RESEARCH FOR GOOD HEALTH.

Viva Research Park is the largest research project for comparative building materials in Europe. Here, the interaction of individual building materials is analyzed and their effects on health and comfort are tested in real research houses built with different construction methods.

In the past three years, external researchers with backgrounds in building construction, interior climatology, building physics and medicine came together to collaborated in Viva Research Park and developed numerous new scientific findings.

This book discusses the origin of this amazing project, illuminates all of the measurements and analyses in detail, and presents all the scientific conclusions gained through this project.

HEALTHY BUILDING.
HEALTHY LIVING.

VIVA RESEARCH PARK

HEALTHY BUILDING. HEALTHY LIVING. Scientific findings on the efficacy of building materials used in Viva Research Park.

VIVA RESEARCH PARK

HEALTHY BUILDING. HEALTHY LIVING.

Scientific findings on the efficacy of building materials used in Viva Research Park.

Julia Posch

We want every person to live in a healthy, energy-efficient and beautiful home.

PREFACE

Dear readers,

We at Baumit want every person to live in a healthy, energy-efficient and beautiful home. However, in order for us to realize this vision concretely, we have to gain in-depth knowledge of what constitutes healthy building and what effects different construction methods and materials have on our health. There is an incredible amount of knowledge and many theses on these subjects, but so far there have been few practical, science-based examples and statements. After we at Baumit had been dealing with conflicts about healthy building and living for a long time, we finally wanted to change this. That's why we built Viva Research Park on the site of our innovation center at our headquarters in Wopfing in Lower Austria – the largest research park for comparative building materials in Europe, now with 12 research centers.

During the past three years, external scientists from various scientific disciplines such as construction, interior climatology, building physics and medicine have worked together in an inter-disciplinary manner to explore how different construction methods behave under the same conditions and what effects different building materials have on our health and well-being.

In this book, we want to take you on a tour of our Viva Research Park. We would like to show you the origin story of this unique project, introduce the astonishing and interesting results of the many measurements and analyses, and present new scientific knowledge about construction methods and the interaction of building materials. Viva Research Park has shaken up and changed many things at Baumit. We know more today than ever before - Here's how you build healthy. and we want to pass on and keep developing this knowledge.

That's why we - in the 30th year of Baumit's history - decided to make healthy building and living our corporate vision and key focus. With Baumit Healthy Living, we want to contribute to healthy life more than ever before with our building materials and our innovations. Join us on our journey.

Sincerely yours,
Robert Schmid

Robert Schmid
Managing Director and owner of
Baumit Beteiligungen GmbH

COMMENTARY

Peter Tappler
General Manager of
IBO Innenraumanalytik OG
General, sworn and court-certified expert and scientific cooperation partner for Viva Research Park

Differences and similarities of construction methods

Again and again I have been asked, in my capacity as an expert for indoor pollutants, which type of construction is the "healthiest". Unfortunately, there were no reliable studies on this topic in the past - every person lives differently, and buildings have such different characteristics that a serious comparison seemed almost impossible. This also explains my skepticism when the building material company Baumit came to me and my colleagues at IBO Innenraumanalytik with the idea of performing a comparative study of different building types as they affect well-being and health. Too expensive, too elaborate, a utopian pipe dream - that was my first reaction.

But when I saw how serious the project was, my scientific curiosity was intrigued. In the planning phase, it was clear that the construction and, above all, the operation of model houses for comparison purposes was a mammoth task that could only be solved satisfactorily with extremely detailed work. So, step by step, we began to solve the many problems posed by ventilation, humidification and climate simulation together as an interdisciplinary scientific team. Looking back, all of the effort and expense was worthwhile. The results are meaningful, conclusive and - which never stops being surprising - they fundamentally reflect the experience of the building diagnostics practice of the past 25 years. Viva Research Park shows the differences and similarities of different construction methods up close and in recorded detail, which is truly unique.

Enormous quantities of data and surprising results

For us, Viva Research Park was and remains an incredibly special project. For the first time, we were able to systematically examine different wall structures under realistic conditions of use and could study their effects on the room climate. To do so, the sensor data had to be automatically read out and saved with a high temporal resolution. Throughout the entire investigation period, more than 200 gigabytes of measurement data was generated. In order to evaluate and interpret this enormous amount of data, a proprietary software solution with tailor-made analysis and visualization algorithms had to be developed. New model-based methods enabling the systematic and reliable interpretation of the complex heat and moisture transport processes were used. Only then could the effects of individual wall layers on the room climate be comprehensibly quantified. Using these methods, we were also able to prove that even just a few centimeters of certain interior coatings are sufficient to noticeably improve the short-term moisture buffering effect. In this context, the unambiguity of the results did surprise us a little.

In short, we see Viva Research Park as a groundbreaking research infrastructure. The use of real boundary conditions, the elaborate sensory equipment and the use of modern, digital analysis methods make it possible to systematically derive new approaches and to further develop building materials in a more targeted manner.

Christian Heschl,
chair of the Master's program "Building Technology and Facility Management" at FH Burgenland and scientific cooperation partner for Viva Research Park

COMMENTARY

New rating system for comfort

Hans Peter Hutter
Environmental Medicine specialist at MedUni Wien [Medical University of Vienna] and scientific cooperation partner for Viva Research Park

Comfort and well-being are elementary requirements when it comes to health in living spaces. But how do you evaluate a variety of physical, climatic and chemical factors in order to achieve sound, meaningful results for different construction methods? Within the scope of the research project, we, as a scientific cooperation partner, were faced with precisely this challenge - to translate comfort and well-being into measurable criteria, using several million data from the individual research houses, covering factors such as: interior temperature, average temperature of the enclosure surfaces, humidity and pollutants. A demanding task, since - as far as we know - such a comprehensive analysis has never before been accomplished. After intensive discussions and considerations, we decided to compare the individual room climate factors, including the humidity and temperature gradients of different houses, by means of an indoor air quality analysis.

For this purpose we developed our own "discomfort score" which covers all relevant comfort parameters. The result is a novel evaluation schematic that makes it possible to make the results of measurements from different types of housing comparable for the first time, and then to draw conclusions about well-being and comfort. Without the project and its elaborate study concept "Construction of different housing types and month-long measurement series" this evaluation method could not have been developed. That a company initiates and finances such an independent, highly scientific research project is certainly not commonplace - which is why we were all the more pleased to be a part of it.

CONTENTS

Page

1. Healthy Living **10 – 17**

---

2. Viva - The Project / Process and Details **18 – 53**
- 2.1. The research project
- 2.2. The houses
  - The construction process in detail
  - The houses in detail
  - Construction methods in Viva Research Park
- 2.3 The measurements
  - The measurement sensors
  - Operating the houses
  - Scientific cooperation partners

---

3. Viva - The measurement results / Building physics, building chemistry and health
- 3.1 Room climate **54 – 103**
  - The operative temperature
    - Air temperature and surface temperature
    - Effects of the surface temperature fluctuations
    - Why does an uninsulated house cool down so quickly?
    - Room temperature development during the different seasons
    - Cooling and heating behavior of wall materials
  - Interior humidity and its effect on health
    - Relative humidity
    - Effect of interior plaster on room humidity and room climate
    - Moisture buffering capability of plaster and concrete
    - What effect does layer thickness have on buffering capacity?
    - Influence of thermal insulation on the humidity
- 3.2 Interior air quality
  - The odors
  - The pollutants
    - VOCs (volatile organic compounds)
    - Formaldehyde
  - Radon
  - Air ions
- 3.3 Sound protection and room acoustics
  - Sound insulation
  - Room acoustics
- 3.4 High-frequency electromagnetic fields
- 3.5 Well-being and comfort

---

4. Viva – The houses / Detailed results and types of houses **104 – 129**
- 4.1 Overall evaluation matrix for houses
- 4.2 The houses in detail
  - The concrete houses
  - The brick houses
  - The houses constructed with wood frames
  - The timber block house
- 4.3 Visitor response

---

5. Healthy building / Tips and service **130 – 141**
- 5.1 How do you build healthy?
  - Insulate first
  - Density is a necessity
  - Interior values
  - Other findings
- 5.2 Which house is right for whom?
- 5.3 How do i make my house healthier?

Lexicon **142 – 146**

1. HEALTHY LIVING

HEALTHY LIVING IS BECOMING MORE.

In the past, „energy efficiency“ or „ecology“, which is what many building owners and builders were focused on, has been superseded by topics such as „living comfort“ or „living health“.

It's actually not a surprise; after all, we spend an average of 90 percent of our life indoors. And that's why interior air quality and room climate in our living space have a direct influence on our well-being and thus on our health.

In the **„2017 Study of Living“**[1] the Linz Market Institute surveyed 1,000 Austrians who have newly refurnished their living spaces during the last five years or are planning to do so in the near future about how important „healthy living“ is for them personally. More than half of the respondents (59%) rated „healthy living“ as a high priority. When asked whether, from their perspective, the importance of "healthy living" in Austria has risen in recent years, 76% answered with a definite yes.

In the winter of 2016, the opinion research institute Hoffmann and Forcher Research performed a qualitative survey on behalf of the "MeineRaumluft.at" platform on the subject of **„Healthy Living”**[2] among owners who had recently completed a construction project or were currently in the planning phase.

In their responses, 68% of those surveyed listed **„Healthy building and living”** as a key factor in their selection of building materials. For those who were still in the middle of the planning phase at the time, this was a key criterion for over 80% of the building owners. Their reasons were: By choosing healthy building materials, they wanted to avoid suffering from any negative health consequences and to achieve a better quality of life and better well-being by using high-quality materials.

DEFINITION OF HEALTH

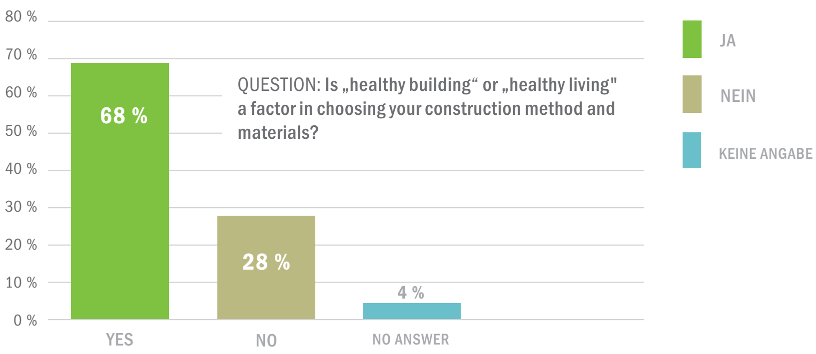
„Health is a state of complete physical, mental and social well-being, not just the absence of illness or ailments.”

Definition of the
World Health Organization (WHO)

[1] Market Institute for Market, Opinion and Media Research, 2017 Living Study
[2] On behalf of the platform "MeineRaumluft.at", [My Interior Climate.at] Healthy Living 2016

More and more planners, architects and master builders are increasingly focusing on the subject of „living health".
And more and more building material manufacturers and manufacturers of ancillary construction products are dealing with the effects their products have on the health and well-being of their customers. Nevertheless, there is still a great deal of work to be done here, as there are still few scientifically valid research findings that simultaneously analyze and evaluate the same room, climate and usage conditions.

„Healthy Living" survey



For 68% of the surveyed building owners, healthy building and living are relevant decision-making factors when choosing their construction methods and building materials. Source: MeineRaumluft.at/Hoffmann and Forcher Research

BAUMIT AND HEALTHY LIVING

Baumit has been involved in healthy building and living for decades and is a clear pioneer in the field of building materials. It all started 30 years ago, in the middle of the 1980s energy crisis. At that time, Baumit developed the first affordable thermal insulation systems.

Next, the company created a milestone in thermal insulation in August 1999. At that time, the building materials company presented its latest product development: Baumit open - The Climate Façade - revolutionizing the building materials market. Until this time, only heating cost savings stood in the foreground for all thermal insulation systems, while at Baumit, experts were already thinking about living comfort. This made Baumit open - The Climate Façade the first breathable thermal insulation façade that created a pleasant living environment and thus increased both comfort and healthy living.

Air conditioning products for a better indoor climate

„Since we now spend most of our lifetime indoors, it was important to us to work intensively on the factors influencing the indoor climate in the Baumit Research and Development department,“ said Robert Schmid. That's why, starting in 2007, Baumit developed its own range of products for better room climate, beginning with its Klima products. In order to make it easier for consumers to obtain information about healthy building materials, Baumit subjected its climate products to extensive health and environmental testing by the Austrian Institute for Building Biology and Construction Ecology.
All Baumit Klima products are certified „natureplus“ - meaning that they meet the high test standards of health, sustainability and environmental protection. The mineral paint Baumit KlimaColor was even awarded the Austrian Ecolabel.

Ionit uses the air ion effect

In its intensive research into effects that can have a positive influence on room climate, Baumit's experts discovered a hitherto little-known component of our air - air ions.
The fact that air ions increasingly occur in waterfalls and that the air is particularly healthy there was already established knowledge at this time. However, the health potential of indoor air ions had seen much less research. Baumit launched extensive trials and began to develop a product that could harness the air ion effect for interior spaces. After five years of research and development, everything was ready to go in 2011: Baumit launched a complete novelty onto the market - Ionit. For the first time, this new interior coating increased the indoor air ion concentration to create healthier indoor air. This positive effect was also confirmed by the first comprehensive aerial ion study by MedUni Wien [the Medical University of Vienna] and by research performed by other institutes.[1]

[1] Hutteretal.: Exposure to Air Ions in Indoor Environments: Experimental Study with Healthy Adults, Int. J. Environ. Res. Public Health 2015

Viva Research Park and Healthy Living

„If you are convinced of something, and you see how many positive things this conviction can set in motion, your conviction won't let you go," said Robert Schmid, explaining why Baumit is so committed to healthy living. „Because it's our vision that every person can live in a healthy, energy-efficient and beautiful home." As a result of this intention, Viva Research Park began to create a unique project in 2014: Europe's largest research park for comparative building materials, providing important insights into the interaction of building materials and their impact on health and well-being. All of this knowledge flows directly into the research and development of building material products manufactured by Baumit.

That's why, today, **„Healthy Living"** is the result of Baumit's consistent redevelopment in pursuit of healthy building and living. Because, thanks to „Healthy Living", the entire Baumit product range is divided into the three health and comfort-promoting areas **„Insulate first", „Density is a necessity" and „Interior values" .** Robert Schmid: „With Healthy Living, we decided to give Baumit an even clearer focus on healthy everyday life.""

INTERVIEW

»He who builds healthy lives healthy.«

Jürgen Lorenz, Head of Research and Development (R & D) Baumit and project manager of Viva Research Park, on the benefits of healthy building materials and the future of healthy living.

Why is Baumit so committed to healthy living?

Jürgen Lorenz: We want to make people's lives better and healthier - that's what we care about most - and that's why we are so committed to the field of healthy living - because those who build healthy, live healthy.

Why are healthy building materials becoming more and more important?

Jürgen Lorenz: Due to climate change, the demands on the functionality of our buildings and building materials are increasing. Heat periods, heavy rainfall and temperature fluctuations are steadily increasing and are affecting our sense of well-being. This makes it necessary to adapt our future construction methods to these new conditions in order to also meet future needs for safety and comfort. In addition to their original function, healthy building materials are also faced with the additional task of contributing to the health and well-being of the building's inhabitants.

This task can be fulfilled using different methods: for example, the permeability and sorption capacity of a paint or a plaster can help ensure a building's high and rapid capability to buffer atmospheric moisture, or, as with Ionit, can increase its efficiency and reduce the pollen load by increasing the amount of air ions.

Why is it important to pay special attention to healthy building materials in interiors?

Jürgen Lorenz: Our interior walls are our third skin. When you think about how large the total area of walls and ceilings in your house or apartment is, it quickly becomes clear that what we're dealing here with a key influencing factor on our room climate. The type of coatings we choose isn't immaterial - on the contrary: we have deliberately developed functional coatings that actively contribute to the room climate and to your comfort. Today, we know that the right interior plaster and the right wall paints can affect our health and well-being.

So it's up to us to ensure a healthy indoor climate by selecting the right building materials - which applies to new structures as well as to renovations.

How can a project such as Viva Research Park contribute to healthy living?
Jürgen Lorenz: With Viva Research Park, we have the unique opportunity to apply and test scientific theories about building materials and building physics simulations in real buildings. As part of this project, we can directly measure the impact of our products on the room climate and can learn more about the relationship between product formulations and their impact on home health and comfort, based on the massive quantity of data and the conclusions. This enables us to develop new products with functional and comfort-enhancing properties, meaning that we will in future be able to bring a variety of wall structure products onto the market that improve room climate, such as bricks, concrete and gypsum plasterboard sheets.
These product recommendations are tested for their utility and performance in Viva Research Park.

What is the future of healthy living?
Jürgen Lorenz: Healthy building and living is becoming more and more important, because climate change is leaving us no choice. Planners and architects will have to construct houses and buildings that take summer overheating, heat and extreme weather conditions into account. This means that we will increasingly use storage density as a buffer for heat and energy - insulating heat as well as cold. We will increasingly resort to solutions that do not require additional energy, such as a canopy that protects against the sun instead of motorized blinds; or windows that are positioned so that they do not have to be shaded from the sun.

2. VIVA THE PROJECT

PROCESS AND

2.1. THE RESEARCH PROJECT

Viva, Europe's largest research park for comparative building materials, has been in operation since March 2015 at the site of the Baumit Research and Innovation Center in Wopfing, Lower Austria. Here, the interaction of individual building materials and their effects on health and well-being is being scientifically investigated in real houses. But how did a construction materials company come to initiate such a massive project? Who performs the scientific investigations? And what was and is actually being measured?

How it all began...

„Actually, Viva Research Park was the logical result of our long-term involvement with the topic of 'healthy living',“ said Jürgen Lorenz, head of Research and Development at Baumit and the project manager of Viva Research Park. „As part of our work, we found that there are many hypotheses but not much concrete knowledge about the way building materials interact. That's when we realized: we need scientifically-based statements about the effects of building materials on health and well-being.“

We're building a research park...

But how can you gain this type of real knowledge? Robert Schmid, Managing Director of Baumit Beteiligungen and owner of Baumit, had a bold idea: "We're building a research park with real houses, built with different commonly used construction methods." Real houses? But how to put this into practice? "I remember exactly how we were all immediately fascinated by this idea right away, and how we all simultaneously thought that we had to build a research park with real houses," recalls Jürgen Lorenz. But the project idea quickly took shape...

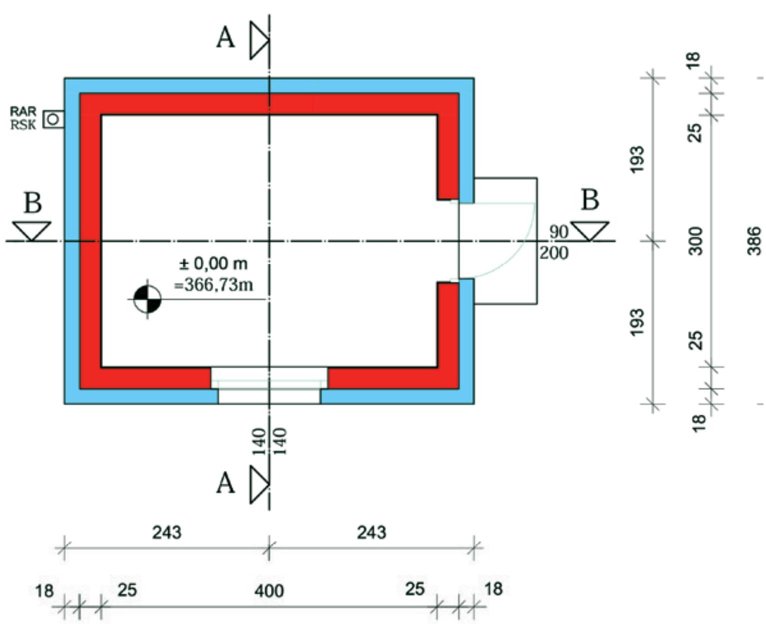
10 houses as measuring stations

Step by step, in 2014, 10 research houses made of concrete, solid bricks, timber block houses and in wood frame construction with gypsum plasterboard paneling, fitted with various interior and exterior coatings, were built next to the Baumit Innovation Center in Wopfing.
From the outside, all the houses look the same: they all have interior dimensions of 4 x 3 meters and measure 2.83 meters in height. They also all consist of a room without partitions, and each has one window and one door.

It was especially important that all houses be exposed to the same outdoor climatic conditions and have the same U-value, because only then could they be comparable. The wide variety of building materials with comparable and similar characteristics did not make the selection process for the research park's construction materials easy. The 10 research houses can only represent a limited selection of building materials and therefore cannot necessarily be regarded as representative; however, they correspond to current state-of-the-art construction technology and represent current construction methods.

Floor plan of the research houses

The room dimensions are identical for all of the houses: Length: 4.00 meters, room width 3.00 meters, room height 2.83 meters.

