauminhalten von Bauwerken und zugehörigen Außenanlagen 2013-08-01
ÖNORM B 8110-4 Wärmeschutz im Hochbau – Betriebswirtschaftliche Optimierung des Wärmeschutzes 2011-07-15
ÖNORM B 8110-5 Wärmeschutz im Hochbau – Teil 5: Klimamodell und Nutzungsprofile 2011-03-01
ÖNORM B 8110-6 Wärmeschutz im Hochbau – Teil 6: Grundlagen und Nachweisverfahren – Heizwärmebedarf und Kühlbedarf – Nationale Festlegungen und nationale Ergänzungen zur ÖNORM EN ISO 13790 2014-11-15
ÖNORM EN ISO 13790 Energieeffizienz von Gebäuden – Berechnung des Energiebedarfs für Heizung und Kühlung (ISO 13790:2008) 2008-10-01
ÖNORM H 5050 Gesamtenergieeffizienz von Gebäuden – Berechnung des Gesamtenergieeffizienz-Faktors 2014-11-01
ÖNORM H 5056 Gesamtenergieeffizienz von Gebäuden – Heiztechnik-Energiebedarf 2014-11-01

ÖNORM H 5057 Gesamtenergieeffizienz von Gebäuden – Raumlufttechnik-Energiebedarf für Wohn- und NichtWohngebäude 2011-03-01

ÖNORM H 5058 Gesamtenergieeffizienz von Gebäuden – Kühltechnik-Energiebedarf 2011-03-01

ÖNORM H 5059 Gesamtenergieeffizienz von Gebäuden – Beleuchtungsenergiebedarf (Nationale Ergänzung zu ÖNORM EN 15193) 2010-01-01

ÖNORM M 7140 Betriebswirtschaftliche Vergleichsrechnung für Energiesysteme nach dynamischen Rechenmethoden 2013-07-01

C. The OIB-3:2015 Guideline

In addition to the legislation directly addressing the energy performance of buildings, there are Austrian regulations at national and regional level that deal with other building physics aspects. This section provides a short summary of the main guidelines covered by the *OIB-3 Hygiene, health and environment protection (Hygiene, Gesundheit und Umweltschutz).*

Moisture protection

Protection against moisture from the soil

Living rooms and other rooms whose intended use requires it, must be protected in all their parts against the penetration and rising of water and moisture from the ground.

Protection against rainwater

Living rooms and other rooms whose intended use requires it, must be designed in such a way that rainwater cannot penetrate the structure of the external components and the interior of the structure.

Avoidance of damage from water vapor condensation

Space-delimiting building components in buildings with living rooms or other structures whose intended use requires it, must be constructed in such a way that damage from water vapor condensation does not occur either in the components or on their surfaces, during normal use. In the case of external components with a low storage capacity (such as window and door elements), appropriate measures must be taken to ensure that adjacent components are not soaked through.

Note: the Viennese building code also addresses moisture protection in its section 4 *Hygiene, health and environment protection.* The requirements described in its §102 are similar to those of the *OIB-3*.

Protection against dangerous emissions – air quality

Concentration of pollutants

Staying rooms are to be designed in such a way that dangerous emissions from building materials and from the underground do not lead to concentrations that can damage the health of the users, when the air exchange in the room is the appropriate for the purpose of the building, according to regulations. This is considered as fulfilled if the building products used for the building meet the national regulations.

Radiation

Living rooms are to be designed in such a way that avoids ionizing radiation from building materials and radon emissions from the underground, which could damage the health of the user. Regarding ionizing radiation from building materials, the requirements are considered as fulfilled if the building products used for the building meet the national regulations.

Note: the protection against dangerous emissions is also covered by the Viennese building code in its section 4, § 105, being the requirements similar to those of the *OIB-3*.

Illumination

In living rooms, the total light entry area (architectural dimensioning from windows, dome lights, etc.) must be at least 12% of the floor area of the room. This dimension increases from a room depth of more than 5.00 m by 1% of the total floor area of the room for each meter of additional room depth.

If components such as balconies, salient, etc. of the same building protrude more than 50 cm horizontally into the required free light incidence area, for each commenced meter, measured from the entry of the projecting component in the free light incidence area to the front edge of the building, the floor area of the room has to be increased by 2%.

Lighting

All rooms and generally accessible areas in buildings must be able to be illuminated according to their intended use.

Ventilation

Staying rooms and sanitary rooms must be adequately ventilated through windows or doors that lead directly to the outside. This can be waived in whole or in part if there is mechanical ventilation that allows an air exchange rate that is sufficient for the intended use of the room. For other interior rooms, except for corridors, ventilation possibilities must be provided.

If natural ventilation in common rooms is not sufficient or is not possible to ensure a healthy indoor climate, mechanical ventilation must be set up for the intended purpose. A natural or mechanical ventilation system must be set up in rooms whose intended use suggests a significant increase in humidity (especially in kitchens, bathrooms, etc.).

Heating

Living rooms and bathrooms must be conditioned in such a way that the resulting room temperature is sufficient for the intended used of the room. This does not apply to non-conditioned rooms or rooms which are not intended for habitation during the heating period.

Note: room illumination, lighting, ventilation, and heating are also covered by the Viennese building code in its section 4, § 106. No additional regulations are mentioned of relevance to this thesis.