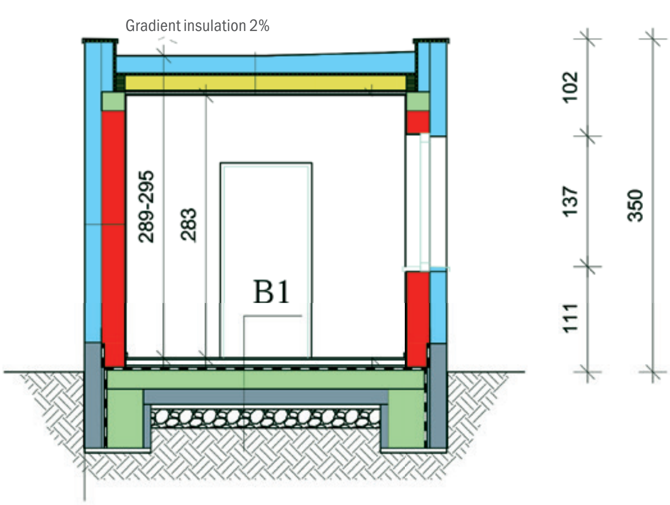


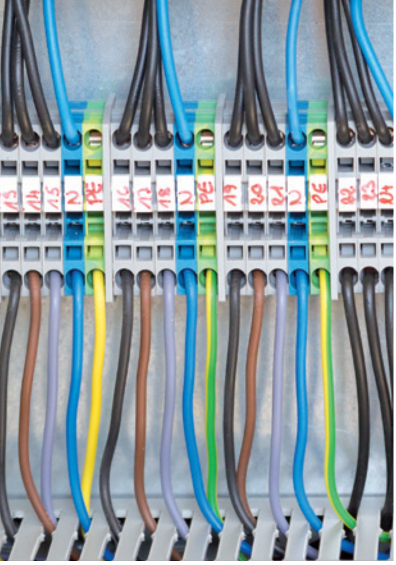
Involving non-affiliated scientists

From the very beginning, Baumit knew that the Viva Research Park project could only be implemented in cooperation with non-affiliated, external scientists. „We provide the data, but the evaluation was carried out by our cooperation partners," explains Jürgen Lorenz. „This was the only way to guarantee the independence of the scientific evaluation results." As early as March 2013, ten scientists from the fields of building physics, construction chemistry and medicine met with the Baumit research team for the first time to discuss how to approach such a project. „Together, we considered which measurements are necessary and how we can analyze the health effects of building materials," recalls Jürgen Lorenz.
The research team decided that, in addition to the different temperature curves (inside and outside) and moisture buffering, variables including formaldehyde, volatile organic compounds (VOC), odors, air ions, sound and acoustics as well as radon and high-frequency electromagnetic fields would all be measured and evaluated.

Research houses step

Carried out identically for all houses: roof construction and floor construction as well as the dimensions and positioning of windows and doors





31 measurement sensors were installed in every research house.
The whole computer system itself received its own measurement technology house.

Most complex measurement methods

The technical effort involved in the construction of the ten research houses was enormous. In addition to the nine research houses, a separate, tenth measurement technology house was built, in which all of the computer technology was installed. Here, all measured values such as air and wall temperature, air humidity and energy consumption can be displayed at a glance. **Per house, 31 measurement sensors** were installed, which recorded a wide range of physical measured variables around the clock. The interiors of the houses were tested for, among other things, toxic and physical factors and the influence of those factors on comfort and well-being. All continuously recorded measurement data was saved and secured on a server. In addition, a controlled ventilation system was installed in every research house. This meant that predetermined air changes and certain conditions of use (such as forced ventilation, continuous ventilation, etc.) could be set and computer-controlled without having to manually open the windows.

3 million euros and 3,000 visitors

The cost of such an unusual project was high. Baumit invested three million euros in the research park in the first two years alone. „If you have an idea that everyone is convinced of, you have to put your money where your mouth is if you want to implement it. This is the only way you can create something truly unique, and it's the only way that such a project will also pay off“, as Robert Schmid believes wholeheartedly. Interest in Viva Research Park was exceptionally large from the very beginning. Although Baumit communicated very little to the public at the beginning, it soon became apparent to the industry that something unique was being created here in Wopfing.

Everyone wanted to see it for themselves and find out what the different houses felt like. „That's exactly what needs to happen“ - that was the common response of many building materials experts in the industry when measurements began. Initially, however, only a few interested people could be allowed into the research houses, since the measurements could not be disturbed. After completing the first research phase, four of the research houses were opened to visitors and can now be visited as part of a guided tour of the factory. Meanwhile, over 3,000 visitors have experienced the research houses in person.

5 million data

The measurements have been running since March 2015: so far, over five million data have been collected and analyzed. „Viva Research Park is by far the largest and most comprehensive research project for comparative building materials that has ever existed,“ said Jürgen Lorenz. „In the meantime, we have gained numerous new insights into the interaction of building materials. Today, Viva Research Park has become indispensable in the further development of building material products.“ Numerous scientific findings gained during the first phase of the project are now being incorporated into Baumit's product developments - while, at the same time, the research continues. For example, two more houses have been built in the meantime which are modeled on Wilhelminian houses. Scientists are currently investigating the living comfort of these houses and are evaluating how this is affected by thermal insulation. In order to optimally reflect the original condition of a Wilhelminian-style house, 23,000 bricks were built in a solid standard format for each Wilhelminian research house - with properties comparable to century-old brick walls.

The research continues...

Other houses with other research interests or adaptations of the existing houses will follow in order to obtain measurements and analyses of new products or systems. Lorenz: „Viva Research Park is a living project that, in keeping with the current state of our research, will always evolve and will never be finished. With the research park, we have changed the research and development possibilities for building materials - and we've changed them fundamentally - for today and for the next few decades.“

INTERVIEW

»Everything about these houses is analyzed and measured.«

Hans Peter Schweiger, Project Coordinator of Viva Research Park, on the challenges involved in the planning and construction of the Viva research houses.

What challenges did you face when constructing the research houses?

Hans Peter Schweiger: We had to be extremely careful that every detail is absolutely perfect and that we could make the houses equally airtight. Because, due to their small footprint - they only measure 4 x 3 meters - every little flaw has a massive impact. For example, the window manufacturers had to rework the windows three times until the connection details and the contact pressure of the seals in all the houses fitted perfectly.

At the same time, we also had to find unusual solutions for the necessary acceptance procedures in order to apply them to our houses. For example, we were forced to adapt the measuring method for the blower door test - the standard test procedure for checking the tightness of a building. Normally. for this type of test, a frame is built into the entrance door and a very large fan is used to create an underpressure or overpressure of 50 Pascals. However, the small size of the houses prevented us from using this method, because you simply can't get the building airtight enough for the test. Therefore, we introduced a pipe into the back of the houses in a measuring opening, built up an overpressure of 50 Pascals with a diaphragm pump, then measured how much air it takes to maintain the pressure. This allowed us to recalculate the tightness.

What did you have to pay special attention to during the planning process?

Hans Peter Schweiger: When we knew what variables we wanted to measure, the question arose: what measurement data do we need to derive well-being factors from the measurement results as part of a next step in order to analyze comfort and health? This also raised the question of how we could simulate user behavior in a realistic manner. Finally, we still had to face the everyday challenges: how do we introduce moisture into the houses? Do we use an evaporator with a timer, or does someone enter the houses several times a day to humidify them? Will they be ventilated manually or automatically?

In the face of all these questions, we cumulatively decided to utilize as much automation as possible in order to minimize disruptions to the measurement process. That's why we chose a ventilation system with control technology. An additional benefit: we were able to easily simulate different user behavior.

Looking back, where were the sticking points in this project?

Hans Peter Schweiger: The Baumit colleagues did much of their own work from planning to construction. Only the prefabricated building parts, the plumbing work, the heating and the windows were assigned to external contractors; otherwise, we carried out all the work ourselves. In doing so, questions arose during every phase: which products do we use in order to reflect common construction methods as accurately as possible? How can we perfectly seal every necessary measurement opening? When is the optimal time to install the measurement sensors? These questions presented incredible challenges to us in terms of interface coordination. During construction itself, unforeseen challenges confronted us again and again.

This meant that, during the last construction phase, after installing all measurement sensors, the tests in one house showed an incomprehensible, relatively high level of VOC contamination. After intense consideration, discussions and analysis, we found that the VOC load came from an adhesive used by the prefabricated house manufacturer, which we also used to seal a pipe duct. We paid careful attention to the absence of pollutants in all of our building materials - and then, thanks to an ancillary construction product, we brought a serious pollutant source into the house. That was a real learning experience.

What surprised you?

Hans Peter Schweiger: We were surprised by the relevance of the odor in the houses and how different every home feels when you enter it. As early as during the construction phase, we noticed how different each of the individual houses smells. Now the houses have been standing for more than three years, but the differences in odor are still present. When you live in a house, your furniture and your repeated cooking, washing and cleaning covers these odors for short periods of time. In the research park, however, you become aware that this inherent odor is simply always there.

What is it about Viva Research Park that makes it so special?

Hans Peter Schweiger: Decades ago, we took our first measurements on small test samples, then tested them on entire walls in the lab. The research park allows us to reflect a real living situation - a milestone that offers us as researchers completely new testing possibilities. Suddenly. we don't just have a measured value; we're experiencing the individual products in their entirety. For me, that's the most exciting thing about Viva Research Park. When you step inside the houses, every single one feels different. That's when you notice that a house is truly the sum of its parts.

The Viva Research Houses (right) are located directly behind the Innovation Center (left) on the Baumit factory premises.

2.2. THE HOUSES

The construction process in detail...

The research park's construction phase lasted 18 months. During this time, the individual building shells were completed step by step and the entire measuring sensor system was installed. Afterwards, the air-tightness of the houses was secured with complex test procedures. Here are the most important project parameters and building phases at a glance:

The grounds of the research park

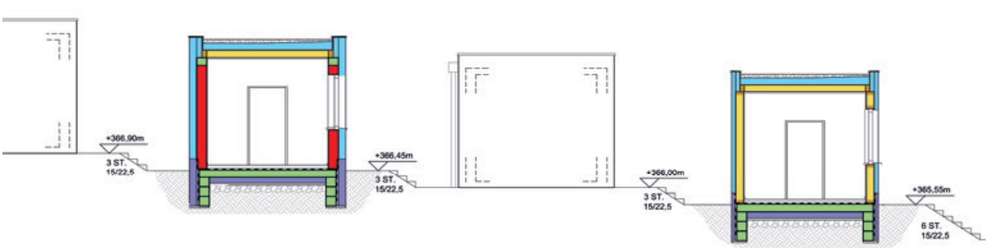
The grounds of Viva Research Park cover an area measuring 2,160 m^2 and is located on a slightly sloping hillside directly behind the Baumit Innovation Center in Wopfing, Lower Austria.

The arrangement of the houses

In order to ensure the same external conditions for solar radiation, the houses were offset to avoid throwing shadows on each other. Additional shading elements such as canopies were deliberately omitted in order to avoid distorting the measurements. However, in order to allow for the possibility of targeted shading, the windows of the research houses were fitted with external shutters.

System profile of the research houses

The research houses were positioned so that they cast no shadows on each other.



The foundations

All research houses received concrete floor slabs. A moisture-insensitive XPS insulation system was installed under each floor slab to minimize heat loss. In addition, the foundation was insulated on the outside.

Concrete floor slabs with XPS insulation

The construction methods

DThe research houses were built using the most common methods of construction - from concrete to brick to wood frame construction with gypsum plasterboard paneling and solid wood construction.

Five of the ten houses are made of bricks, one of which was built with type 50 bricks (bricks measuring 50 cm thick, filled with mineral wool), and one house was modeled after non-renovated older construction and therefore remained uninsulated. The two concrete houses and the two timber-framed houses were each constructed from precast elements.

Research houses made of bricks (l) and concrete (2)

Research house as a timber block house (1) and with wood frame construction (2)

The construction - air-tightness and pollution-free

In order to minimize VOCs, a solvent-containing structural seal was dispensed with. Instead, an extremely low-VOC sealing compound was used.

At the same time, the coated floor slab was covered with a glued VOC-free polyethylene aluminum composite waterproofing sheet. The system adhesive used was also VOC-free. The waterproofing membranes were also used as a vapor barrier in the roof. Here, too, special attention was paid to careful workmanship (e.g. over-glued joints and extra glued corner areas), so that maximum tightness could be guaranteed for the research buildings.

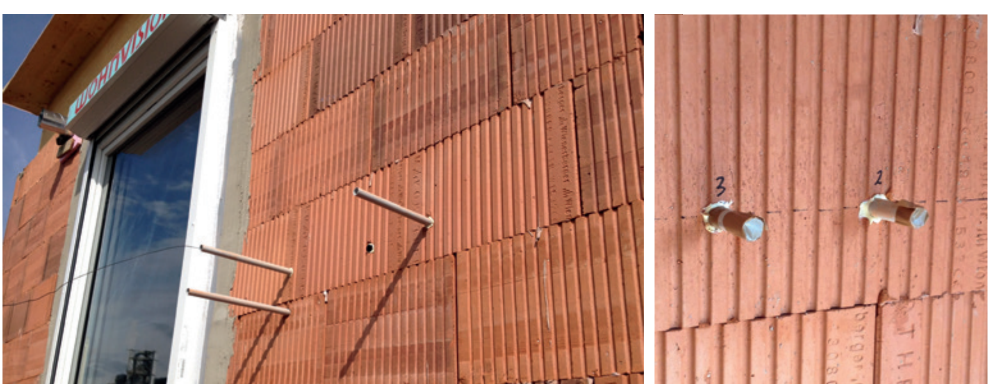
VOC-free base seal (1), VOC-free sealing angle (2), VOC-free waterproofing membrane as a vapor barrier (3)

Air-tightness was also a top priority when installing windows and doors; the installation company had to rework them several times. The scientists dismissed the installation of windows with fans integrated in the frame, since, according to FH Burgenland, both the uniformity of the air volume flow and the air-tightness when the fan was switched off would not meet requirements. Therefore, the team chose a ventilation system with a supply and exhaust air duct with an integrated sealing flap system and volume flow measurement.

Sealing on windows and doors

The measurement sensors

The empty piping for the in-wall material climate sensors was installed at the four measuring points in the masonry and in the thermal insulation composite system on the north and south sides of each model house



Empty ducts for the measurement sensors

Installation of empty piping for the measuring sensors in the houses with wood frame construction

In houses with wood frame construction, installing the sensors was very time-consuming, since the vapor barrier kept getting pierced and had to be reglued to be completely air-tight. Afterwards, the wall cladding was reinstalled.

The thermal insulation

Even though the building materials are different, all houses - except for the uninsulated house - were designed to have a U-value of 0.15 W/m2K (corresponding to the lowest approved energy standard). In order to achieve this uniform value, the different wall materials with their different thicknesses received thermal insulation. The house with type 50 bricks already had the thermal insulation integrated into the bricks and therefore received no additional external insulation.

Depending on the construction, the applied insulation thicknesses were between 6 cm and 20 cm. One house had insulation integrated into the wall structure and one house was not insulated.

Water-based underfloor heating system in all houses

Air supply and exhaust system

The heating and ventilation system

All research houses have a water-based underfloor heating system which is supplied by a boiler installed in the external technical room. The heating demand was determined by an energy meter. An air supply and exhaust system was installed in each research house. This meant that a predetermined air change in the houses could be set to simulate certain conditions of use (forced ventilation, continuous ventilation...).

The connections and data lines

In order to avoid the influence of electric fields on the air ion concentration, the electrical connections, sensors and heating system were housed in insulated, external equipment rooms. External distribution boxes were also constructed for the power supply and data lines from the measurement house to the individual research houses.

The houses in detail

From the outside, all 10 research houses look the same: They all have an interior area measuring 4 x 3 meters and are 2.83 meters high. Each one has a window and a door. Inside, they consist of one room without partitions. All of the houses have a comparable U-value (0.15 W/m2K). But their wall structures are completely different. There are houses made of concrete, brick houses, houses with and without integrated thermal insulation, houses with wood frame construction with gypsum plasterboard paneling, and there is a timber block house.

EXTERNAL THERMAL INSULATION COMPOSITE SYSTEM (ETICS)

A system for insulating the exterior walls of buildings. The structure consists of the type of attachment (glued and/or dowelled or a track system), an insulating material, a base layer of plaster (reinforced, in-wall) and a surface layer (top coat).

The wall structures

In addition to different construction methods, every house has a different wall structure. One of the goals of the research project was to test the influence of different wall structures, thermal insulation systems and interior coatings on factors such as temperature curves in the interior and exterior walls or moisture buffering. It was also necessary to find out how the various construction methods and materials behave in terms of VOC and formaldehyde outgassing, odors, air ions, sound and acoustics, radon and high-frequency electromagnetic fields.

The table provides a good overview of all the construction methods and materials used. Here, all houses with their wall structures, types of insulation and interior coatings are listed in detail. The wall thicknesses and insulation thicknesses are also listed.

House	Wall materials	Thickness of wall materials in cm	Insulation/ façade system	Insulation thickness in cm	Plaster systems	Wall paints
The wall structures of the research houses in Viva Research Park:						
1	Concrete	18	Baumit WDVS XS 022 with Baumit façade insulation panel XS 022	14	Dispersion filler Baumit FinoFinish	Dispersion paint Baumit Divina Classic
2	Concrete	18	Baumit open®air climate protection façade with Baumit open®air façade panel	20	Lime plaster Baumit KlimaPutzS	Special paint Baumit Ionit
3	Wienerberg Porotherm 25 N+F bricks	25	No insulation for Baumit MPA 35	0	Gypsum plaster Baumit GlättPutz	Dispersion paint Baumit Divina Classic
4	Wienerberg Porotherm 25 N+F bricks	25	Baumit open®air climate protection façade with Baumit open®air façade panel	18	Lime plaster Baumit KlimaPutzS	Mineral paint Baumit KlimaColor
6	Vario construction wood frame wall with gypsum plasterboard paneling	18	Baumit WDVS ECO with Baumit facade insulation panel ECO plus	6	No interior plaster, only gypsum plasterboard sheets	Dispersion paint Baumit Divina Classic
7	Vario construction wood frame wall with gypsum plasterboard paneling	18	Baumit WDVS ECO with Baumit facade insulation panel ECO plus	6	Gypsum plasterboard sheets + special plaster Baumit Ionit Spachtel	Special paint Baumit Ionit
9	Wienerberg Porotherm 50 W.i object plan (filled with mineral wool)	50	Insulation in bricks filled with mineral wool Baumit GrundPutz Leicht	0	Lime plaster Baumit KlimaPutzS	Mineral paint Baumit KlimaColor
10	Timber block house (solid house)	20	Baumit WDVS Nature with Baumit solid soft wood fiber panel	20	No interior plaster, only timber block wall	No interior coating

Ceiling and floor

The ceiling and floor structures are identical in all research houses. Both tables show the ceiling and floor structures. The description of the layer structure progresses from the interior to the exterior.

Ceiling structure of the research houses

Layer	Type of layer	Layer thickness (cm)
1	Gypsum plasterboard sheet	1,3
2	Air layer/support structure 5-layer vapor barrier aluminum-laminated Valutect	2
3	3-layer panel of wood insulation according to ÖNORM (Austrian standard) B2209 ALE 30KSK	10
4	Thermal insulation panel EPS W25 SF	26
5	Thermal insulation panel EPS W25 SF - gradient insulation	2-10
6	PVC waterproofing membrane	0,18
Ceilings - average total thickness for houses		**45.5**

Floor structure of the research houses

Layer	Type of layer	Layer thickness (cm)
1	Ceramic coating + adhesive	2
2	Heating screed	7
3	Rolljet	3
4	TSD EPS W30 5-layer vapor barrier aluminum-laminated Valutect	3
5	Reinforced concrete C25/30	20
6	Thermal insulation panel XPS Top 30 SF	16
7	Granular sub-base	5
8	Gravel layer	20
Floors - average total thickness for houses		**76**

PHYSICAL BUILDING SIZES

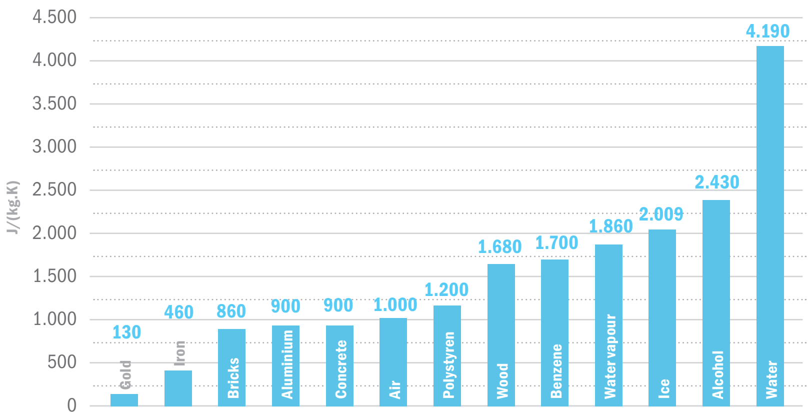
There are different physical parameters that are necessary in order to be able to analyze and compare the differences between the wall structures in terms of their heat storage behavior, their thermal conductivity and their moisture absorption capacity. Below is a short explanation of the most important parameters:

HEAT CAPACITY

The heat capacity describes how well a substance can store thermal energy. The specific heat capacity corresponds to the amount of heat needed to heat 1 kg of a substance by 1 °C. The unit of specific heat capacity is given in J/(kg.K).