D. The Viennese housing promotion and dwelling renovation act

This section contains a description of the requirements that had to be fulfilled when applying for building subsidized in 2015. This were set in the document *Guideline No. 1 of the MA 25 on increased thermal insulation requirements for subsidized apartment buildings according to the WWFSG 1989,* which was published in 2011. Among the requirements are:

Energy certificates

Compliance with the requirements established in the *OIB-6* Guideline including U-values and input data (geometry, building physics, building technologies).

In addition, the certifications may only be produced with computer programs based on the examples in the supplements of the corresponding ÖNORM's.

The author of the energy certificate has to be qualified and authorized to do so. The author has to sign the energy certificate and confirm compliance with the requirements set in the Viennese building code, as well as all applicable guidelines and regulations set out in the *WWFSG 1989*, and in the *Vereinbarung gemäß Art. 15a B-VG.*

Building ecology and energy requirements

Housing projects whose heating systems are based on coal, coke, briquette, oil or electric resistance (except residual current heating in passive houses) are not subsided.

If no district heating connection is possible, the following heating systems are allowed in combination with thermal solar systems:

- heating systems for biogenic fuels;
- electrically operated heating heat pump systems with an annual performance factor of at least 4; or
- gas heating with gas condensing technology.

Thermal solar systems are to be built with at least 1 m² collector area per residential unit. Their implementation is only avoidable if their erection proves to be technically unreasonable (it has to be documented).

In addition, construction materials that hold greenhouse gasses (CFC, HFC, HFC, HCFC) are not permissible, if other alternative materials are available on the market.

Minimum thermal requirements

A heightened thermal performance was one of the most important requirements to fulfil to be granted building subsidies. It is defined through the maximum annual heating demand, which should not exceed the values defined in Figure 25:

Referenzlinie für $HWB_{BGF,zul}$	$HWB_{BGF,zul}$ (bzw. $HWB^*_{V,NWG,max,RK}$) bei l_c				
	1,25 m	2 m	3 m	4 m	5 m
Wohngebäude: 14,67 x (1 + 1,82/l_c)	36,0	28,0	23,5	21,3	20,0
Nichtwohngebäude $HWB^*_{V,NWG,max,RK}$: 5,0 x (1 + 1,82/l_c) in kWh/m³a	12,3	9,6	8,0	7,3	6,8

Figure 25. Energy performance requirements (MA25a, 2011, p. 4)

Moreover, additional subsidies can be claimed if the thermal performance of the building is improved by 25%, according to the following Figure 26:

Referenzlinie für $HWB_{BGF,zul}$	$HWB_{BGF,zul}$ (bzw. $HWB^*_{V,NWG,max,RK}$) bei l_c				
	1,25 m	2 m	3 m	4 m	5 m
Wohngebäude: 75% von 14,67 x (1 + 1,82/l_c)	27,0	21,0	17,7	16,0	15,0
Nichtwohngebäude $HWB^*_{V,NWG,max,RK}$: 75% von 5,0 x (1 + 1,82/l_c) in kWh/m³a	9,2	7,2	6,0	5,5	5,1

Figure 26. Higher energy performance requirements (MA25a, 2011, p. 5)

Likewise, constructional thermal bridges should be built in a way that reduces potential thermal losses.

Building tightness

A building tightness concept has to be formulated already in the planning phase, and correctly conducted in the execution phase. In case exhaust air systems are implemented, controlled air supply has to be also guaranteed. The measurement of the building tightness must be carried out by an accredited test center, by a certified building expert or by technical offices.

For building subsidies, the air exchange rate requirements are also higher than the defined in the *OIB-6*, according to the following maximum values:

- In buildings with window ventilation or with exhaust air systems, n50 <1.5 air exchange rate per hour
- In building with controlled ventilation systems (both exhaust air and air supply system) with heat recovery, n50 <0.6 air exchange rate per hour

Here the difference with the requirements defined in the *OIB-6* means that the airtightness in subsided buildings is 50% higher in the case of buildings without controlled ventilation and 60% higher in case of buildings with controlled ventilation systems.

The airtightness of the building has to be also certified, for which different methods are defined according to the configuration of the building:

1. Measurement of the entire building based on the net room volume. In addition, a random sample measurement of at least 2 apartments in an unfavorable location is necessary.

2. If the measurement of the entire building because of its configuration is not possible, the measurement must be carried out per staircase (or per unit of exhaust air ducts).

From the measurements obtained per staircase, a weighted mean value either over the apartment floor area or over the gross floor area is to be calculated, which will represent the airtightness for the entire building. The random sample measurement of at least 2 apartments in an unfavorable location is also necessary.

3. In buildings with balcony-like access or other configuration that do not allow a measurement of the entire building or per staircase, the measurements have to be conducted in at least 5 apartments or at least 10% (here the guideline is not clear about what this 10% is referring to).

In addition, the following points have to be observed:

- any single measured value should be lower than the defined maximum air exchange rate;
- in buildings with window ventilation or exhaust air systems at least 2 apartments or 5% of the apartments have to be evaluated;
- intermediate measurements during construction process are recommended;
- when testing buildings with exhaust air systems, the air supply outlets must be sealed;

- building permeability is assessed using the differential pressure method (e.g., through the blower door test) in accordance with the *ÖNORM EN 13829*, method A (ASI 2001).

The measurements have to be documented and its results delivered to the MA25. The date and location of the tests have to be agreed with the MA25.

Procedure in case of design and component changes in the project

Any design and component changes in the project, that result in a change of its visual appearance or in the quality of the building are subject to approval by the MA25, the MA50 and the property advisory board or the competition jury.

In accordance, the energy performance certificate must be updated to include any changes carried out in the project. It must also be submitted to the corresponding building authority for the completion notification as well as its final version submitted to the MA25.