Heat capacities of different substances

Specific heat capacities of different substances Source: Chemie.de

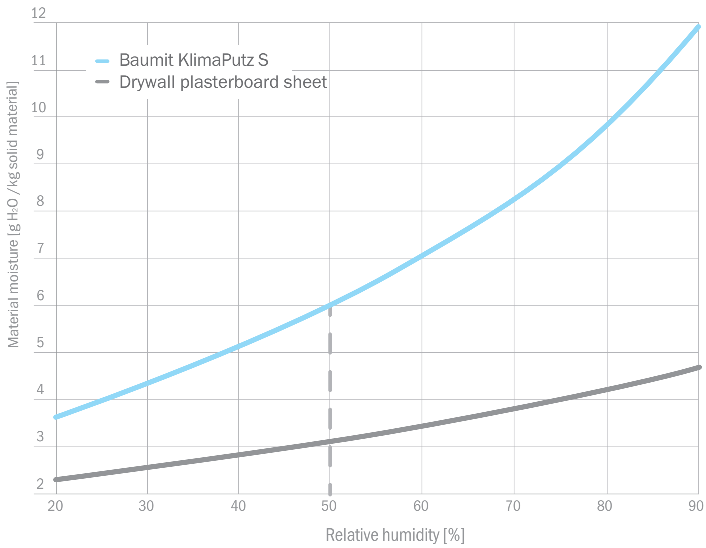


SORPTION ISOTHERMS

The sorption isotherms represents the material-specific relationship between the relative humidity and the moisture content of a material in its equilibrium state. This relationship makes it possible to determine the moisture content based on the relative humidity. The figure on page 34 illustrates the sorption isotherm for Baumit KlimaputzS and a gypsum plasterboard sheet. This demonstrates that, with a relative humidity of 50%, the gypsum sheet can absorb approximately 3.2 g water/kg of solid content, while Baumit KlimaPutzS can absorb approximately 6.0 g water/kg of solid content.

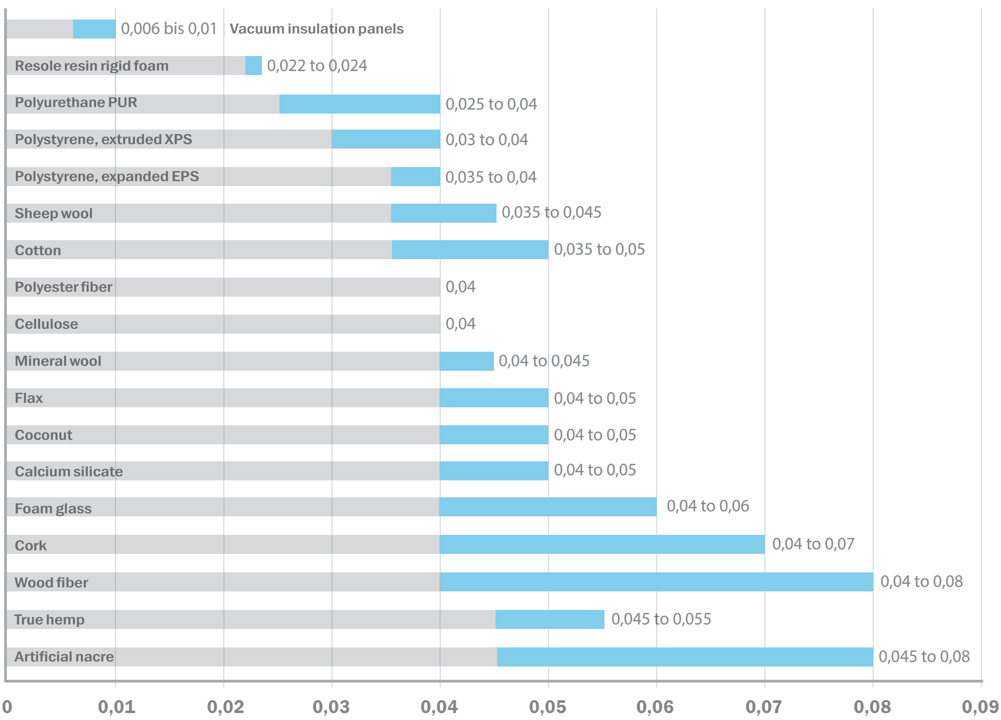
Sorption isotherms

from Baumit KlimaPutzS and a gypsum board, source: FH Burgenland



Thermal conductivity in λ (Lambda) of different insulation materials in W/(m • K)

Source: EnergiesparInfos.de



WATER VAPOR DIFFUSION RESISTANCE

The water vapor diffusion resistance (also known as vapor barrier value) expresses to what degree the diffusion of water vapor in the building material is prevented. The characteristic value for water vapor diffusion resistance is the water vapor diffusion resistance coefficient µ. This expresses the factor by which the material in question reduces the diffusion of water vapor in relation to an equally thick layer of air. The greater the water vapor diffusion resistance coefficient µ , the more vapor-tight the building material.

THERMAL CONDUCTIVITY

The thermal conductivity describes how well a material can conduct heat. Thermal conductivity A indicates the amount of heat which is con-ducted through 1 m2 of a 1 m thick layer if the temperature gradient is 1 K (1 °C).
The smaller the value of A, the better the insulating capacity of a building material.

Construction methods in Viva Research Park

The houses in Viva Research Park were constructed of concrete, solid brick, wood and with wood frame construction with gypsum plasterboard paneling; each received a variety of interior and exterior coatings.

Solid concrete houses

The two concrete research houses were built using in-situ concrete and precast concrete elements. Both houses were insulated.

Haus 1: Concrete + dispersion plaster + dispersion paint

House 1 was built of concrete. Only a dispersion plaster was applied as interior plaster; Baumit Divina Classic was used as wall paint. The Baumit façade insulation panel XS 022 was used as the exterior insulation material

Haus 2: Concrete + lime plaster + Baumit Ionit

House 2 was also built out of concrete. Here, Baumit KlimaPutz was used as interior plaster, while Baumit Ionit was applied as wall paint. For thermal insulation, the Baumit open®air façade panel was used.

Wall structure for House 1: Concrete + dispersion plaster + dispersion paint							
Wall structure	**Product**	**Wall thick-ness** s [cm]	**Density** [kg/m³]	**Specific heat capa-city*** c [J/kg K]	**Thermal conductivity** λ [W/(m K)]	**Water vapour diffusion resistance** μ [-]
Wall paint	Dispersion paint Baumit Divina Classic	0,02	1.600	800	0,7	100
Plaster system	Dispersion filler Baumit FinoFinish	0,1	1.300	800	0,7	50
Reinforced concrete	Reinforced concrete FT wall panel C30/37 B2	18	2.400	1.000	2,5	130
Adhesives	Baumit adhesive plaster and | Baumit KlebeAnker	1,5	1.200	1.000	0,8	50
Insulation	Baumit façade insulation panel XS 022	14	35	1.400	0,02	40
Plaster + textile glass mesh	Baumit Dickschicht-klebeSpachtel (primed with Baumit Premium Primer)	0,5	1.200	1.000	0,5	25
Exterior plaster	Baumit NanoporTop	0,2	1.800	1.000	0,7	25

Wall structure for House 2: : Concrete + lime plaster + Baumit Ionit						
Wall structure	**Product**	**Wall thick-ness** s [cm]	**Density** [kg/m³]	**Specific heat capa-city*** c [J/kg K]	**Thermal conduc-tivity** λ [W/(m K)]	**Water vapour diffusion resistance** μ [-]
Wall paint	Special paint Baumit Ionit	0,02	1.450	800	0,7	15
Plaster system	Lime plaster Baumit KlimaPutz S	2	1.050	960	0,4	7
Reinforced concrete	Reinforced concrete FT wall panel C30/37 B2	18	2.400	1.000	2,5	130
Adhesives	Baumit adhesive plaster and Baumit KlebeAnker	1,5	1.200	1.000	0,8	50
Insulation	Baumit open®air façade panel	20	15	1.450	0,03	7
Plaster + textile glass mesh	Baumit openKlebeSpachtel W (primed with Baumit Premium Primer)	0,5	1.350	1.000	0,8	18
Exterior plaster	Baumit NanoporTop	0,2	1.800	1.000	0,7	25

* Standard value

Solid brick houses

Three of the research houses in which measurements were taken are brick houses. One is made of type 25 bricks with external insulation, one of type 50 bricks with integrated thermal insulation, and one of type 25 bricks which remained uninsulated for research and comparison purposes - it corresponds to non-renovated older construction. Two other brick houses, the data measurement house (house 8) and a house for product tests (house 5) were not included in the research project.

House 3: Uninsulated brick + gypsum plaster + dispersion paint

House 3 is a special case among the houses in Viva Research Park. It was constructed as a brick house with type 25 bricks, but received no thermal insulation. The reason: The scientists wanted to analyze the behavior of buildings without thermal insulation when compared to an identically constructed building with thermal insulation (house 4). This construction method does not meet today's building standards. The interior coating used was a gypsum plaster plaster in combination with the wall paint Baumit Divina Classic.

House 4: Type 25 bricks + lime plaster + mineral paint

House 4 was built of type 25 bricks. Baumit KlimaPutz was used as interior plaster; the wall paint used was Baumit KlimaColor. The house was insulated with the Baumit open®air façade panel.

House 5: Type 25 bricks

In House 5, no comparative measurements were performed because it is used to test product developments (hence no wall structure table).

House 8: Type 25 bricks

House 8 serves as a central measurement house. This is where all of the collected data from the research houses was collected. Therefore, no comparative measurements were taken in this house, either (therefore no wall structure table).

House 9: Type 50 bricks + lime plaster + mineral paint

The wall structure of house 9 consists of type 50 bricks with integrated thermal insulation. As with houses 2 and 4, Baumit KlimaPutz was used as the interior plaster. Baumit KlimaColor was used as the wall paint.

Wall structure for House 3: Type 25 bricks, uninsulated+ gypsum plaster + dispersion paint						
Wall structure	**Product**	**Wall thick-ness** s [cm]	**Density** [kg/m³]	**Specific heat capacity*** c [J/kg K]	**Thermal conducti-vity** λ [W/(m K)]	**Water vapour diffusion resis-tance** μ [-]
Wall paint	Dispersion paint Baumit Divina Classic	0,02	1.600	800	0,7	100
Plaster system	Gypsum plaster BaumitGlättPutz	1,5	1.100	1.000	0,6	10
Type 25 bricks	Wienerberg Porotherm 25 N+F bricks	25	798	1.000	0,26	5–10
Exterior plaster	Lime cement plaster Baumit MPA 35	2	1.400	1.000	0,5	15
Façade paint	Façade paint Baumit Granopor-Color	0,04	1.640	800	0,7	225

Wall structure of house 4: type 25 bricks + lime plaster + mineral paint						
Wall structure	**Product**	**Wall thick-ness** s [cm]	**Density** [kg/m³]	**Specific heat capa-city*** c [J/kg K]	**Thermal conductivity** λ [W/(m K)]	**Water vapour diffusion resistance** μ [-]
Wall paint	Mineral paint Baumit KlimaColor	0,02	1.500	800	0,7	5–10
Plaster system	Lime plaster Baumit KlimaPutz S	1,5	1.050	960	0,4	7
Type 25 bricks	Wienerberg Porotherm 25 N+F bricks	25	798	1.000	0,26	5–10
Adhesives	Baumit open adhesive plaster W and Baumit KlebeAnker	1,5	1.350	1.000	0,8	18
Insulation	Baumit open®air façade panel	18	15	1.450	0,03	7
Plaster + textile glass mesh	Baumit open KlebeSpachtel W (primed with Baumit Premium Primer)	0,5	1.350	1.000	0,8	18
Exterior plaster	Baumit open Fascina	0,2	1.550	1.000	0,8	10

Wall structure of house 9: type 50 bricks + lime plaster + mineral paint						
Wall structure	**Product**	**Wall thick-ness** s [cm]	**Density** [kg/m³]	**Specific heat capa-city*** c [J/kg K]	**Thermal conductivity** λ [W/(m K)]	**Water vapour diffusion resistance** μ [-]
Wall paint	Mineral paint Baumit KlimaColor	0,02	1.500	800	0,7	5–10
Plaster system	Lime plaster Baumit KlimaPutz S	1,5	1.050	960	0,4	7
Type 50 bricks	Porotherm 50 W.i object plan (filled with mineral wool)	50	725	2.020	0,08	3,8
Base plaster	Baumit GrundPutz Light	1,6	1.200	1.000	0,4	15
Plaster + textile glass mesh	Baumit KlebeSpachtel (primed with Baumit PremiumPrimer)	0,5	1.300	1.000	0,8	18
Exterior plaster	Baumit open Fascina	0,2	1.550	1.000	0,8	10

* Standard value

Houses with woodframe construction with gypsum plasterboard paneling

Two houses in the research park were built with wood frame construction with gypsum plasterboard paneling. The two houses are insulated and their wall structures are identical; only the inner layers are different.

House 6: Woodframe construction with gypsum plasterboard paneling + gypsum plasterboard sheets with no interior plaster + dispersion paint

House 6 was built with wood frame construction with gypsum plasterboard paneling. Baumit façade insulation panel ECO plus was used for thermal insulation. The walls were painted with Baumit Divina Classict.

House 7: Woodframe construction with gypsum plasterboard paneling + gypsum plasterboard sheets with Baumit Ionit plaster + Baumit Ionit

House 7 was built with wood frame construction with gypsum plasterboard paneling. The Baumit façade insulation panel ECO was used as the thermal insulation. Baumit Ionit was used for the interior coating.

The timber block house

In order to explore the widest possible range of construction methods, a house made of solid wood with insulation was built in addition to the solid and framed construction methods.

House 10: Timber block wall - no interior plaster and no wall paint

Solid, five-ply glued squared timber in spruce and pine. In addition, wood fiber insulation panels were installed as thermal insulation. No coating was applied in the interior.

Wall structure for House 10: Timber block wall - no interior plaster and no wall paint

Wall structure	Product	Wall thickness s [cm]	Density [kg/m³]	Specific heat capacity* c [J/kg K]	Thermal conductivity λ [W/(m K)]	Water vapour diffusion resistance μ [-]
Timber block wall	Square timber in spruce and pine, with 5 layers of glue	20	500	1.600	0,13	50
Insulation	Pavatex pavawall Bloc wood fiber insulation	20	130	2.100	0,04	3
Plaster + textile glass mesh	Baumit Dickschichtklebespachtel (primed with Baumit Premium Primer)	0,6	1.200	1.000	0,5	25
Exterior plaster	Baumit CreativTop Trend	0,25	1.800	800	0,7	35–40

Wall structure for House 6: Wood frame construction with gypsum plasterboard paneling + gypsum plasterboard sheets with no interior plaster + dispersion paint						
Wall structure	**Product**	**Wall thick-ness** s [cm]	**Density** [kg/m³]	**Specific heat capa-city*** c [J/kg K]	**Thermal conductivity** λ [W/(m K)]	**Water vapour diffusion resistan-ce** μ [-]
Wall paint	Dispersion paint Baumit Divina Classic	0,02	1.600	800	0,7	100
Fire-retardant gypsum plasterboard panel	Variohaus System Energyline	1,8	680	960	0,25	10
PAE foil as a vapor barrier	Variohaus System Energyline	0,02	900	1.260	0,5	500.000
Mineral wool	Variohaus System Energyline	18	115	1.030	0,04	1
Engineered wood panel	Chipboard P5 EI	1,6	600	2.500	0,12	15–50
Adhesive + wooden dowels	Baumit SupraFix	1,5	1.300	1.350	0,8	50
Insulation	Baumit façade insulation panel ECO plus	6	15	1.450	0,03	35–80
Plaster + textile glass mesh	Baumit thick-layer adhesive plaster (primed with Baumit Premium Primer)	0,5	1.200	1.000	0,5	25
Exterior plaster	Baumit CreativTop Trend	0,25	1.800	800	0,7	35–40

Wall structure for House 7: Wood frame construction with gypsum plasterboard paneling + gypsum plasterboard panels with Ionit plaster + Ionit						
Wall structure	**Product**	**Wall thick-ness** s [cm]	**Density** [kg/m³]	**Specific heat capa-city*** c [J/kg K]	**Thermal conductivity** λ [W/(m K)]	**Water vapour diffusion resistan-ce** μ [-]
Wall paint	Special paint Baumit Ionit	0,02	1.450	800	0,7	15
Plaster system	Special plaster Baumit Ionit Spachtel	0,25	950	900	0,35	10
Fire-retardant gypsum plasterboard panel	Variohaus System Energyline	1,8	680	960	0,25	10
PAE foil as a vapor barrier	Variohaus System Energyline	0,02	900	1.260	0,5	500.000
Mineral wool	Variohaus System Energyline	18	115	1.030	0,04	1
Engineered wood panel P5	Chipboard	1,6	600	2.500	0,12	15–50
Adhesive + wooden dowels	BaumitSupraFix	1,5	1.300	1.350	0,8	50
Insulation	Baumit façade insulation panel ECO plus	6	15	1.450	0,03	35–80
Plaster + textile glass mesh	Baumit Dickschichtklebespachtel plaster (primed with Baumit Premium Primer)	0,5	1.200	1.000	0,5	25
Exterior plaster	Baumit GranoporTop	0,2	1.800	800	0,7	125

* Standard value

2.3. THE MEASUREMENTS

Comprehensive measurement data was collected around the clock in each Viva Research Park house. In the first two years of the project alone, more than 5 million data were measured and analyzed. The following parameters were examined:

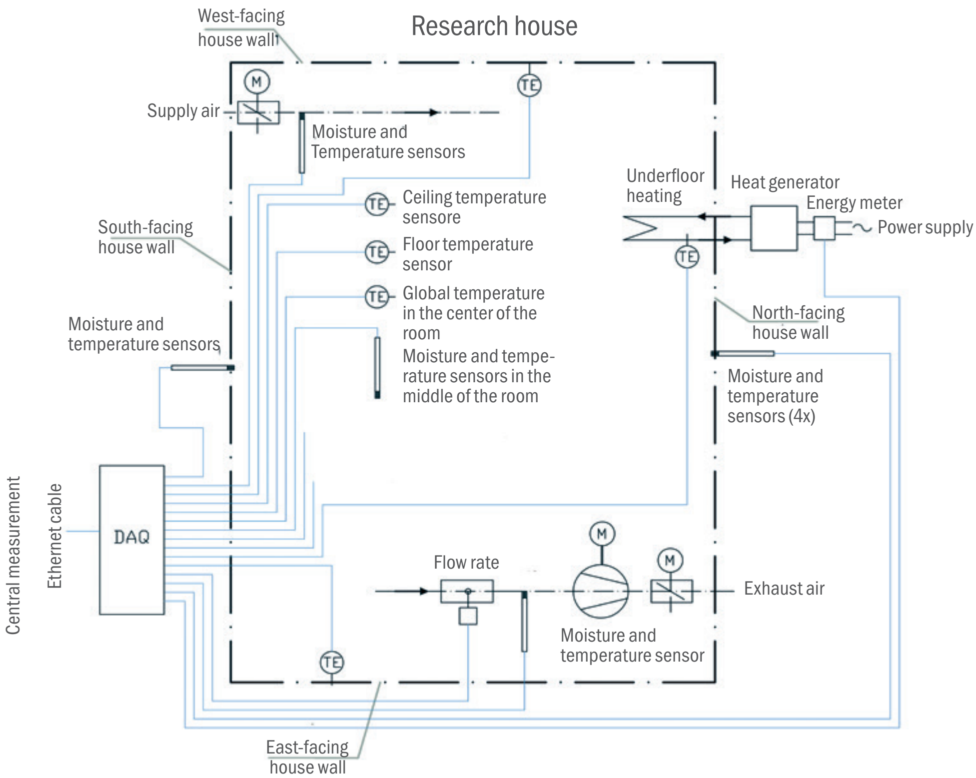
- Relative humidity of the interior air
- Interior temperature:
- Surface temperature
- Air ions
- Formaldehyde
- Volatile organic compounds (VOCs)
- Radon
- Odor
- Sound/Acoustics
- Moisture sorption of building materials
- Water vapor diffusion of building materials
- Attenuation of high-frequency electromagnetic fields

31 measurement sensors were installed in every house, which recorded all the relevant physical measured variables around the clock. All of this data was sent to the central data collection house (building 8) via Ethernet, where it was collected and then sent to FH Burgenland for detailed analysis. In addition to the research house data, scientists also surveyed the ambient conditions such as the outside temperature, outside air humidity, precipitation, wind speed and wind direction. They even measured the global radiation, diffuse radiation and UV radiation in four directions was measured.

The 31 measuring sensors per house in detail:	
Temperature combined sensor	11
Humidity combined sensor	11
Temperature PT 100	5
Temperature globe thermometer	1
Heating return flow temperature	1
Volume flow of exhaust air	1
Power consumption of boiler heating element	1
Total measuring sensors per research house	**31**

The measurement sensors in the research houses

The 31 measuring sensors are located between the exterior plaster, the thermal insulation and the wall structure, on the ceiling and the floor, and in



In addition to the ongoing data collection, punctual measurements (e.g. of VOCs, formaldehyde, sound parameters, odor, air ions, etc.) were also performed. After all of the data was evaluated by the interior analysis and building physics experts, the records were sent to the Medical University of Vienna, anonymized and transmitted by a notary so that no conclusions about the construction methods could be made in advance. The researchers at the Medical University analyzed the data in terms of health and comfort.

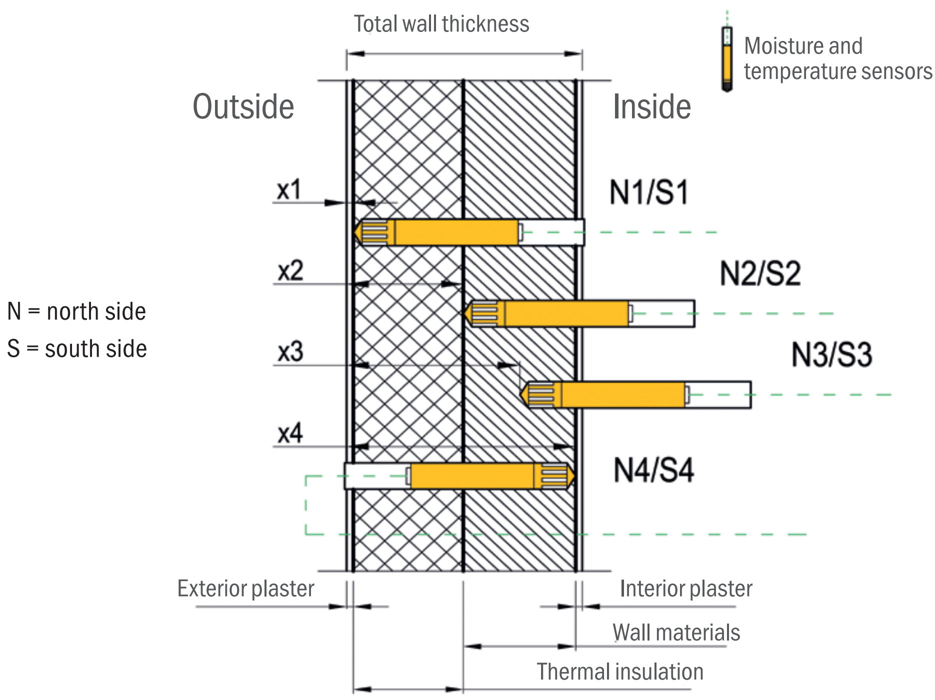
The measurements continued even after the first project phase was completed: on the one hand, long-term observations of various factors (such as VOCs, odors, moisture buffers, etc.) were performed, while on the other hand, new research projects (.e.g living comfort in Wilhelminian houses - the impact of thermal insulation) were and are constantly being started and implemented.

The measurement sensors

In order to record the hygrothermal properties, 4 moisture and temperature sensors were installed in the north and south walls in each of the research houses.

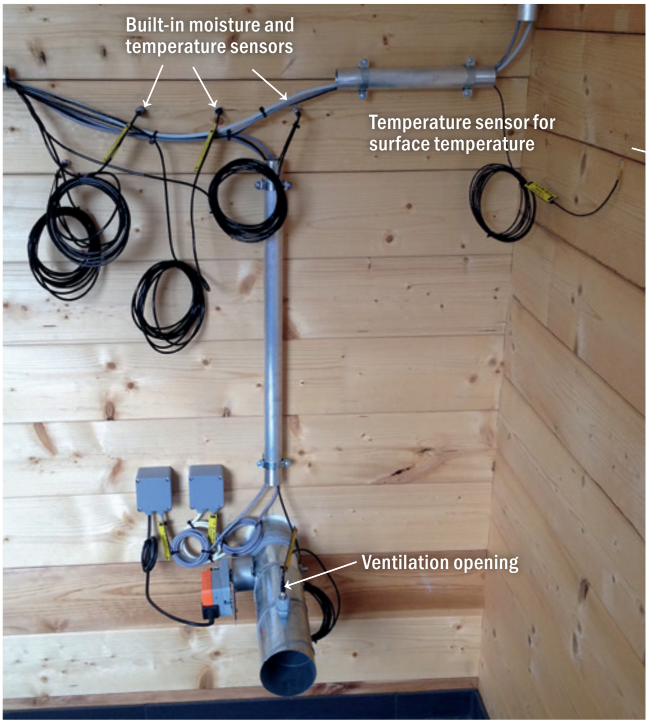
The moisture and temperature sensors

Arrangement of moisture and temperature sensors in the building wall



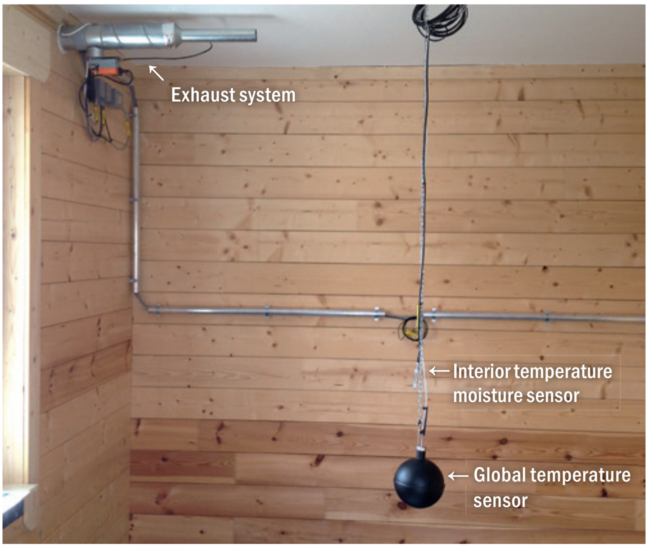
Sensor 1 is located between the exterior plaster and the thermal insulation. **Sensor 2** is located in the topmost layer of the wall structure. In order to record the moisture and temperature inside the wall structure, **Sensor 3** was positioned in the wall so that it was located in the middle of the wall structure. In order to determine the relative humidity and the temperature on the inside of the wall, **Sensor 4** was placed between the interior plaster and the wall structure.

In addition to determining the relative humidity and the temperature within the north and south-facing building walls, the interior surface temperatures of the east-facing and west-facing building walls were also recorded. Moreover, the surface temperatures on the ceiling and the floor of the research houses were also determined.



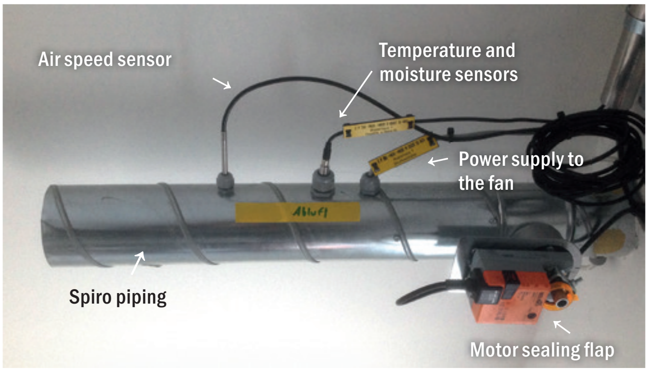
Moisture and temperature sensors in the building walls of the research houses

In addition to the sensors for examining the hygrothermic properties, the scientists also built additional moisture and temperature sensors into the buildings. For example, they placed a sensor in the center of the room with which the interior temperature and the relative indoor air humidity were recorded. In addition, the research houses were equipped with a sensor to record the global temperature. This sensor is built into a black ball and, in combination with an interior air temperature sensor, makes it possible to determine the operative room temperature. The operative temperature can also be called the "perceived" temperature.



Moisture and global temperature sensor (shown here in the timber block house)

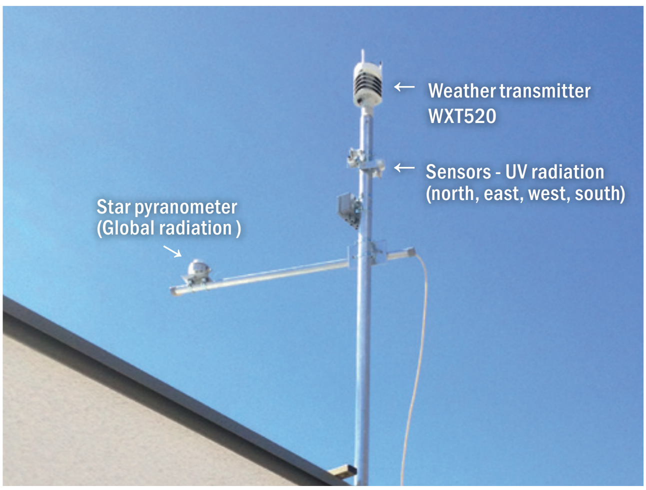
Furthermore, the experts investigated the **air ion concentration** in selected research houses. The positively and negatively charged air ions were measured with the help of the selected ionometer In addition, the sensors measured the **temperature and moisture of the supply and exhaust air.**



Exhaust air system of the research houses

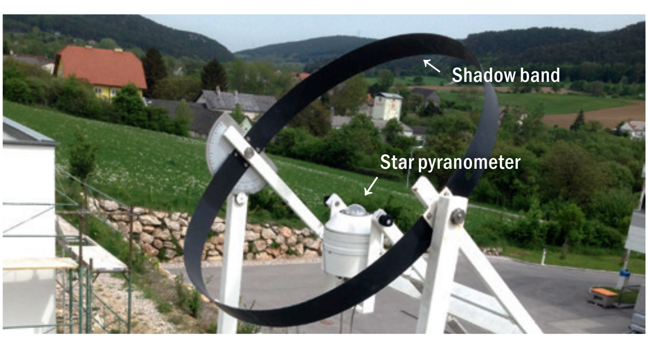
The **heating energy requirements** for every research house was detected using a three-phase energy meter. The interior temperature served as the control temperature for the underfloor heating system. In addition, the return temperature of the underfloor heating system also flows into the control strategy. For this purpose, a temperature sensor was attached to the return flow for the underfloor heating system.

A weather transmitter was used in order to **measure the environmental conditions.** With this measuring device, scientists were able to centrally record the air pressure, the outside air humidity, the outside air temperature, the wind speed and the wind direction. In addition, the weather transmitter records the amount of rainfall. The global radiation and the diffuse part of the global radiation were recorded with two star pyranometers which were installed on the roof of the research measurement house.



Weather transmitter and radiation meter on the roof of measurement house no. 8

The diffusion radiation was recorded with a **star pyranometer,** which was fitted with a **shadow band.** In order to ensure that only the diffused portion of the radiation was detected while the measurements were taken, the installed shadow band was readjusted every 2 days.



Star pyranometer with shadow band for measuring the diffuse radiation component of global radiation

GLOBAL RADIATION

Global radiation is understood to mean the total solar radiation arriving on a horizontal receiving surface on the earth's surface. It consists of direct solar radiation - direct radiation - and diffuse radiation, which reaches the Earth's surface by being scattered through clouds, particles of water and dust.

Cooking is one of the primary sources of moisture in the household, in addition to showers, and can have a significant effect on the interior humidity.

Operating the houses, or: how do you simulate user behavior?

How can you simulate user behavior if nobody is living in the research houses? This question posed particular challenges to the scientists.

„Of course we also considered allowing our houses to be inhabited by test groups,“ said Jürgen Lorenz, Head of Research and Development at Baumit. „But because we wanted to obtain scientifically reliable data, it was important to collect certain measuring factors under exactly the same conditions, which we could not have achieved if we had had subjects in the houses.“ This meant that the experts had to define parameters with which they could simulate the user behavior of a building.

Humans in homes breathe, produce moisture by cooking, showering, and washing, and in winter they heat their homes to make them comfortable. Therefore, the project needed measurable factors for these behaviors. To do so, the scientists decided to install a „mini ventilation system“ in each house to simulate a defined air supply and an air humidification system, as well as installing underfloor heating including an electricity meter.

For the two summer and winter operating scenarios, the experts specified exactly when and how often each house was ventilated and how much water was supplied by a humidifier.

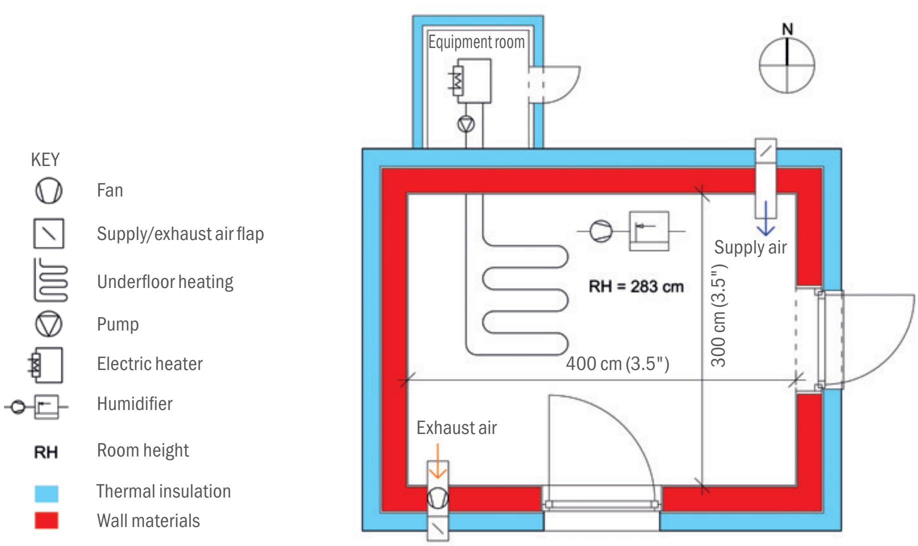
Ventilation

To ensure the specified ventilation rates, the scientists incorporated a „mini ventilation system“ with an air supply and exhaust system into all the research houses.

The operating scenario for ventilating the research houses was set so that multiple window ventilations per day were simulated. During the winter period, a ventilation cycle with a duration of 1.5 h each was performed in the morning and in the evening. During the summer period, this was adjusted from 2 to 3 ventilation cycles. This ensured that all of the room air was largely replaced during each ventilation cycle.

Ventilation and heating system:

The supply and exhaust air openings in the room were arranged to be diagonally offset. The defined air exchange rate was achieved by means of a fan which was integrated into the exhaust air opening.



Heating

Every research house was equipped with underfloor heating. The heat supply was provided via a water heater, which was located in an external equipment room. The equipment room was built on the outside of each research house in order to avoid influencing the air ion measurements. In winter, the heaters were set to a constant room temperature of 21 °C.

Equipment room with electric water heating

Humidification

In addition to the mechanical ventilation of the research houses, moisture was also regularly added to the interior air using humidifiers integrated into the building technology.

In order to determine the daily relevant amount of water vapor to be supplied, the following regularly occurring sources of moisture in a household were taken into account:

Humidification plan for the research houses	
Moisture source	**Emissions**
Persons	2.200 g/d
Plants	250 g/d
Cooking and dishwashing	600 g/d
Bathing, showering, personal care	600 g/d
Total quantity (for 130 m^2)	3.650 g/d
Total quantity for research house (for 12 m^2)	337 g/d

In order to simulate the use of the research houses (usable space of 12 m^2), exact humidification quantities per day were determined for the different humidity sources in a household. Source: FH Burgenland

Based on the average moisture emissions from these sources, the scientists specified a required humidification level of 3 x 110 g of water per day for each house to simulate the operation of the research houses.

Operating scenarios for the research houses, winter and summer				
Operating period	**Ventilation**	**Humidification**	**Room temperature**	**Heating mode**
Winter	2 x every1,5 h with 30 m³/h 06:00–07:30 22:00–23:30	3 x 110 g (= 3 x 25 min with 263 g/h) 08:00–08:25 12:00–12:25 18:00–18:25	21 °C	On
Summer	3 x every 1,5 h with 30 m³/h 06:00–07:30 22:00–23:30 02:00–03:30	3 x 110 g (= 3 x 25 min with263 g/h) 08:00 - 08:25 12:00–12:25 18:00–18:25	Dependent on the outdoor tempe-rature	Off

List of operating parameters according to the winter and summer periods

Scientific cooperation partners

In order to conduct and evaluate all of the different measurements, Viva Research Park need to involve project partners from a variety of scientific fields. This was the only possible way to thoroughly test the interactions of the individual building materials. For three years, a ten-member team of renowned scientists worked together in Viva Research Park. Jürgen Lorenz, Head of Baumit Research & Development: „The success of this project was due to the fact that many different scientific disciplines, such as construction, metrology, building physics and medicine, all cooperated on this interdisciplinary work. Something like this had practically never been done before.“

IBO Innenraumanalytik – Interior air quality experts

The Austrian Institute for Building Biology and Construction Ecology (IBO), interior air analysis department, is an expert on the interior air quality of apartments and houses. The Institute was responsible for interior climatology at Viva Research Park. Peter Tappler, Managing Director of IBO Innenraumanalytik OG: „For the first time, we directly collected valid data on pollutant emissions, odors, noise and electromagnetic fields as part of a major project. This allowed us to gain completely new insights into many different building structures.“ Over three years, IBO Innenraumanalytik OG has repeatedly measured and evaluated the VOCs (volatile organic compounds) and the formaldehyde emissions in the houses, while also performing elaborate odor tests. In addition, the IBO performed comprehensive sound and acoustic measurements and investigated the electromagnetic fields.

FH Burgenland – Building technology experts

FH Burgenland [the University of Applied Sciences of Burgenland] has been addressing the subject of building technology for a long time and is well-known for its comprehensive building and plant simulation expertise. „In Viva Research Park, we investigated the influence of the hygro-thermal behavior of building materials on the indoor climate and on thermal comfort,“ explained Christian Heschl, chair of the Master's program „Building Technology and Facility Management“ at FH Burgenland. "To do so, we measured the outdoor, room and material climates in the research houses and supported the interpretation of the measurement results using 'computational fluid dynamics' simulations."

AGES – Health and food safety experts

The Agency for Health and Food Safety GmbH (AGES) is a company based in the Republic of Austria and is an expert on the safety of humans, plants and animals. AGES performed the radon measurements in the houses at Viva Research Park.

MedUni Wien [Medical University of Vienna] – Housing and health experts

For many years, MedUni Wien has dealt scientifically with questions relating to the topic of „housing and health“. In the research houses, they investigated the combination of the factors influencing each of the „housing units“. As part of a so-called comparative indoor air quality (IAQ) analysis, the individual „factor bundles“ of each building type (indoor climate factors, air ions, VOCs, particles, sound and odor) were assessed in terms of their effects on health and well-being from a healthy living perspective.

3. VIVA THE MEASUREMENT RESULTS

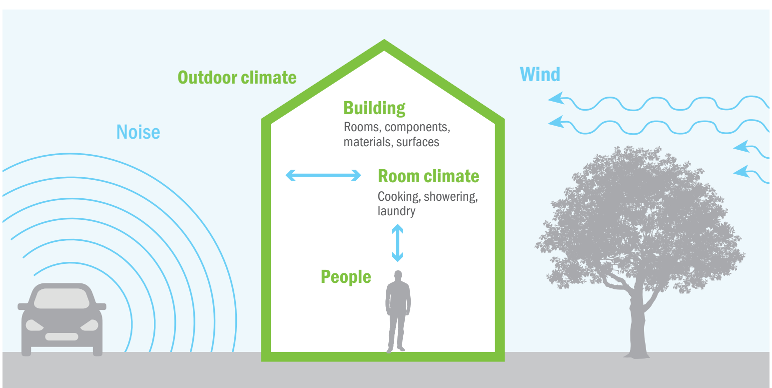
BUILDING PHYSICS, BUILDING CHEMISTRY AND HEALTH

3

Building physics defines the technical requirements of buildings in terms of heat, moisture or sound insulation, thus addressing topics such as the room climate, lighting or sound and acoustics.

In recent decades, building physics considerations have increasingly been incorporated into the design and construction of buildings, as the construction of a building is always balanced between architectural, functional and aesthetic requirements while also being limited by the properties of the available material and the fundamental laws of physics. These fundamental laws include all interactions that occur between the building and the interior or exterior.

Interactive effects between interior and exterior spaces



There are many factors that affect a building: From the outside, for example, these include factors such as street noise, wind and the outdoor climate; from the inside, these include people, furnishings, walls and the room climate.

Over five million data were analyzed to achieve the results of the first project phase in Viva Research Park. **Scientists were able to gain numerous new insights in the following areas of building physics and construction chemistry:**

- Room climate
- Interior air quality
- Sound insulation and room acoustics
- High-frequency electromagnetic fields
- Health and comfort

3.1. ROOM CLIMATE

The room climate of a building has a decisive influence on our health. Essential conditions for a comfortable and healthy living environment are the room temperature and the relative humidity. Depending on their level of activity and clothing, people feel most comfortable at a relative humidity of between 40 and 60% and a room temperature between 20 and 22 °C.

The operative temperature

How warm or cold we feel in a room depends on the operative temperature (perceived temperature), which is determined by two factors: the air temperature and the surface temperature (radiation).