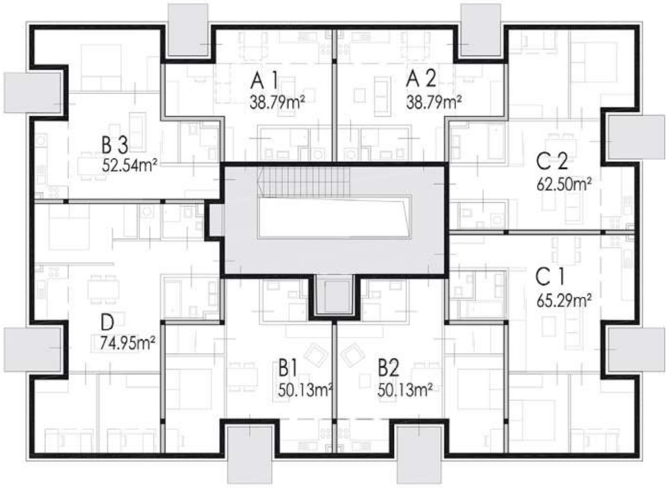
Controlled room ventilation with heat recovery systems

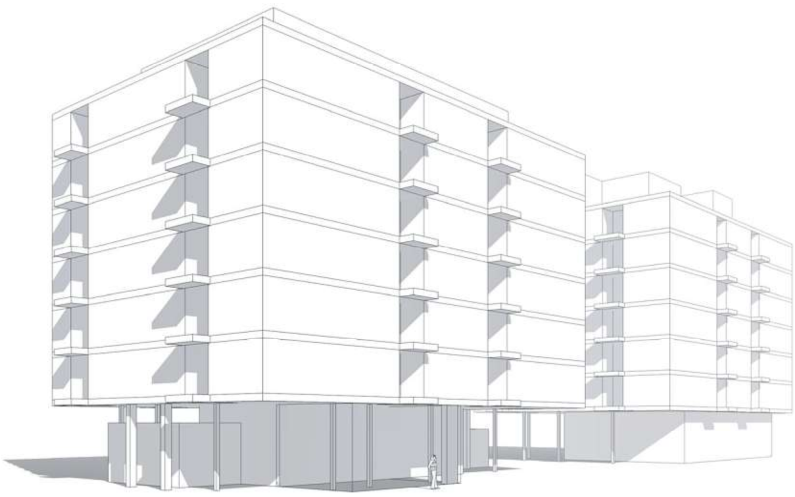
There are additional subsidies that can be granted in case that heat recovery systems are implemented in the project. The technical requirements are described in section 3. Because of the extension of the section and because these systems are not implemented in the project object of this thesis these are not further explained. Likewise, the last section of the guideline is dedicated to requirements for passive houses. This section is also not addressed as it is of no relevance to this thesis.