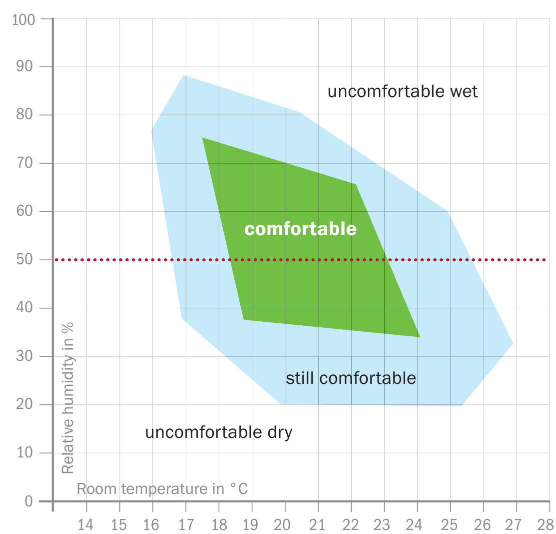
Air temperature and surface temperature

Air temperature is the temperature of the air that surrounds people in a room. It is measured in the middle of the room at a height of about one meter above the floor. The surface temperature, on the other hand, refers to the temperature of the enclosing surfaces - such as walls, ceilings, floors or furniture. It is partly influenced by the prevailing outdoor temperature and partly by the thermal conductivity of a building material. The smaller the value for thermal conductivity A, the better the thermal insulation capacity of a building material.

Criteria for a feeling comfortable in a living space:

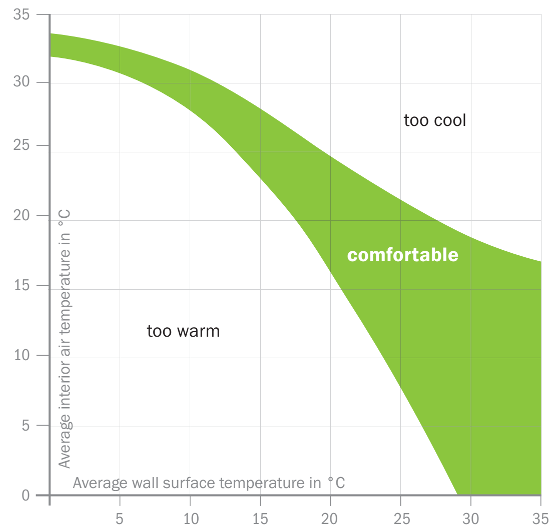
Not too cold and not too warm. Not too dry and not too humid. For a healthy room climate, room temperatures between 20 and 22 ° C are ideal during the colder months.

The maximum building physics for the relative humidity to avoid condensation and mildew during the colder months of the year is between 45 and 50%.



Building physics upper limit for relative humidity during the colder months of the year: 45 to 50%

With very good thermal insulation properties, the achievable surface temperatures of the exterior walls are close to the room air temperature during the colder months. However, If the thermal insulation is poor, the surface temperatures in winter are still far below the room air temperature, even after the heater has been on for a longer period of time. This noticeably impacts comfort: Because the surface temperature of the exterior walls decreases by one degree Celsius as a result of the lower outdoor air temperature, we perceive this as a reduction in the room air temperature. In order to compensate, we turn the heat up higher.



When is it comfortable?

The comfortable range is very narrow. If the wall surface temperature increases, the room air temperature can be lowered.

Most people feel comfortable when the average of the air temperature and the surface temperature is above 20 to 22 °C. At the same time, the difference between the air temperature and surface temperature and the temperature difference between the floor and the ceiling should not exceed 4 °C.

If the surface temperature of a building is increased by improved thermal insulation, the body‘s heat output is reduced due to heat radiation while the air temperature remains constant. The cooling of the interior air near surfaces is reduced. The formation of layers of cold air on the floor is suppressed. Comfort increases without requiring the expenditure of additional heating energy.

What temperature for which room?

Room	Optimal temperature
Living spaces and working spaces	20 – 22 °C
Bedrooms	17 – 18 °C
Children's rooms	20 – 22 °C
Kitchen	18 °C
Bathrooms	23 °C
Basements	10 – 15 °C

Ideally, the room temperature is between 20 and 22 °C. In the summer, this can be significantly warmer due to the warm outdoor air.

WHAT IS THE „U-VALUE“?

The U-value (also called the heat transfer coefficient) is a unit measuring the transmission heat losses of a wall. The U-value describes the quantity of heat per second and square meter of wall surface that is lost when the room temperature is one degree higher than the outdoor temperature.

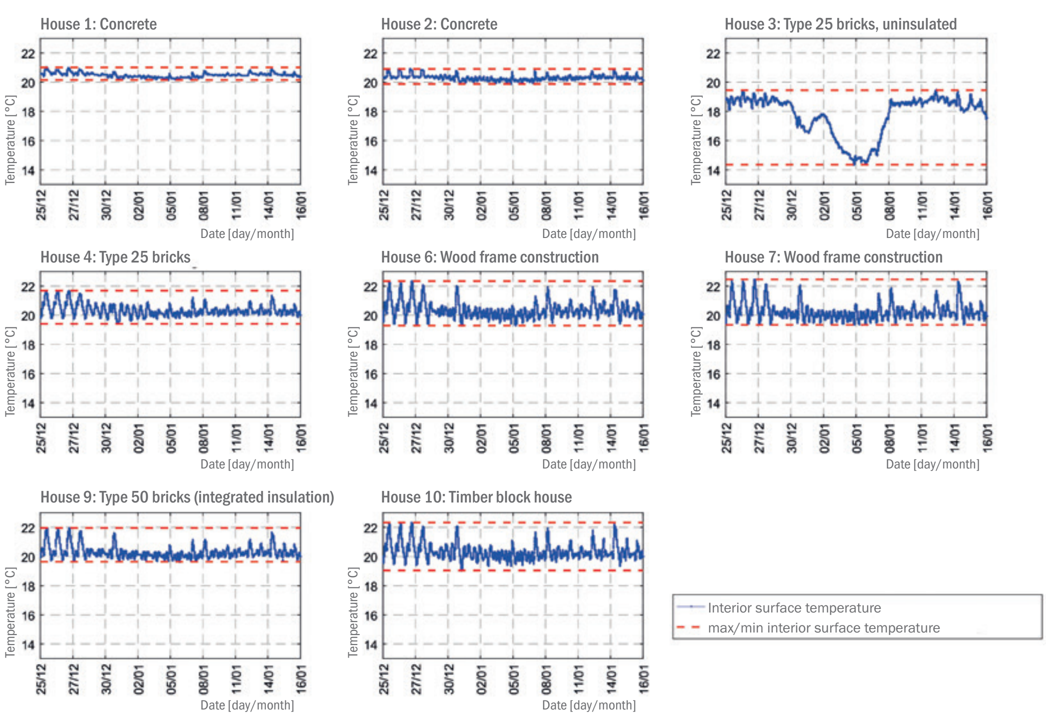
Effects of surface temperature fluctuations

Concrete houses have the least amount of variation in the interior surface temperature of the exterior walls in both winter and summer. This means that these homes create the most balanced room temperature. Uninsulated houses have the highest fluctuation of interior surface temperatures. Such houses also demonstrate room temperatures that fluctuate more than in any other house.

The surface temperature of the walls has a powerful effect on the operative room temperature. But what effect does the construction have on surface temperature fluctuations in the different seasons, and what role does thermal insulation play in this? Scientists investigated these questions in Viva Research Park and analyzed the measurement data from all research houses during one winter period and two summer periods.

Fluctuations in the interior surface temperature of the exterior walls in winter

Measurements during the winter period: The uninsulated brick house (House 3, non-renovated older construction) demonstrated the strongest fluctuations of the interior surface temperature of the exterior walls; the two concrete houses (Houses 1 and 2) showed the lowest fluctuations. Source: FH Burgenland

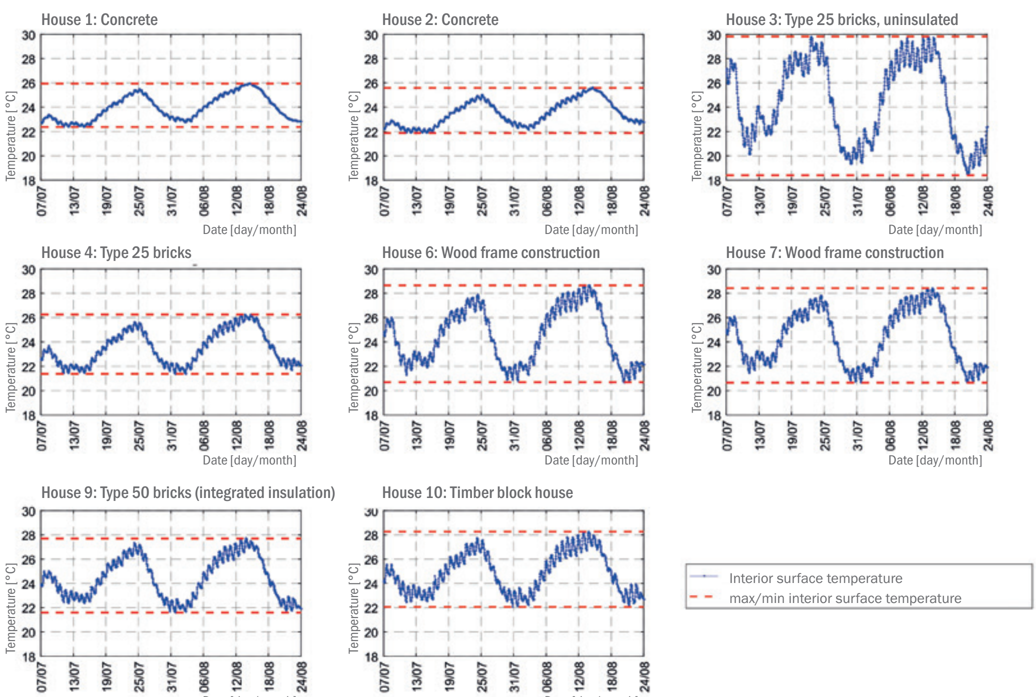


In the winter, the curves of the interior surface temperature of the exterior walls clearly showed that the smallest temperature fluctuation of 1 °C occurred in the concrete houses. In the case of the wood house and in both houses with wood frame construction, the temperature variation was 3 °C.

The surface temperature profiles of the two analyzed summer periods showed similar results as during the winter. Here, too, the smallest temperature fluctuations occurred at around 4 °C in the concrete houses. In contrast, the variation in surface temperature in houses with wood frame construction was 8 °C. Since all houses (with the exception of the uninsulated house) have a similar U-value (11 = 0.15 W/m²K), this higher fluctuation of the surface temperature is related to the lower heat storage capacity of the house with wood frame construction as compared to the concrete house.

Fluctuations in the interior surface temperature of the exterior walls in summer

Measurements during the summer periods: Once again the uninsulated brick house (House 3, non-renovated older construction) demonstrated the strongest fluctuations of the interior surface temperatures. Equally, the two concrete houses (Houses 1 and 2) once again showed the lowest fluctuations. Source: FH Burgenland



Fluctuations in the interior surface temperature of the exterior walls by house type		
House	**Wall structure**	**Fluctuations in the interior surface temperature of the exterior walls**
1	Concrete + dispersion plaster + dispersion paint	low
2	Concrete + lime plaster + special Ionit paint	low
3	Type 25 bricks, uninsulated+ gypsum plaster + dispersion paint	very high
4	Type 25 bricks + lime plaster + mineral paint	average
6	Wood frame construction with gypsum plasterboard paneling + gypsum plasterboard sheets, no interior plaster + dispersion paint	high
7	Wood frame construction with gypsum plasterboard paneling + Ionit plaster + special Ionit paint	high
9	Type 50 W.i object plan (filled with mineral wool) + lime plaster + mineral paint	average
10	Timber bock wall - no interior plaster and no wall paint	average

The fluctuations in the interior surface temperatures of the exterior walls are the lowest in the concrete houses. They are strongest (except for in the uninsulated house) in the houses with wood frame construction. Source: FH Burgenland

The evaluations of the interior surface temperatures of the exterior walls clearly show that insulated houses have lower surface temperature fluctuations. In addition to building insulation, it is apparent that a solid construction - especially concrete - performs particularly well in both winter and summer.

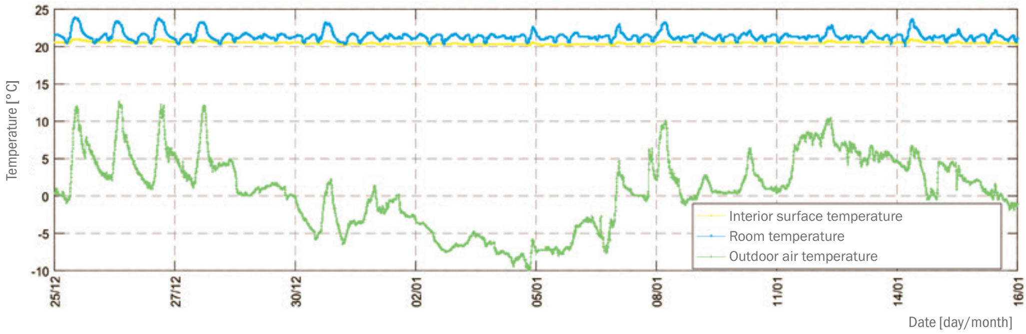
Why does an uninsulated house cool down so quickly?

To get to the bottom of this question, the scientists compared the interior surface temperature profiles of the exterior walls for uninsulated brick house 3 with those of concrete house 1, also comparing room temperature and outdoor air temperature.

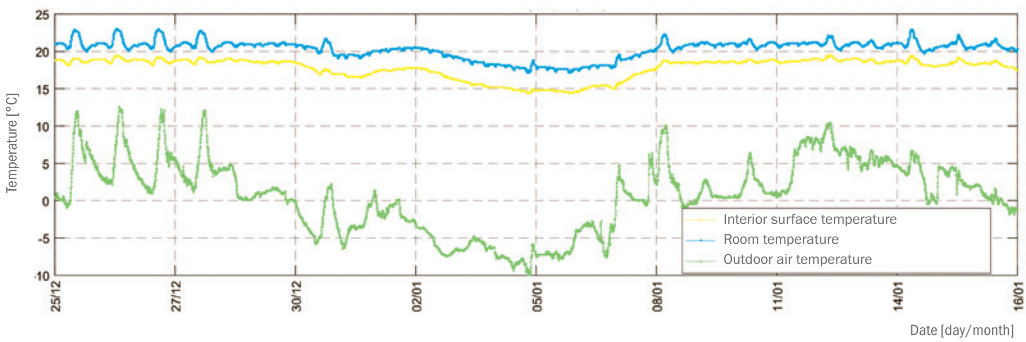
Fluctuations in the interior surface temperature of the exterior walls

Comparison of surface temperature development and outdoor temperature development in the uninsulated house and in the insulated concrete house. Source: FH Burgenland

House 1: Concrete



House 3: Type 25 bricks, uninsulated



What is striking is that the surface temperature of the uninsulated house during the entire measurement period fell well below the room temperature. In contrast, the difference between surface and room temperature was much lower for the concrete house. In addition, the surface temperature of the uninsulated house is strongly linked to the outdoor temperature. When the outdoor temperatures dropped sharply, House 3 was no longer able to reach the set room temperature of 21 °C for a period of several days due to the lack of thermal insulation. This resulted in the significant cooling of all surfaces.

Room temperature development during the different seasons

How does the room temperature of each individual research house behave during the summer, the winter and during the transitional periods? And what effect does insulation have?

In order to be able to answer these questions, the scientists at Viva Research Park spent over two years evaluating the temperature developments in all of the houses. Here are your results:

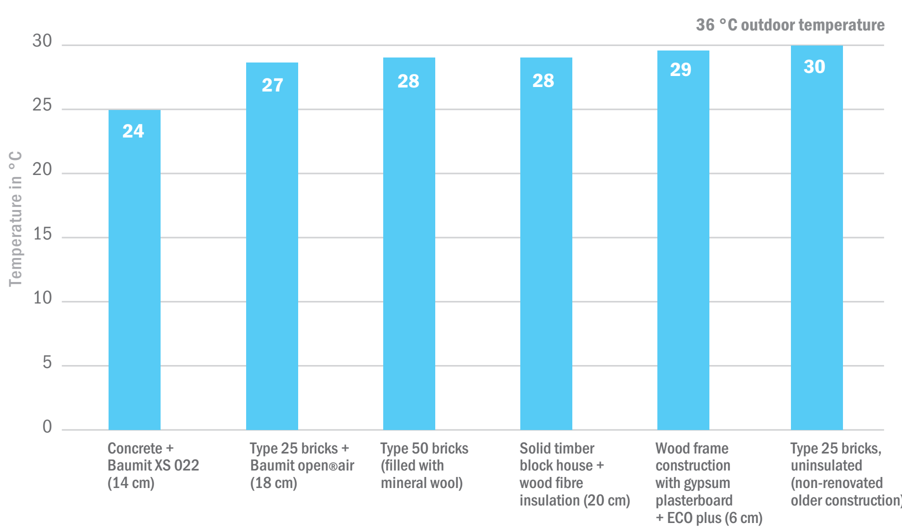
» Temperature development during the summer

In tropical heat, insulated houses keep the room temperature at tolerable levels. Solid buildings support the cooling effect and ensure more constant room temperatures.

The long-term measurements in Viva Research Park clearly showed: Insulation protects against summer overheating. Even in heat spells with outdoor temperatures of up to 36 °C, the room temperatures in the insulated solid houses made of type 25 bricks and of concrete were between 24 °C and 27 °C. In the uninsulated house (older construction, type 25 bricks with no insulation), however, it was tropically warm at 30 °C. In addition to the insulation, the storage mass of the wall structure also has a decisive influence on the room temperature. Solid walls provide more constant room temperatures and create a cooler and more comfortable indoor climate in summer.

Temperature development in research houses at high temperatures (36 °C)

At outdoor temperatures of up to 36 °C, the interior temperatures of the insulated solid concrete and type 25 bricks with external insulation remained between 24 °C and 27 °C. The insulated house reached a room temperature of 30 °C.



» Temperature development during the transitional periods

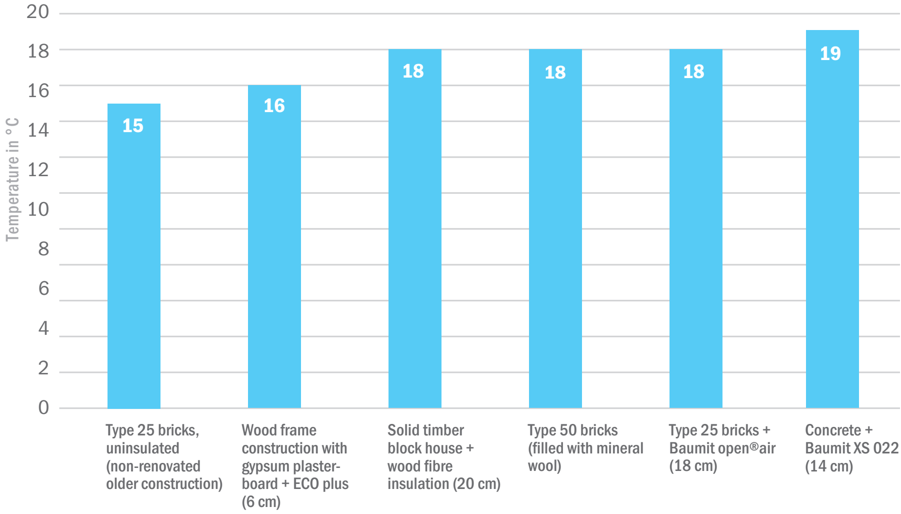
Insulated solid houses can store energy better and return it to the room air in the event of a drop in temperature. This ensures stable room temperatures for longer periods of time.

In which houses does it stay warm the longest during the transitional period in autumn or spring without heating? In fall 2016, the scientists at Viva Research Park performed comprehensive measurements in all research houses. The results showed that the insulated solid brick and concrete houses can save energy for a longer period of time due to their solid construction.

What was surprising was that the timber block house was also able to retain its interior temperature well. This was due to the high specific mass and the high specific thermal capacity of the wood material. The uninsulated brick house (older construction, type 25 bricks) had an interior temperature of 15 °C after only a few cool nights. However, the insulated concrete and brick houses retained a room temperature of 18-19 °C, even after several cool nights.

Temperature development in the research houses during the transitional periods

During the transitional period, the solid brick and concrete houses as well as the wood log cabin were able to retain heat for the longest amount of time. The houses which cooled down the fastest were the wood-frame construction houses and the uninsulated house.