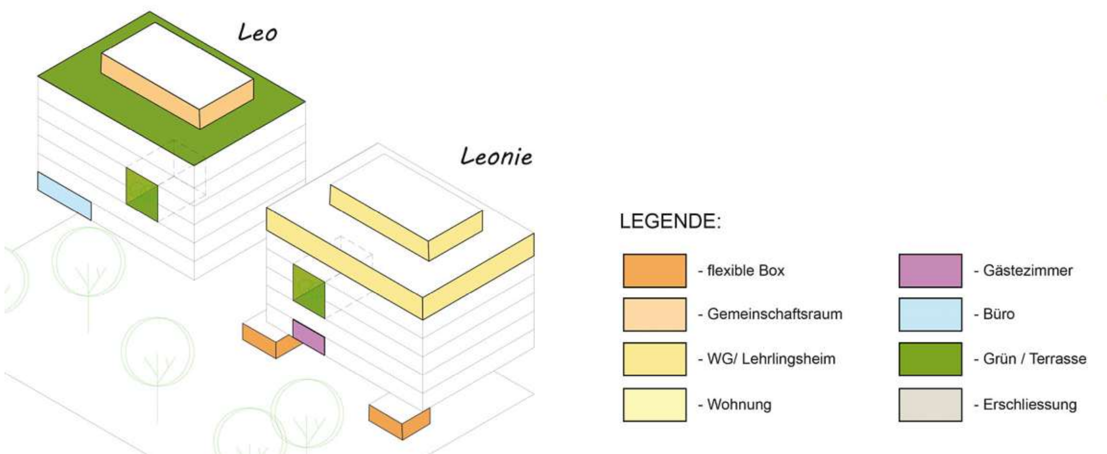
E. Project documentation

P1 Development phase

Typical ground floor, axonometry, sketch with uses

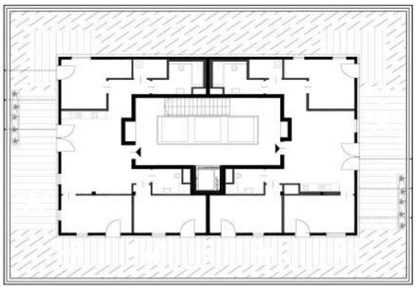


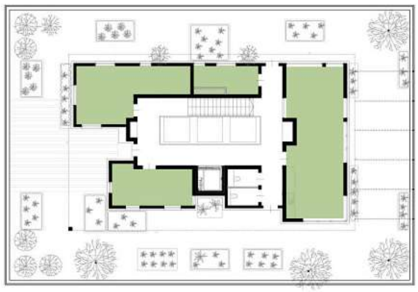


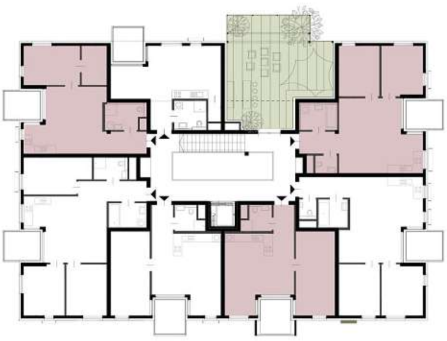


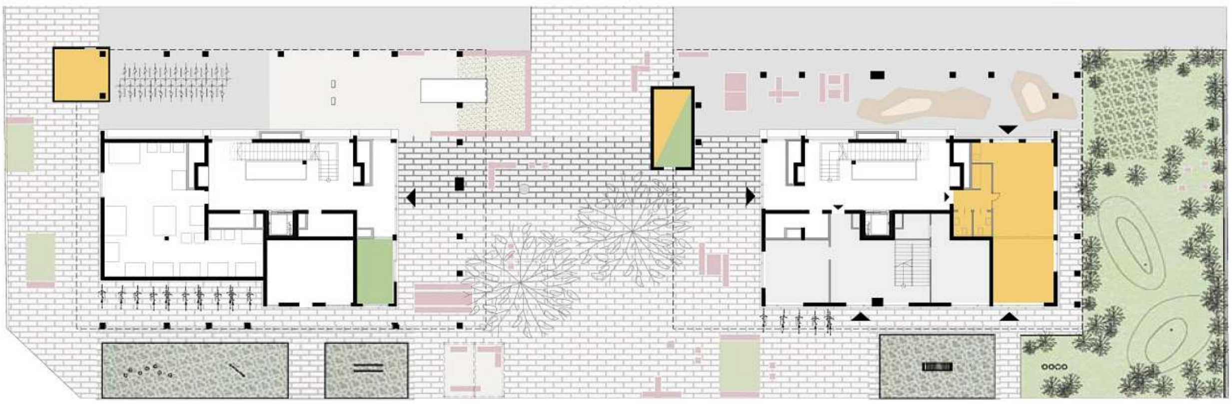
P2 Preliminary design phase

Roof top-, third-, and ground floor plans; Longitudinal section; Views









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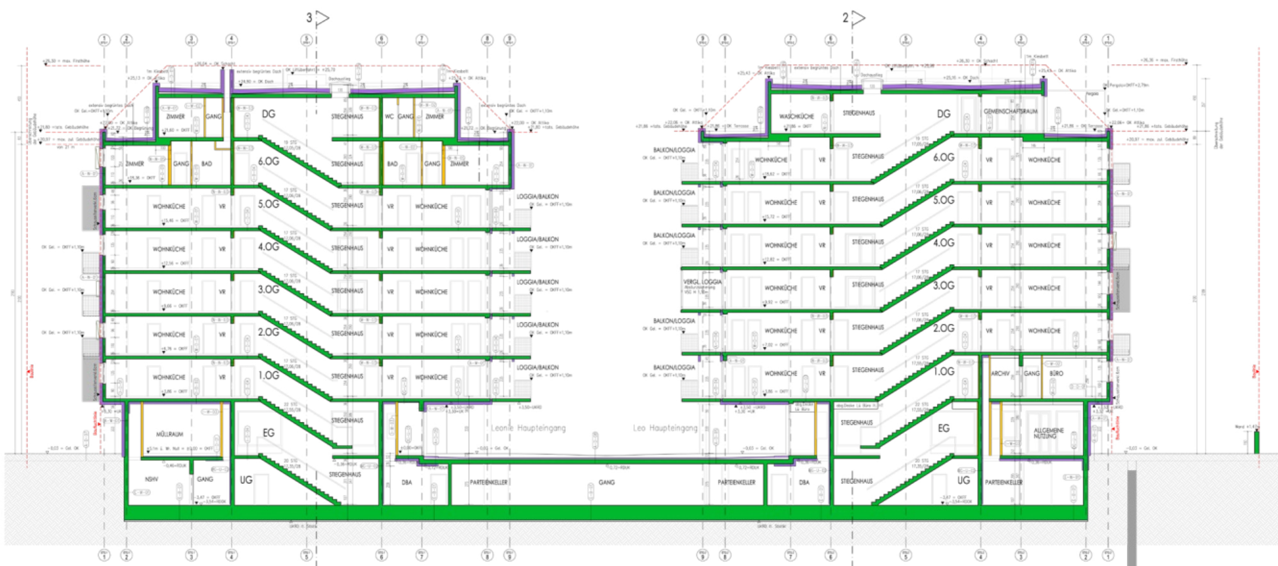
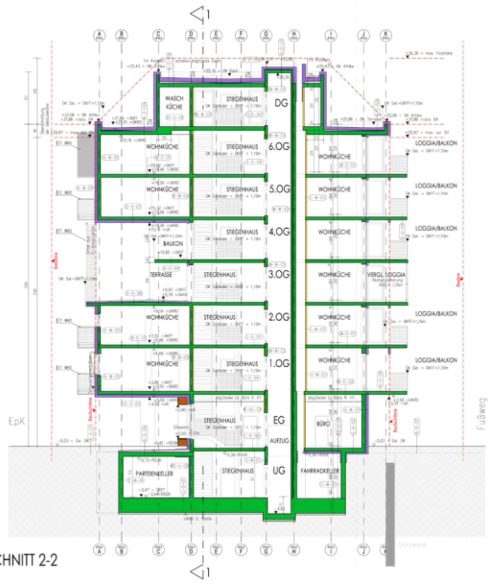
P3 Design phase