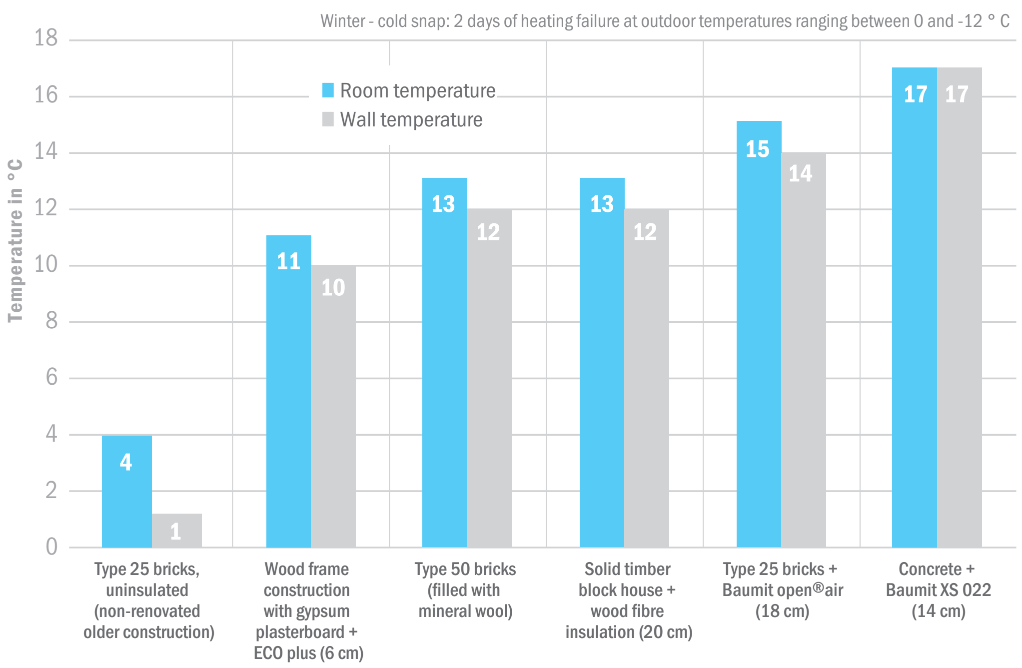
» Temperature development during the winter

In the event of a heating failure during the winter lasting for 48 hours, an insulated solid house retains a tolerable room temperature. In uninsulated houses (older construction), the internal temperature drops to very low values in the event of a heating failure.

How quickly do the wall structures of the research houses cool down in freezing temperatures? In order to answer this question, the scientists simulated a heater failure and turned off the electricity and heaters in all houses for 48 hours. What happened next also surprised the experts, as the differences in the heat storage capacity of the individual wall structures were striking. This meant that the uninsulated brick house (older construction, type 25 bricks) demonstrated a room temperature of only 4 °C and a wall temperature of 1 °C after 2 days. The insulated solid houses (Type 25 bricks or concrete) retained values between 14 and 17 °C for room and wall temperatures after 48 house without heating.

Temperature development in the research houses - cold snap

Temperatures after a heating failure: When the heating failed at outdoor temperatures of 0 to -12 °C for 48 hours, the insulated type 25 bricks and insulated concrete houses retained room and wall temperatures best. The uninsulated brick house (older construction, type 25 bricks) performed the worst.



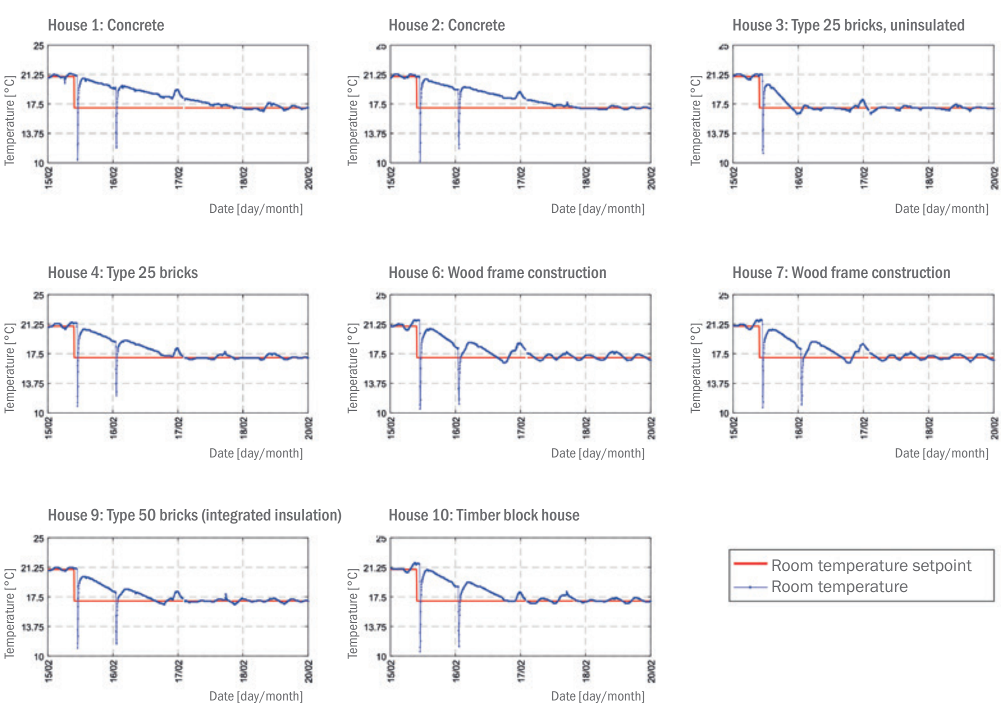
Cooling and heating behavior of wall materials

The storable mass of wall material has a clear effect on its cooling and heating behavior. The following applies here: Wall materials with higher storage mass, such as bricks or concrete, cool down slowly but also do not heat up quickly. On the other hand, wood frame construction houses with gypsum plasterboard paneling cool down quickly due to the lower mass, but they also regain heat quickly.

The scientists at Viva Research Park conducted a variety of test scenarios to gain meaningful insights into the heating and cooling behavior of the various wall materials. For example, in spring 2016 for 13 days, they lowered the setpoint for the room temperature in all houses from 21 to 17 ° C What happened?

Which house cools the fastest?

Temperature curves in room temperature: How quickly does the room temperature in the individual houses change when the heating setpoint drops from 21 to 17 °C? Source: FH Burgenland



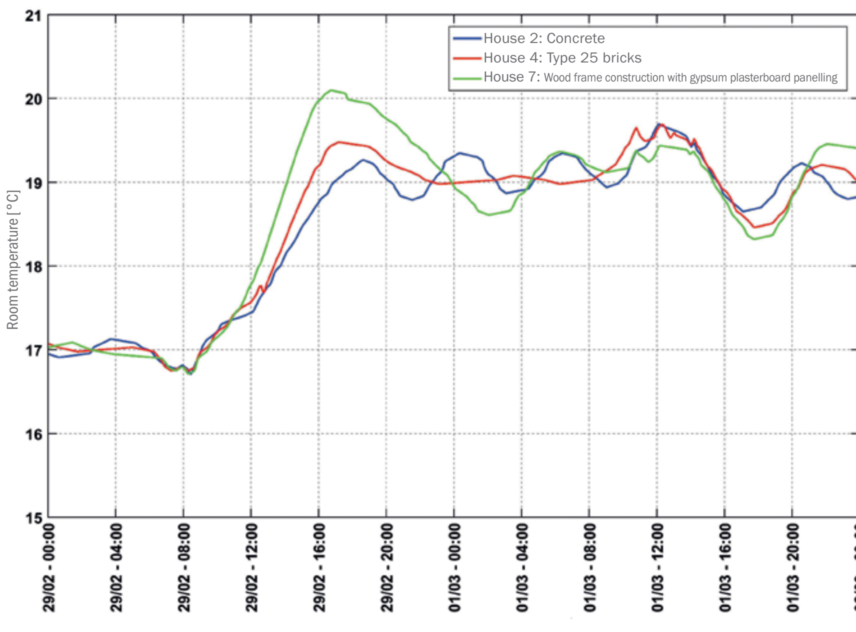
The thermally insulated brick and concrete houses cooled the slowest. The uninsulated house (type 25 bricks, older construction), however, had a room temperature of 17 °C after only one day.

The effect was reversed when the wall materials were heated: In this scenario, it was assumed that the residents spent a week on winter vacation, setting the room temperature setpoint to a constant 17 °C. How quickly would the individual houses heat up again after their return? The scientists compared the measured room temperatures of a concrete house (House 2), a brick house (House 4) and a wood frame construction house with gypsum plasterboard paneling (House 7).

The temperature curves showed that the concrete house heated up the slowest, followed by the brick house. The room temperature in the wood frame construction house with gypsum-plasterboard paneling rose the fastest.

Which house heats up the fastest?

Heating behavior: The concrete house (House 2) was the slowest to heat. The temperature of the wood frame construction house with gypsum plasterboard paneling (House 7) rose the fastest. Source: FH Burgenland



Interior humidity and its effect on health

In order to feel comfortable indoors, you also need the right amount of humidity in addition to the right room temperature. We perceive a comfortable room climate within a relative humidity range between 40 and 60%. Low humidity - less than 30% - causes the mucous membranes of the nose and throat to dry out, as well as the conjunctiva. Furthermore, wood floors or furniture also experience increased drying - and dust is also promoted at low levels of humidity. In addition, bacteria and viruses can remain suspended in dry air for longer periods of time. This and the dehydration of the mucous membranes increases the risk of infection for humans and animals.

If the humidity is too high, the moisture released into the room can no longer be adequately absorbed by the air. Moisture condenses on walls and in cool room corners, especially during the colder months, and can lead to mold growth and damage to building components. In winter, therefore, the relative humidity should not permanently exceed a value between 45 and 50% (depending on method of construction and age). Humans themselves add the most moisture to living areas. For example, for a Viva Research House, 3.65 liters was calculated for one household's worth of cooking, showering, breathing, drying clothes and green plants.

Excessive humidity can create serious adverse health effects. In a representative housing survey1) in Germany, for example, scientists found that there are numerous correlations between moisture damage in apartments and health impairment. Visible moisture damage was present in 22 percent of the 5,530 homes inspected. The presence of moisture damage increases the risk of developing asthma by 50% and the risk of developing allergies by 30%.

[1)] Brasche et al.: Occurrence, causes and health aspects of moisture damage in residences - Bundesgesundheitsblatt- Gesundheitsforschung- Gesundheitsschutz 46, 2003

Relative humidity

Air cannot absorb water indefinitely. The absolute humidity indicates how many grams of water are present in one cubic meter of air. The relative humidity is the actual water vapor content in relation to the physical maximum capacity. For example, if the maximum were 20 g/m^3, but if only 10 g/m^3 is present in the room's air, the relative humidity is 50 %.

Generally applicable: The higher the temperature, the more water the air can absorb. However, the correlation is not linear. As the temperature rises, there is a massive increase in the maximum possible quantity of water vapor in the air. If the maximum value of the absolute humidity at 0 °C is just under 5 g/m^3, the value at 30 °C is 30 g/m^3.

Like any other gaseous substance, water vapor exerts pressure on its environment. This depends on the amount of vapor and the temperature. As long as the water vapor partial pressure is lower than the saturation vapor pressure, the water remains in a gaseous state. If the amount of water vapor and thus the vapor pressure increases, the counter-pressure can no longer prevent the tiny vapor droplets from combining to form larger droplets. The excess moisture is excreted and condenses.

RELATIVE HUMIDITY

The relative humidity is calculated as follows:

$$\varphi[\%] = \frac{\text{Partial pressure of water vapor} \times 100\ \%}{\text{Saturation vapor pressure of the water vapor}}$$

The relative humidity is the ratio between the actual water vapor pressure in the air and the maximum possible vapor pressure.

Effect of interior plaster materials on interior air humidity and room climate

Interior plaster have a noticeable moisture-buffering effect. In houses with interior plaster (with lime and lime cement bases), the fluctuations in relative humidity are more strongly damped - the room climate is more balanced.

How well can different wall structures store moisture, and what are the effects of interior plaster and wall paints? To answer these questions, scientists at Viva Research Park performed special indoor humidity measurements for 2 weeks. Depending on the season, all houses received added moisture 3 times per day (per 110 g water) and were ventilated 2-3 times per day (per 30 m^3 for 1.5 hours). The results of the measurements clearly showed: mineral, diffusion-open interior coatings have a noticeable moisture-buffering effect and ensure a more balanced room climate. This means that the fluctuations in the relative humidity of the interior air in the houses coated with Baumit Klima-Putz were lowest - regardless of their construction. The excellent moisture buffering capacity of the solid wood house should also be noted.

Which houses buffer interior humidity best?

House	Wall materials	Cleaning systems	Wall colours	Buffering interior humidity
2	Concrete	Lime plaster Baumit KlimaPutzS	Special paint Baumit Ionit	high
4	Wienerberg Porotherm 25 N + F bricks	Lime plaster Baumit KlimaPutzS	Mineral paint Baumit KlimaColor	high
9	Wienerberg Porotherm 50 W.i object plan (filled with mineral wool)	Lime plaster Baumit KlimaPutzS	Mineral paint Baumit KlimaColor	high
10	Timber block house (solid house)	No interior plaster, only timber block wall	no wall paint	high
7	Vario construction wood frame wall with gypsum plasterboard paneling	Gypsum plasterboard sheets + special plaster Baumit Ionit Spachtel	Special paint Baumit Ionit	average
1	Concrete	Dispersion filler Baumit FinoFinish	Dispersion paint Baumit Divina Classic	low
6	Vario construction wood frame wall with gypsum plasterboard paneling	No interior plaster, only gypsum plasterboard sheet	Dispersion paint Baumit Divina Classic	low
3	Wienerberg Porotherm 25 N+F bricks, uninsulated	Gypsum plaster BaumitGlättPutz	Dispersion paint Baumit Divina Classic	low

Interior plasters buffer moisture: all houses with Baumit KlimaPutzS were able to buffer humidity very well Source: FH Burgenland

Moisture buffer capacity of plaster over concrete

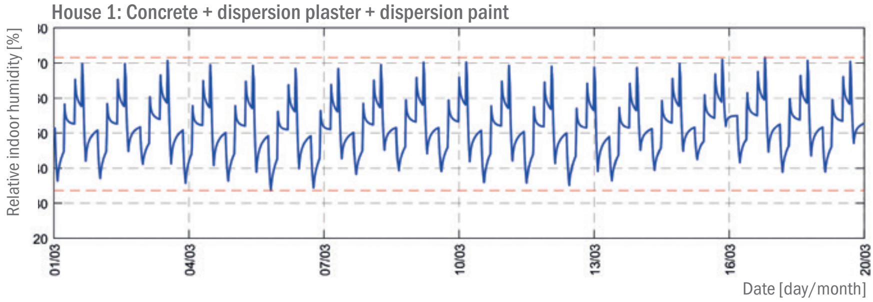
Concrete is one of the most commonly used building materials in residential construction. However, the moisture buffering capacity of concrete is low compared to other building materials. Just a thin, 1.5 to 2 cm layer of interior putty containing lime significantly improves the room climate. Mineral, vapor-permeable interior plasters buffer moisture. This applies to all common wall types - including concrete walls.

Can the use of interior plaster on concrete improve the moisture buffering capacity - and thus the room climate - in concrete houses? The scientific research in Viva Research Park resulted in surprising conclusions: For example, the concrete research house coated with Baumit KlimaPutz and Baumit Ionit exhibited a constant relative humidity of 40 to 60% - perfectly corresponding with the comfort range. The concrete house coated with only a thin layer of dispersion plaster, however, repeatedly exceeded or fell below comfort levels. This means that the humidity in this building had far greater fluctuations and was always either too low or too high.

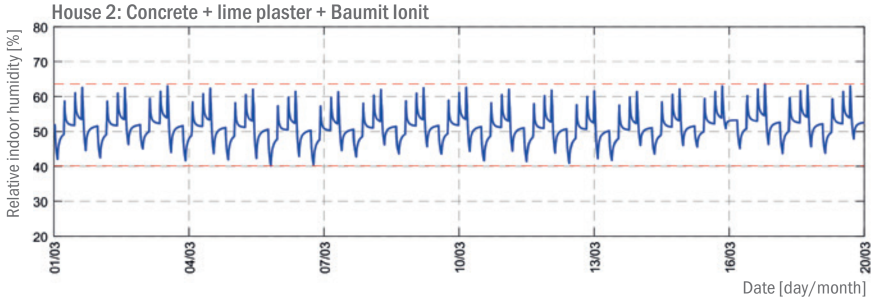
Comparison of moisture buffering with and without Baumit KlimaPutz S

Interior humidity and Baumit KlimaPutz S: Research house 2 with Baumit KlimaPutz S and Baumit Ionit ensured constant relative humidity in the optimum comfort range of 40 to 60%. On the other hand, research house 1, which only received interior dispersion paint, repeatedly exceeded or exceeded comfort levels. The air was always too dry or too humid. Source: FH Burgenland

House 1: Concrete + dispersion plaster + dispersion paint



House 2: Concrete + lime plaster + Baumit Ionit

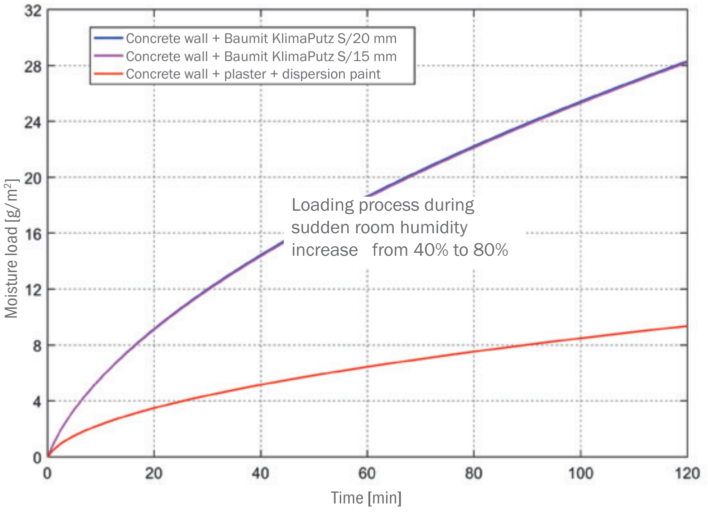


In order to be able to analyze the moisture buffering capacity of different coatings and layer thicknesses, special tests were performed in Viva Research Park.

How fast can how much moisture be buffered?

With a sudden increase in relative humidity from 40% to 80% (due to showering or boiling water, for example), a concrete wall with Baumit KlimaPutz S can store more than twice as much moisture in two hours as a concrete wall only coated with plaster and interior dispersion paint. During this period, there was no difference in moisture loading between the 15 and 20 mm thick layers of plaster (see figure). Source: FH Burgenland

Loading process during sudden room humidity increase from 40% to 80%

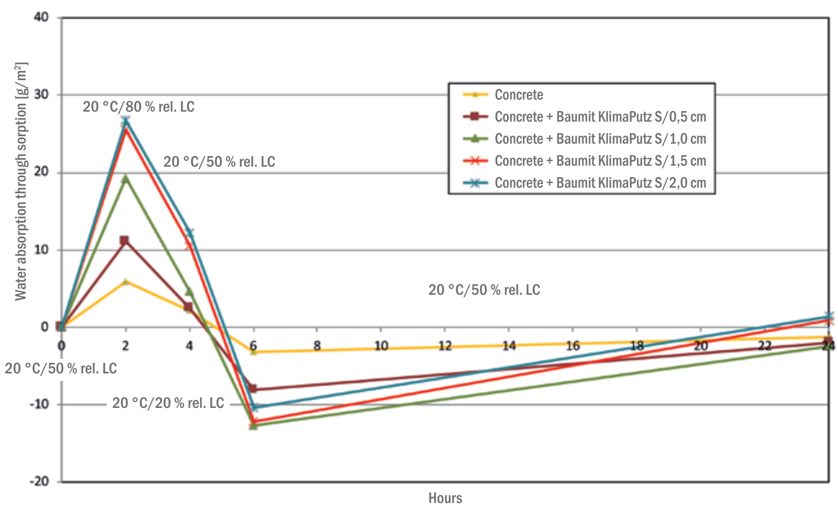


Without plaster on concrete surfaces at critical wall locations - these are places that are a bit cooler than the air in the room - condensate or wall moisture at high humidity, which favors mold growth. If these concrete surfaces are coated in plaster, the plaster has a balancing effect and can buffer critical indoor air humidities. During periods of high humidity, the humidity is absorbed so that it can be released again during periods of low humidity. The fact that even thin layers of 1.5 to 2 cm show such a marked difference in moisture buffering capacity was surprising to the scientists at Viva Research Park.

What effect does layer thickness have on buffering capacity?

In connection with the moisture buffering of Baumit KlimaPutz on concrete, the Viva Research Park scientists tested the moisture absorption in relation to the layer thickness in further laboratory tests. The layer thicknesses from 0.5 cm to 2.0 cm were tested on concrete test specimens. At 20 °C and 50% relative humidity, the test subjects he specimens were conditioned at time intervals of 2 hours at 20 °C and 80% relative humidity, and then again under „drying“ conditions (first at 20 °C and 50% relative humidity and then at 20% relative humidity), during all of which the moisture absorption and release were determined. After 6 hours, the specimens were once again stored at 20 °C and 50% relative humidity. The thicker the layer of plaster, the better the moisture absorption.