Longitudinal and cross sections; Roof top-, third-, and ground floor plans

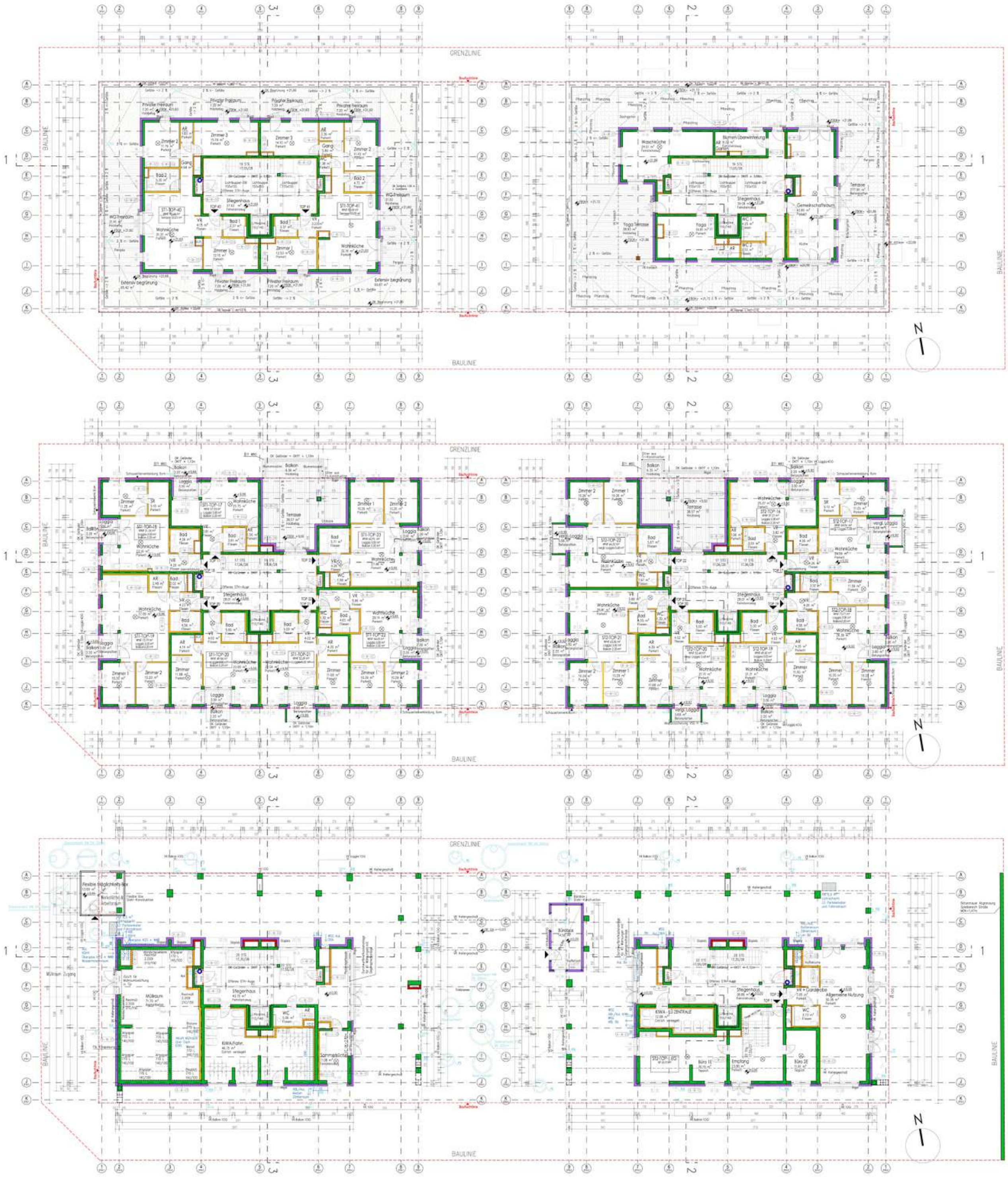


SCHNITT 1-1



SCHNITT 2-2

SCHNITT 3-3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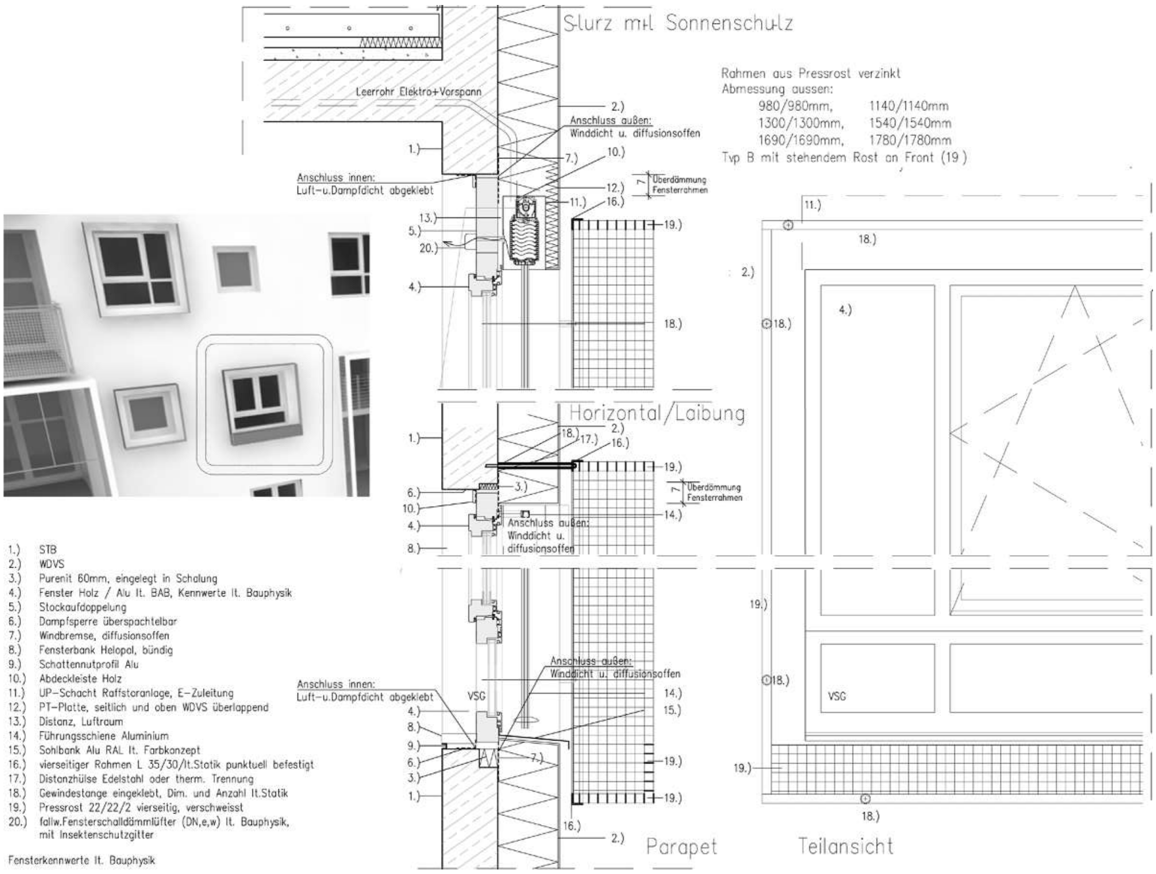
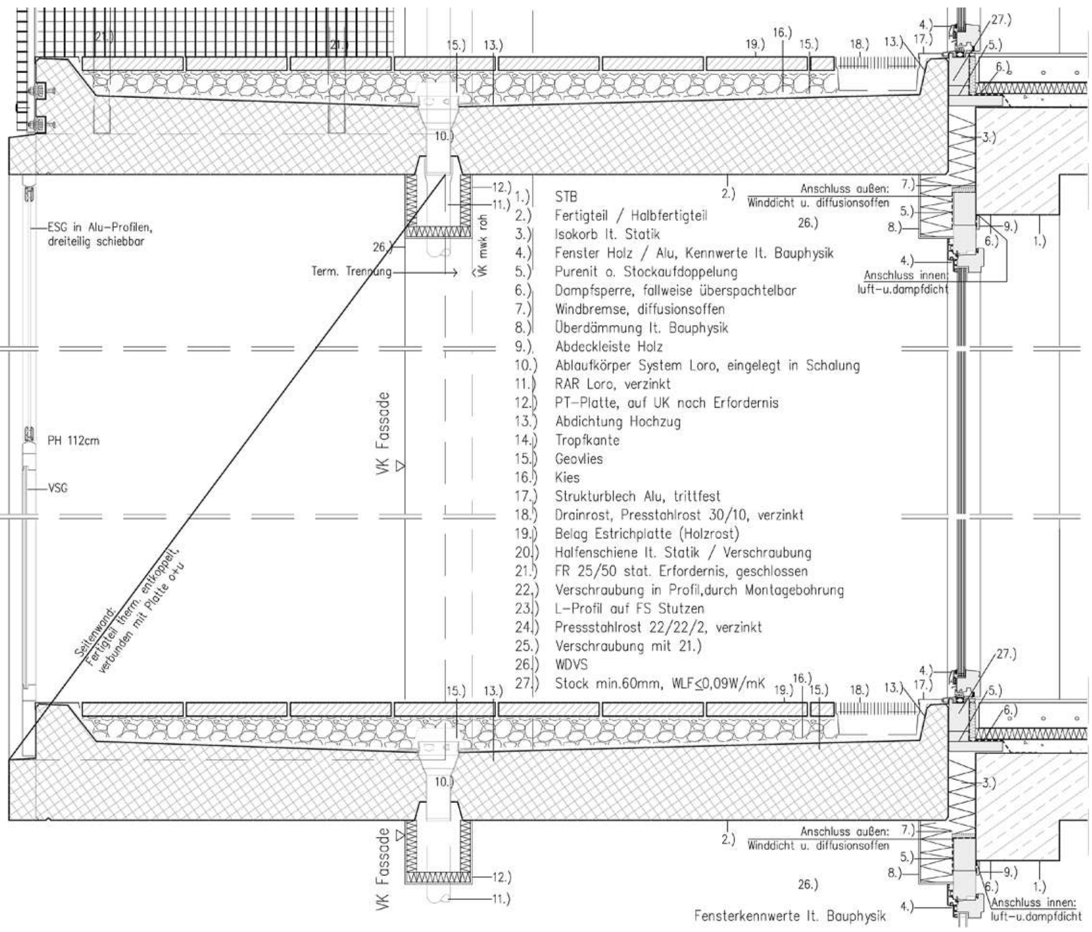
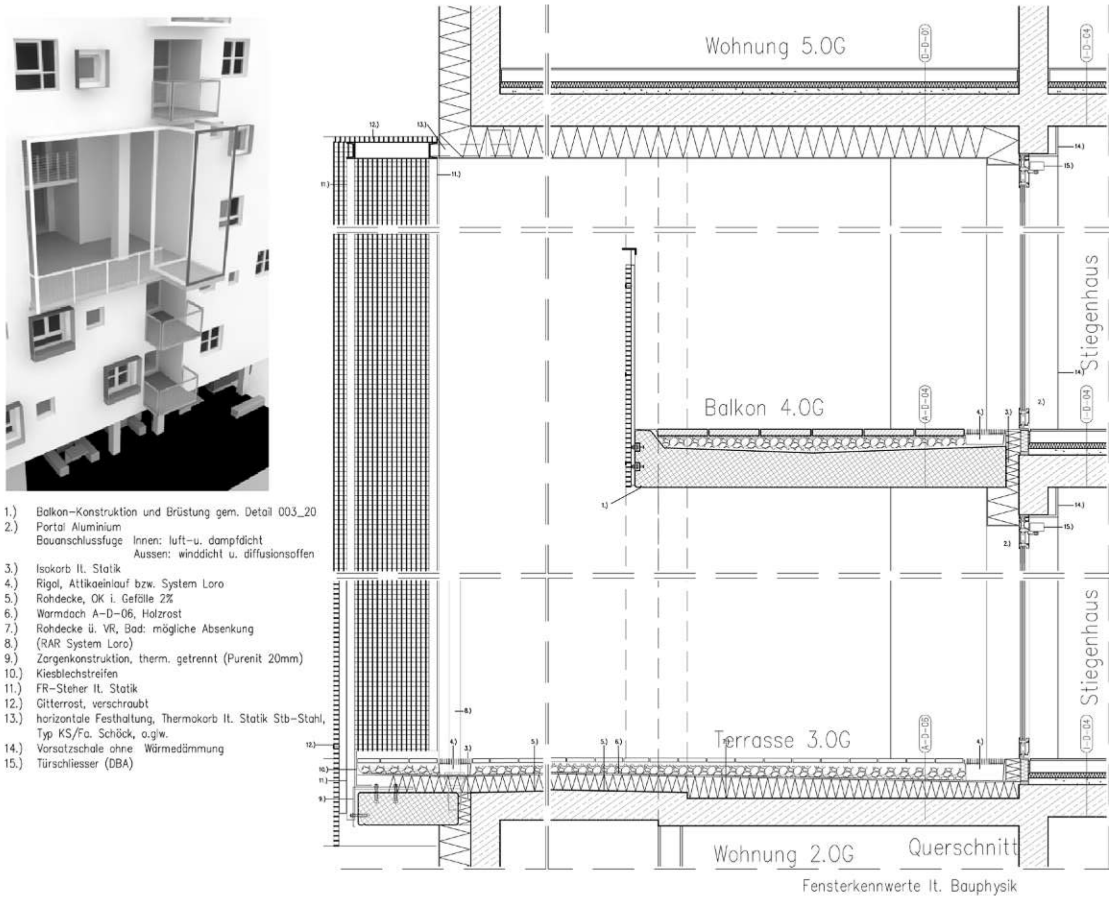
P4 Call for tender phase