Moisture absorption and desorption on concrete as a function of layer thickness

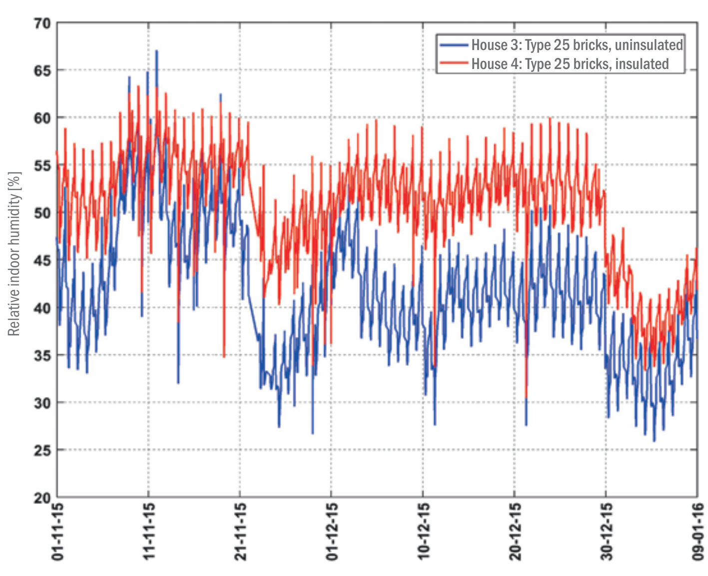


Results: As the layer thickness increased, the moisture absorption improved significantly. An interesting effect was that, during a time period of two hours, the moisture absorption capacity reached its optimum **at a 1.5 cm layer thickness** and that thicker layers (e.g. 2 cm) did not achieve any significant improvement in moisture absorption.

Influence of thermal insulation on the humidity

Thermal insulation clearly has a positive effect on the relative humidity and therefore also on a balanced room climate. What effect does the thermal insulation have on humidity? The measurements taken by scientists during the heat period in Viva Research Park showed that the insulated type 25 brick house had an average relative humidity of about 10 percentage points higher than the uninsulated house.

This occurs because, in an uninsulated house, the exterior walls cool down more in winter, meaning that the interior surface temperature of the walls also decreases. In order to achieve a tolerable room temperature throughout the entire space, the room temperature in uninsulated houses in the middle of the room must, as a rule, be significantly higher than the temperature near the walls. This reduces the comfort while simultaneously requiring more and more heating in order to compensate for the heat exchange with the cool walls.
Warm air can absorb more moisture than cold air. Air that is heated by a heating system is therefore considered to be drier because the relative humidity decreases. If, for example, cold outdoor air drafts with temperatures of 1 °C and a high relative humidity get inside during the winter, that air is heated here, thus reducing its originally high relative humidity. Conclusion: Suddenly, the air is dry.



Comparing humidity in an insulated house - uninsulated house:

Comparison of relative humidity during the heating season (November 2015 to January 2016): insulated type 25 brick house (red) and uninsulated brick house with non-renovated older construction blue) The insulated brick house had an average relative humidity of 51%, while the uninsulated house had an average relative humidity of 42%. Source: FH Burgenland

3.2. INDOOR AIR QUALITY

In addition to temperature and relative humidity, there are other criteria that affect the quality of the indoor air. The scientists at Viva Research Park investigated the following areas, taking comprehensive measurements and doing thorough analyses:

- **Odors**
- **Pollutants**
- **Radon**
- **Air ions**

The odors

Whether a new building smells good or bad partially depends on its design. When analyzing the odor load in the interior, the insulated solid brick and concrete houses performed far better than the other construction methods.

„Is there a correlation between odor pollution and style of construction?“ Unwanted odors caused by building materials are not only annoying; they may also indicate the use of harmful substances. Together with specially trained odor experts, the scientists conducted two series of odor tests in the Viva Research Houses. The first took place seven months after the construction was completed; the second after 14 months.
The results of both odor investigations were clear: For example, the concrete and brick houses with plaster had much lower odor intensity values and their odor remained neutral to pleasant. The houses with wood frame construction with gypsum plasterboard paneling and the timber block house, however, retained a high level of odor intensity, even after a year. Only the wood frame construction house smelled unpleasant to the majority of the testers. And in terms of acceptance, the houses with wood frame construction fell below the average and were ranked „barely acceptable“. This could be due to the odors of the components and the location of the vapor barrier. **Summary:** There is a clear correlation between perceptible odors and the chosen construction method.

How were these tests performed?

Odors are usually caused by a variety of different substances. Even if they are perceptible, the concentrations of the individual substances are often below the analytical detection limit and are therefore not easy or are even impossible to detect with measuring instruments. Therefore, with such low concentrations, sensory odor tests are performed by certified odor testers. Odor testers are persons who have undergone special sensory training according to ÖNORM (Austrian standard) S 5701 in order to recognize, distinguish and evaluate individual odor substances.

What is being evaluated?

In an odor test, four parameters are tested: the odor intensity, the personal odor preference (so-called hedonics), the acceptance and the odor quality.

The odor intensity increases as the concentration of an odorant increases. The scale ranges from „no odor (0)“ to „very strong odor (5)“. Hedonics is rated on a nine-part rating scale between „extremely pleasant“ and „extremely unpleasant“, and it is highly subjective. Acceptance demonstrates satisfaction with a certain smell in interiors, taking into account the use of the areas. Their evaluation scale ranges from „clearly unacceptable“ to „clearly acceptable“. The odor quality is described verbally.

Measurement table for hedonics								
–4	–3	–2	–1	0	1	2	3	4
extremely uncomfortable				neither comfortable nor uncomfortable				extremely comfortable

The personal odor preference (hedonics) is also evaluated immediately after entering the room. If several testers are giving evaluation, the average value shall be the end result. Source: IBO Innenraumanalytik OG.

Measurement table for acceptance								
–1								+1
clearly unacceptable				barely acceptable				clearly acceptable

The acceptance of an odor is also evaluated immediately after entering the room. The use of the room also affects the evaluation. Source: IBO Innenraumanalytik OG

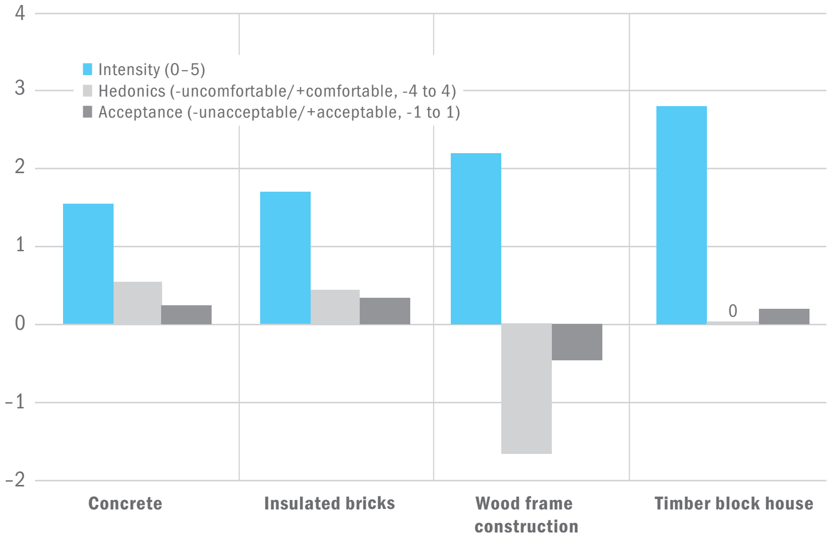
Results of the odor test 7 months after completion of construction								
Parameter	**House 1**	**House 2**	**House 3**	**House 4**	**House 6**	**House 7**	**House 9**	**House 10**
Wall structure	Concrete + dispersion plaster + dispersion paint	Concrete + lime plaster + Ionit	Type 25 bricks, uninsulated + gypsum plaster + dispersion paint	Type 25 bricks + lime plaster + mineral paint	Wood frame construction with gypsum plasterboard paneling + gypsum plasterboard sheets, no interior plaster + dispersion paint	Wood frame construction with gypsum plasterboard paneling + Ionit plaster + Ionit	Type 50 W.i object plan (filled with mineral wool) + lime plaster + mineral paint	Timber block wall - no interior plaster and no wall paint
Intensity [0...5]	1,5	1,6	0,6	1,8	2,3	2,1	1,6	2,8
Hedonics [–4...4]	0,8	0,3	1,5	0,3	–1,8	–1,5	0,6	0
Acceptance [–1...1]	0,4	0,1	0,5	0,3	–0,4	–0,5	0,4	0,2
Odor quality	Concrete, lime, wall paint, mineral building materials	Wall paint, lime, plastic, mineral building materials, sweet	Wall paint, slightly sweet	Wall paint, concrete, plaster, lime, damp mineral building materials	Wall paint, plastic, latex	Damp wood, damp plaster, damp paper, musty	Wall paint, concrete, lime, mineral building materials	Wood, terpenes, resin

The research houses were evaluated in the odor test according to the criteria of odor intensity, personal hedonics preference, acceptance and odor quality. Source: IBO Innenraumanalytik OG

On the intensity scale, the values of the houses made of plastered brick and concrete were below 2 (= weak smells). The houses with wood frame construction with gypsum plasterboard paneling as well as the timber block house still showed intensities higher than 2 after seven months. However, intense does not automatically mean uncomfortable: Therefore, the odor was only perceived as unpleasant in the houses with wood frame construction; these houses fell below average even during acceptance. In the intensively odorous timber block house, the odor was classified as acceptable and evaluated as neutral in terms of hedonics on average

Wall materials, compared: Results of odor testing after 7 months

The odor analysis according to wall materials (average values of the individual house types) clearly shows that the houses made of plastered brick and concrete performed best in terms of both odor acceptance and hedonics. The timber block house is a special case - the intensive wood odor was very pleasant for some people but much too intense for others. Source: IBO Innenraumanalytik OG



The scientists performed the second odor test 14 months after the construction of the research houses had been completed. An interesting finding was that every house had maintained its „typical“ personal odor, even after a year. In inhabited buildings, this odor is rarely noticeable, as it is masked by other odors caused by cooking, washing, smoke, etc.

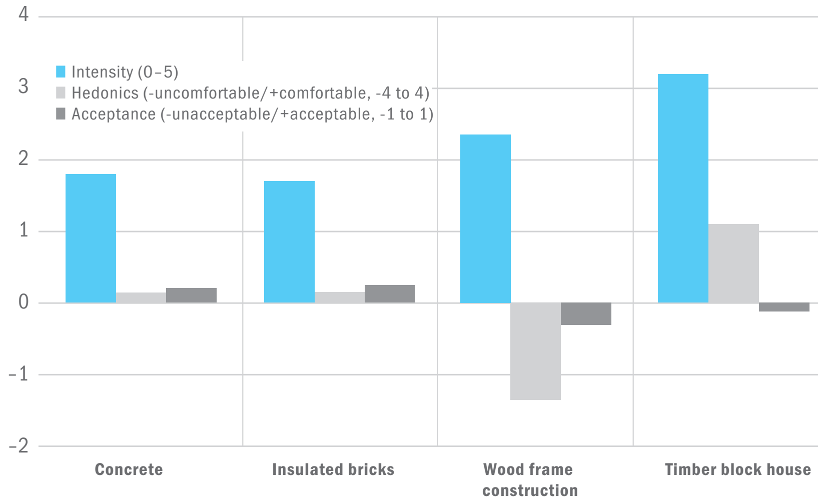
Results of the odor test 14 months after completion of construction

Parameters	House 1	House 2	House 3	House 4	House 6	House 7	House 9	House 10
Wall structure	Concrete + dispersion plaster + dis-persion paint	Concrete + lime plaster + Ionit	Type 25 bricks, uninsulated + gypsum plaster + dispersion paint	Type 25 bricks + lime plaster + mineral paint	Wood frame construction with gypsum plasterboard paneling + gypsum plasterboard sheets, no interior plaster + dispersion paint	Wood frame construction with gypsum plasterboard paneling + Ionit plaster + Ionit	Type 50 W.i object plan (filled with mineral wool) + lime plaster + mineral paint	Timber block wall - no interior plaster and no wall paint
Intensity [0...5]	1,7	1,9	1,9	1,9	2,2	2,5	1,5	3,2
Hedonics [–4...4]	–0,1	0,4	–0,3	0,3	–0,9	–1,8	0	1,1
Acceptance [–1...1]	0,1	0,3	0,2	0,2	–0,3	–0,3	0,3	–0,1
Odor qualities	Concrete, lime, wall paint, plaster, mineral wool	Concrete, plaster, wall paint, lime, plaster, slightly fishy, musty	Sweet, plastic, wall paint, cardboard	Wall paint, plaster, concrete, lime, plaster	Plastic, wall paint, plaster, plaster aromatic, stings slightly	Musty, damp cardboard, wood, dusty, lime, wall paint	Concrete, plaster, wall paint, lime	Wood, wood fibers, terpenes

The odor measurements of the research houses after 14 months showed similar results as after 7 months. Source: IBO Innenraumanalytik OG

Results of odor testing after 14 months

The houses with wood frame construction with gypsum plasterboard paneling and the timber block house retained a high level of odor intensity, even after a year. Only the wood frame construction house smelled unpleasant to the majority of the testers. Source: IBO Innenraumanalytik OG



Make sure to use healthy building materials!

Undesirable odors caused by building materials are not uncommon in new buildings. Not only can they cause unpleasant odors, but they can also indicate the presence of harmful substances (e.g. certain VOCs).

Fortunately, humans have a very finely tuned warning system - our sense of smell. In general, we already perceive a substance to be odoriferous if it is present in very small quantities - often even before it has reached a health-endangering concentration. Odors in a newly built house can usually be eliminated by frequent airing. What is problematic is if unpleasant odors are still noticeable after a few months despite airing and if, at the same time, the inhabitants begin to experience complaints such as headache, fatigue or irritation. Then the cause must be determined. Anyone who wants to rule out possible odor pollution in advance ensures the use of low-emission and odorless building materials.

VOC

VOCs (volatile organic compounds) are irritants and odors that are found in many products, including building materials. They can evaporate easily or outgas at low temperatures.

The VOCs include aliphatic compounds, alicyclic compounds, aromatics, chlorinated substances, esters, aldehydes, ketones and terpenes. Many are used to make plastics, solvents, dyes, tannins, perfumes and medicines. In higher concentrations, VOCs can lead to health problems.

The pollutants

The health of our residential areas is more important than ever, so the issue of indoor air quality and indoor pollution levels is becoming increasingly important.

Today, the scientific community possesses increasingly detailed toxicological insights into the influence of pollutants on the human organism. Increased pollution levels indoors are possible, especially in new buildings or after renovations; these levels can cause odors or create health problems for the residents. Pregnant women, infants, children and other sensitive persons (e.g allergy sufferers) are particularly affected by these pollution levels. They can cause symptoms of irritation (upper respiratory tract, eyes) and discomfort (tiredness, fatigue, headache) or even allergic complaints, among other things. Definitions of terms, fundamentals and guideline values relating to the topic „indoor pollution" can be found in the „Guideline for the Assessment of Indoor Air"2, which has been published by the Federal Ministry for Sustainability and Tourism since 2003 (loose-leaf collection).

Which pollutants are emitted by the different building materials into the room air in what quantities? The scientists at Viva Research Park investigated these topics and measured VOCs as well as formaldehyde pollutants.

VOC (volatile organic compounds)

Buildings made of concrete and bricks with an interior mineral coating are already largely free of volatile organic compounds - so-called VOCs (volatile organic compounds) - directly after completion.

Houses with wood frame construction may exhibit increased VOC values in the first few months. Depending on wood type and the nature of the wood, timber block houses often give off wood-specific substances into the room air over long periods of time, such as terpenes.

VOCs can pollute the room air in new buildings and can even endanger health at high concentrations. But which wall structures give off an especially high quantity of VOCs, and how long does this pollution last after construction has been completed?

[2] www.bmnt.gv.at/umwelt/luft-laerm-verkehr/luft/innenraumluft/richtlinie_innenraum.html

To answer these questions, scientists at Viva Research Park tested VOC concentrations in all research houses. In the first two years after construction was completed, they performed a total of three series of measurements and were thus able to comprehensively analyze the development of VOC concentrations. The results were clear: Shortly after completion, the insulated houses made of concrete and brick exhibited inconspicuous VOC values (< 500 µg/m³). Significantly higher values were found in the houses with wood frame construction, with more than 1,000 µg/m², as well as the timber block house with over 8.000 µg/m³.

Volatile organic compounds (VOCs) can cause discomfort and health problems in new buildings

» Reduction in VOC values

When measured 15 months after completion, the VOC concentrations in the interior air had decreased in all homes. However, the timber block house still contained a high concentration of terpenes.

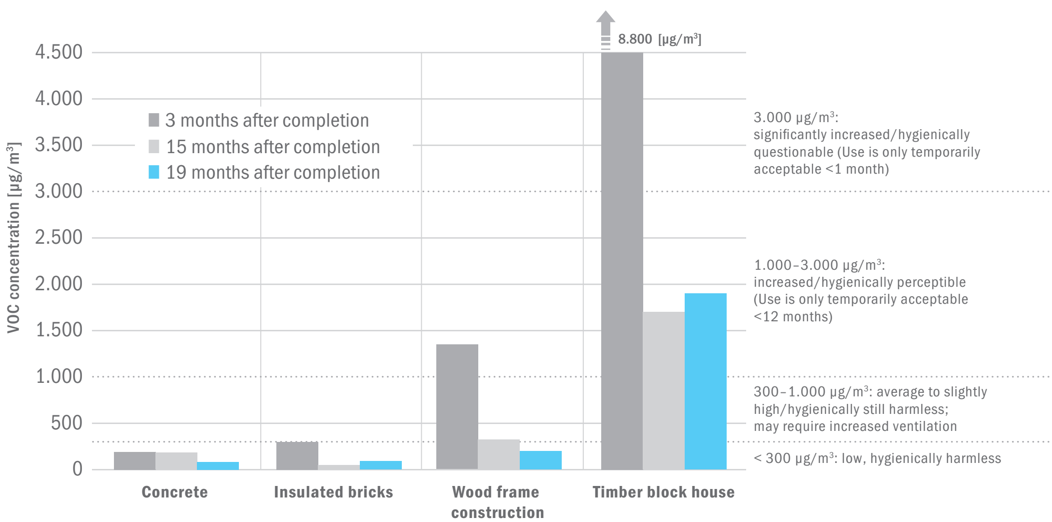
Summary: You can move into a solid house without hesitation immediately after its completion, but sensitive people should, if possible, wait a few months to purchase a wood frame construction house. Anyone who builds a wood house must be aware that, under certain circumstances, wood-specific substances such as terpenes can be present in the interior air for a very long time.

» Mineral interior paints and plasters

The measurement results for the interior paints and plasters were also good: The interior coatings used in Viva Research Park - from Baumit Ionit to Baumit KlimaPutz to Baumit Divina interior paint - did not demonstrate any relevant pollutant emissions during VOC testing. The reason: all products used were mineral and low in emissions.

Results of VOC measurements after 3, 15 and 19 months

The measurement results in Viva Research Park (average values of the individual house types) show: For the insulated brick and concrete houses with mineral interior coatings, VOC concentrations fell to a very low range after just three months. Source: IBO Innenraumanalytik OG



INTERVIEW

»Houses made of bricks and concrete had very low VOC values.«

Bernhard Damberger, pollutant expert for IBO Innenraumanalytik OG, performed the pollutant tests in Viva Research Park. Here, he explains the exact measurement process and reveals his summary of the VOC measurements.

What exactly did you investigate during the VOC measurements?

Bernhard Damberger: During our measurements, we examined substances that have a potential health risk and „evaporate". These substances are also referred to as VOCs (volatile organic compounds). In order to be able to draw detailed conclusions about the individual sources of VOCs, we not only examined the total VOC content but also the various individual substances, such as aliphates, alicyclics, aromatics, chlorinated substances, aldehydes or terpenes. For example, a high concentration of aliphatics and alicyclics may indicate the presence of solvents.

How were the VOCs measured in Viva Research Park?

Bernhard Damberger: We took the samples according to ÖNORM (Austrian standard) M 5700-2 by sampling the air in the middle of the rooms. With the help of an adsorbent, the air was separated from the pollutants to be measured. We performed the evaluation using gas chromatography/mass spectrometry.

What is your summary of the VOC measurements in Viva Research Park?

Bernhard Damberger: The houses made of brick and concrete had the lowest values in our VOC measurements, while the timber block house took longer to exhaust. However, it is also important to keep in mind that pollutants can also be introduced through the fittings added to rooms (such as floor coverings and furniture) and that low-emission products should also be used for these as well.

INTERVIEW

FORMALDEHYDE

Formaldehyde is not a VOC due to its volatility. It is a colorless irritant gas that can lead to health impairments, even in very low concentrations. Today, formaldehyde is primarily used in the production of synthetic resins. They are contained in chipboard, adhesives and insulating foams. The slow decomposition of these resins leads to the prolonged release of formaldehyde into the air. Shorter but significantly higher loads may occur after the use of acid-cured parquet seals. Formaldehyde is also contained in tobacco smoke. It has a strong irritant effect on the mucous membranes of the upper respiratory tract and the eyes with stinging in the nose and throat, coughing, and burning eyes. Prolonged exposure can cause bronchitis and asthma. Formaldehyde can be measured relatively easily and reliably in the interior air. Initial irritant effects, especially around the eyes, begin to occur at concentrations of 100µg/m^3 . For sensitive persons, these can begin at lower concentrations. There is no risk of cancer in this low concentration range.