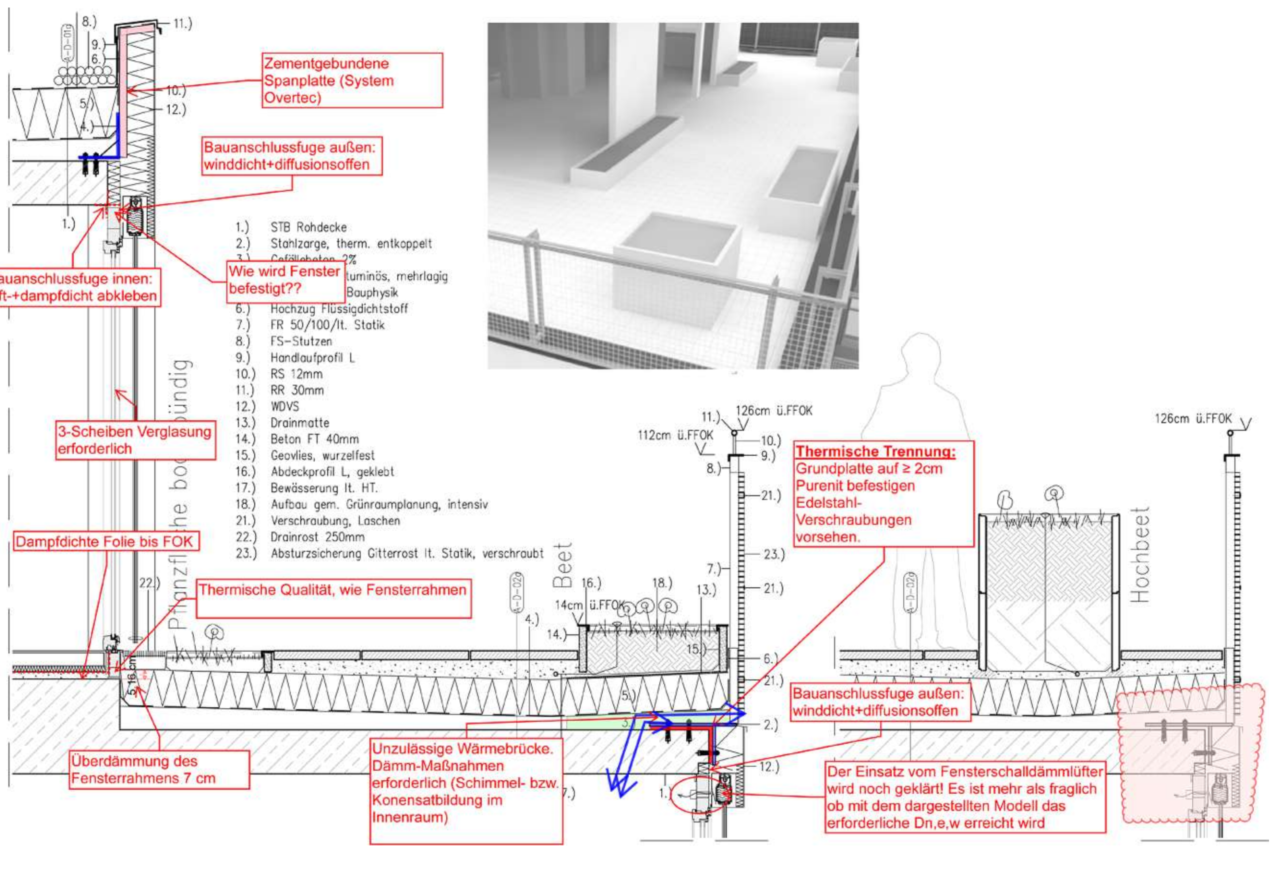
Exemplary details: window-, winter garden-, and community loggia-cross sections





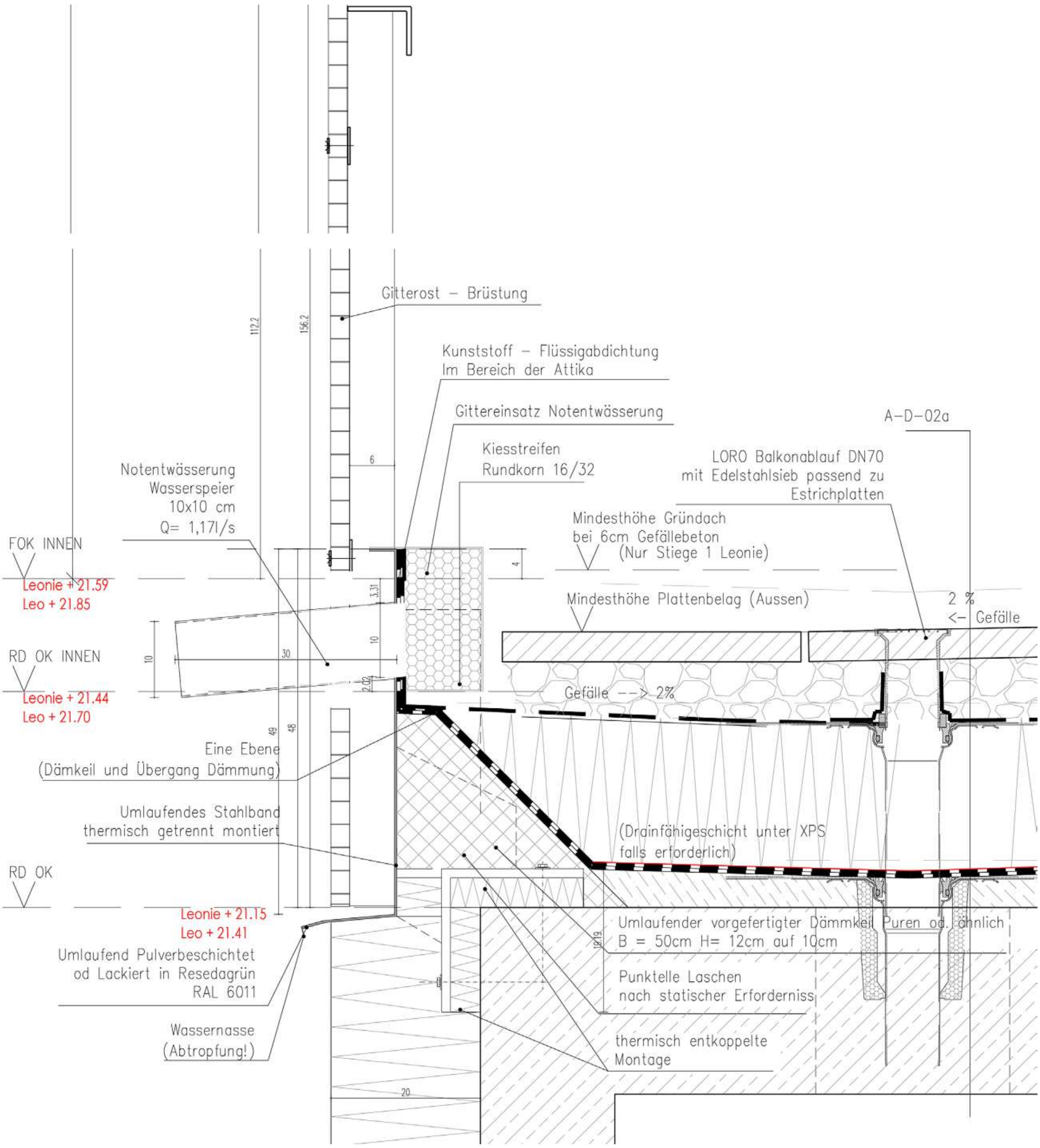


Exemplary BP-correction: roof-top floor construction and wall cross sections



P5 Execution phase

Exemplary detail: adaptation of roof-top construction



Longitudinal section; Roof top-, third-, and ground floor plans