» Too little time to dry

There are many sources of VOCs from building materials. In addition to paints and varnishes, the sources are often adhesive or plastic coatings. In general, VOCs will evaporate relatively quickly, depending on their intensity. In a best-case scenario, a new house with good ventilation is virtually VOC-free after one year at the latest. However, if substances such as moisture insulation cannot dry out for a long enough period of time due to time constraints on the construction site, the situation becomes critical.
In this case, this source of VOCs is virtually „locked in“ and often keeps evaporating over the years. Further sources of risk are fire protection coatings, such as steel beams. These contain health-relevant aromatic hydrocarbons. If fire-retardant paints are not applied several times in the thin layer thickness specified, outgassing may continue for years.

Formaldehyde

The formaldehyde measurement results in Viva Research Park demonstrate: In the houses made of brick, concrete and with timber block construction, the formaldehyde levels were completely harmless from the very beginning. Only the wood house demonstrated higher values for all measurements.

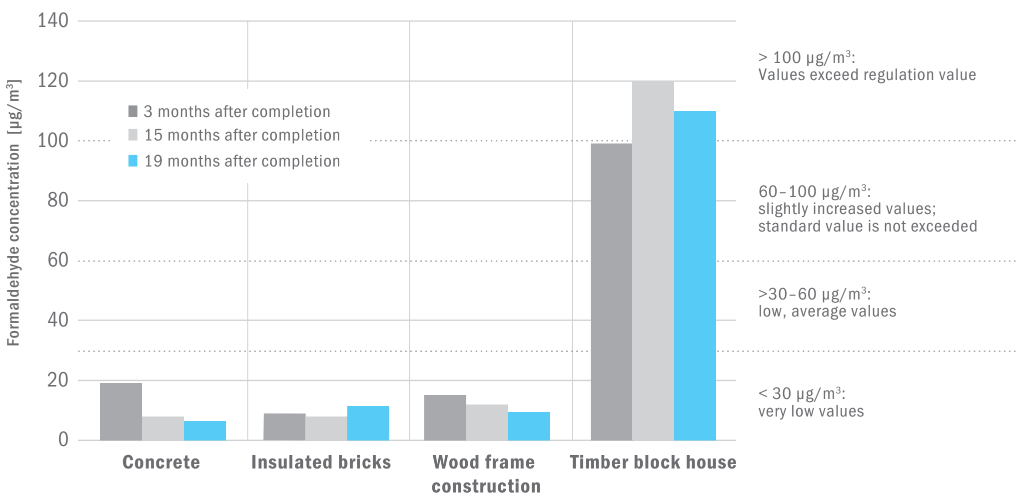
Formaldehyde is one of the best-known and best-researched indoor air pollutants. In the 1980s in particular, formaldehyde became the focus of attention due to the high level of and permanent outgassing of chipboard and wood composites. For this reason, formaldehyde regulations were introduced in Austria in 1990. These regulations stipulate that only wood-based materials of emission class EI may be sold. The interior reference value for formaldehyde in Austria is 100 µg/m^3.

The scientists at Viva Research Park wanted to know how much formaldehyde each wall structure was emitting. Since formaldehyde is a long-term effluent, in this case three measurements were taken over a period of 3 to 19 months after construction was completed.

As early as the first measurement - 3 months after completion of construction - testers found that the formaldehyde values in all houses made of concrete, brick and wood frame construction were only between 9 and 19 ug/m³ and thus extremely low. These values decreased further during later measurements. Only the timber block house demonstrated an excessive formaldehyde load from the beginning. Therefore, at the time of measurement 3 months after completion of construction, the value was 99 ug/m³ - i.e. within the range of the guideline value of 100 ug/m³, above which concentrations may be hazardous. For the two other measurements after 15 and 19 months, respectively, the formaldehyde vales were 120 and 110 ug/m³ and had thus increased significantly.

Results of formaldehyde readings after 3, 15 and 19 months

The formaldehyde measurement results in Viva Research Park (average values of the individual house types) show: In the houses made of brick, concrete and with timber block construction, the formaldehyde levels were completely inconspicuous from the very beginning. Only the wood house demonstrated higher values for all measurements. Source: IBO Innenraumanalytik OG



RADON

Radon is a natural, common radioactive noble gas that is colorless, odorless and tasteless. It is an intermediate product of the decay series of the radioactive heavy metal 238Uranium, which occurs naturally in soils and rocks, while radon is directly produced from 226Radium. Radon can escape relatively easily from soils and rocks and can spread through soil vapor or by dissolving in water. It can also get into the interior air of buildings.

The EU-wide reference value for radon concentration is 300 Bq/m^3. In new buildings, a medium radon concentration of 200 Bq/m^3 should not be exceeded (planning reference value) The medium value for residences is 60 Bq/m^3.

BECQUEREL (BQ)

Becquerel (Bq) is the international unit of radioactivity (symbol A). The unit is named after French physicist Antoine Henri Becquerel, who, together with Marie Curie, received the Nobel Prize in 1903 for their discovery of radioactivity. The Becquerel indicates the number of atoms that decay per second.

Radon

The radon concentrations in the houses in Viva Research Park were generally very low. The lowest concentrations of radon were found in the concrete houses and the wood house.
Radon accounts for the largest proportion of the population's average exposure to radiation and is the second leading cause of lung cancer after smoking. The radon concentration in the interior air inside buildings can far exceed the concentration in the outside air.

The most important sources for radon are:

- **the soil vapour underneath buildings**
- **the building materials with which a building is constructed**

The largest percentage of radon comes from the soil vapours underneath buildings. On the other hand, the proportion of radon emitted from building materials or from water into the indoor air is much lower and usually negligible. Building materials made of concrete, brick or sand-lime brick normally only radiate a small quantity of radon. You have to be careful only with natural stones with increased radium concentrations or with building materials with mining or industrial residues with increased radium contents.

Radon content of building materials as ^{226}radium

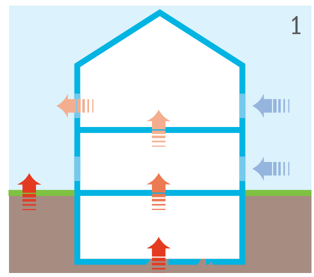
Materials	^{226}Radium in Bq pro kg	
	Average value	Range
Granulite	10	4–16
Natural gypsum, anhydrite	10	2–70
Sand-lime brick, aerated concrete	15	6–80
Gravel, sand, gravel sand	15	1–39
Diabase	16	10–25
Gypsum from flue gas desulphurization	20	< 20–70
Basalt	26	6–36
Concrete	30	7–92
Clay, loam	< 40	< 20–90
Bricks, clinker	48	10–200
Gneiss	75	50–157
Lignite filter ashes	82	4–200
Granite	100	30–500
Tuff, pumice	100	< 20–200

^{226}Radium content of selected building materials, source: Bundesamt für Strahlenschutz [Federal Office of Radiation Protection], Info Sheet 03/02

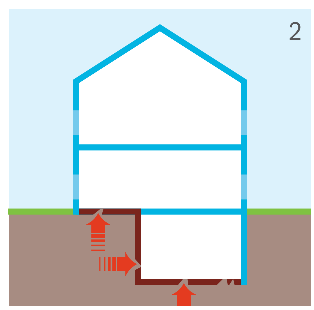
Factors influencing the interior radon concentration.

The level of radon concentration in the interior air depends on various factors:

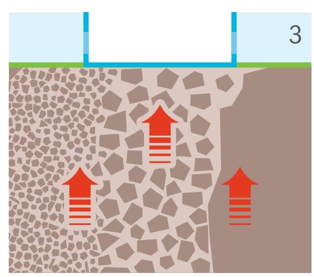
Air exchange in the building (Fig. 1): The exchange between indoor and outdoor air has a significant effect on the level of indoor radon concentration. Drafty windows and doors lead to higher air exchange rates. On the other hand, if the air exchange is reduced, such as by installing tight-fitting windows and doors and without mechanical ventilation, the indoor air concentration of radon can increase considerably.



Building condition (Fig. 2): The crucial factor is the permeability of a building to the soil vapor in the foundation area as well as in masonry which comes into contact with the ground. Air ingress can take place through cracks and gaps as well as along cables and pipe ducts. The radon-containing soil vapor is sucked into the building through negative pressure arising in the building (chimney effect due to temperature differences between indoor and outdoor air or through wind pressure). If basements or other building areas with ground contact are open to floors above these areas, it is especially easy for radon to spread throughout the entire building



Nature of the substrate[1]» (Fig. 3): In addition to the composition of soil and rock (uranium, radium content), the grain size of the rock (emission of radon into the soil vapor) and the permeability of the substrate (transmission of radon-containing soil vapor) play an especially important role. Special caution is advised in the case of rubble cones and slopes, weathered granite, karst and gravel soils - in contrast to very compact or loamy soils.



[1] Radon-Potenzialkarte Österreich: https://geogis.ages.at/GEOGIS_RADON.html

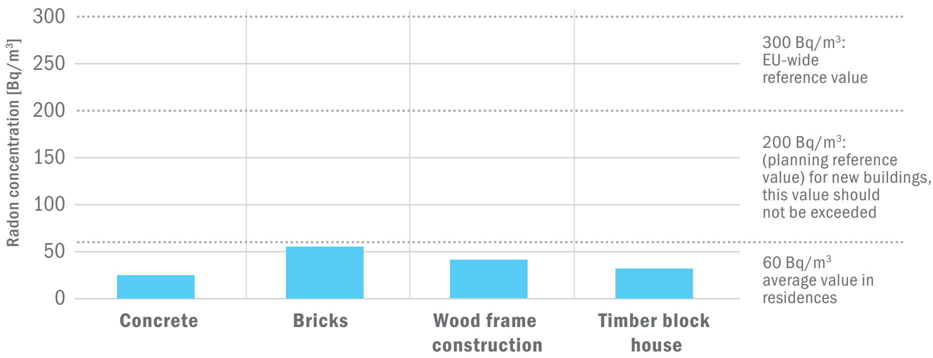
Radon measurements in Viva Research Park

Viva Research Park is located on an area with low radon risk; the houses have a dense foundation slab.

Nevertheless, the scientists wanted to play it safe and clarify a possible radon load. In order to do so, they performed extensive radon measurements in the research houses while simultaneously also testing the building materials used for their radon output. The results were quite gratifying: all research houses had a very low radon load, all with values below 60 Bq/m³. The lowest values were found in the concrete houses and the timber block house.

Results of radon measurements in the research houses

The radon measurements in Viva Research Park demonstrated: The radon load in all houses is low - overall, they were all under 60 Bq/m³. Source: AGES



Air ions

Some studies found that air ions have a positive effect on indoor air quality, partly because higher air ion concentrations reduce pollutants and particulate matter in interior air. Experiments with test subjects showed improvements in intellectual capacity [1).]

How can the air ion content in the interior air be increased, and what effects do special functional coatings such as Baumit Ionit have? To dissuade the effect of the special coating Baumit Ionit in Viva Research Park, the scientists used Baumit Ionit as a wall coating in two of the research houses and performed compa-

[1)] Hutter et al.: Exposure to Air Ions in Indoor Enviroments: Experimental Study with Healthy Adults, Int. J. Environ. Res. Public Health 2015

Comparison of air ion concentration in the research houses					
	House 1	**House 2**	**House 6**	**House 7**	
Wall materials	Concrete	Concrete	Wood frames with gypsum plasterboard paneling	Wood frames with gypsum plasterboard paneling	
Plaster system	Dispersion filler Baumit FinoFinish	Lime plaster Baumit KlimaPutzS	No interior plaster, only gypsum plasterboard sheets	Gypsum plasterboard sheets + special plaster Baumit Ionit Spachtel	
Wall paint	Dispersion paint Baumit Divina Classic	Special paint Baumit Ionit	Dispersion paint Baumit Divina Classic	Special paint Baumit Ionit	**Outside air**
Average air ion concentration = sum of positive and negative air ions	**2.800**	**4.200**	**2.300**	**4.700**	**1.200**

Air ion measurements were performed at Viva Research Park from September 2016 to September 2017. Results: The mean air ion concentration in the Ionit-coated houses (house 2 and house 7) was about twice as high as in houses without Baumit Ionit.

rative measurements of the air ion concentrations. They found that the average air ion concentration in houses with a Baumit Ionit coating was about twice as high as in the identical houses without Baumit Ionit.

How Ionit works

The minerals in the Ionit plaster and wall paint enrich the interior air with air ions. The minerals in Ionit attract air particles and convert them into air ions. These ions then leave the wall surface and make room for new air particles. The process is completely natural and requires no external energy input. But how long does Ionit‘s effect last? As early as the product launch in 2011, the scientists set up their own test containers, whose interiors were coated with Ionit, in the Baumit Innovation Center. Since then, they have been consistently measuring the air ion density. Results; The results of the long-term tests showed that even after seven years, the production of air ions by the Ionit wall coating remained constant. This showed that the air ion-active layer works permanently and does not wear off. This effect is physical, comparable to a magnet on the surface.

!

AIR IONS

Air ions are electrically charged molecular particles that carry either a positive or negative charge. These charged particles can consist of clusters of H_2O molecules, O_2, N_2 and CO_2 and measure approximately 1-50 nanometers in size. In nature, air ions are formed when charge shifts generate high polarization fields. This happens during electrical discharges such as lightning, piezoelectric effects and waterfalls. Air ions are also produced by radioactive, cosmic radiation and open fire (plasma), among other things. Technicologically, air ions are produced by generating very high charge densities on small needles with high electrical voltage.

3.3. SOUND INSULATION AND ROOM ACOUSTICS

With solid construction and thermal insulation, noise pollution from outside can be noticeably reduced in interior spaces

Soundproofing and room acoustics are relevant quality features for buildings and are extremely important in terms of the well-being and health of users. Sound insulation is designed to buffer sounds from outside or from adjoining rooms. The room acoustics are responsible for the acoustic quality in the interior.

Sound insulation

The sound measurements in Viva Research Park demonstrate: Solid components and thermal insulation reduce external noise by up to 50 percent.

Noise is one of the most uncomfortable environmental influences and is one of the most serious environmental stressors. According to the 2015[2] micro-census survey, around 39 percent of Austrians feel anything from slightly to very disturbed in their home during the day and/or night due to noise. Therefore, soundproofing is one of the most important prerequisites for ensuring people‘s well-being and health.

[2] Austria Statistics, 2015 Microcensus, Environmental Conditions, Revaluation Behavior

Continuous loud noise makes us ill

Noise is defined as unwanted, disturbing and annoying or damaging sound. Noise is not a physical concept; it is subjective. Whether sound is perceived as noise depends on the feelings of those affected.

Noise is only partially objectifiable by measurable quantities (such as loudness, signal curve, pitch). The disturbing effects of noise range from mild irritations to actual health impairments.

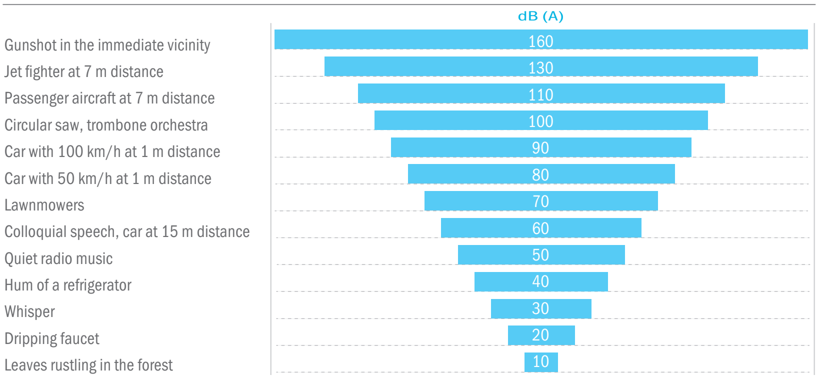
The primary effects of noise include disorders of the cardiovascular system with associated complications, such as heart attacks. This serious physical reaction can be explained as follows: The noise stressor can increase muscle tension, narrow the peripheral blood vessels, increase heart rate and heart rate, and increase the release of stress hormones, especially cortisol. At the same time, the electrical skin resistance decreases, causing the skin temperature and the blood circulation of the skin to drop. This means that the organism is constantly being put into a „fight and flight readiness“ state. It‘s easy to see how this can‘t be healthy in the long run.

Epidemiological studies showed that, for example, road traffic-related noise reaching more than 60 dB (A) during the day increases the risk of heart attack. Such levels are frequently achieved, especially in urban areas. The WHO specifies an average annual noise level (outdoor) of 42 dB in its „Night Noise Guidelines“ (2009).

SOUND

Sound that reaches our ear is a physical vibration of the air molecules that leads to small pressure fluctuations. The strength of the sound is accordingly characterized by fluctuations in air pressure. Since the fluctuations fall within a large range of one to one billion, the sound level in daily use in a logarithmic system is expressed in decibels (dB). Increasing or decreasing the sound level by 10 dB means that the volume is either doubled or halved.

Sound sources in decibels



FREQUENCY

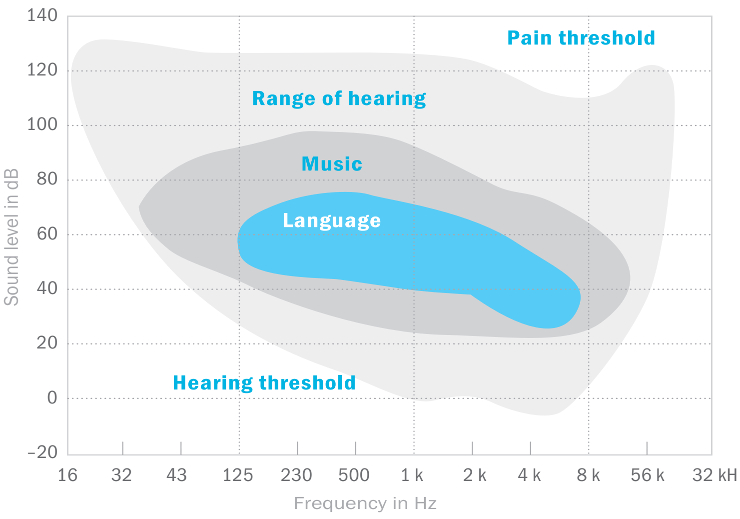
The frequency indicates the number of oscillations per second. The unit of frequency is called hertz (Hz). One hertz is 1 oscillation per second. For building acoustics, the frequency range from 50 to 5,000 Hz and the room acoustics range from 63 to 8,000 Hz are key. Sound which is completely undetectable by the human ear - ultrasound - starts at 20,000 Hz.

What sounds can we hear?

Our ability to hear a sound depends on the audio pressure and the frequency. The most minimal sound pressure that triggers a hearing sensation defines the threshold of hearing. The pain threshold occurs when the sound pressure is so high that our ears hurt. The lowest frequency that can still be heard is around 16 hertz (hertz = number of oscillations per second); the highest perceptible frequency is around 16,000 hertz for young people and drops to about 6,000 to 8,000 hertz as humans age. For us humans, the range between 500 and 4,000 hertz is especially pleasant. This is also the range in which speech and music comprehension occurs.

The human range of hearing

The range of hearing includes the frequency ranges that can be detected by the human ear. The lowest audible frequency is 16 hertz, the highest audible frequency is 16,000 hertz.



Factors influencing noise

The greatest factor influencing exterior noise for residences living is the location of the property on which a person‘s home or apartment is located. Noise exposure during the day should not exceed the planning guidelines specified in the table in ÖNORM (Austrian standard) B 8115-2. At night, the planning guidelines are 10 dB lower.

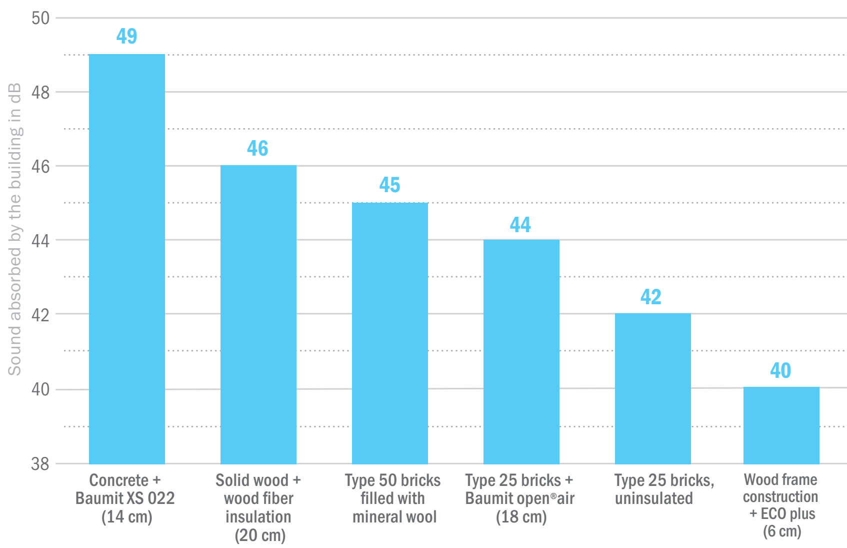
Noise categories for real estate		
Category	**Region**	**Noise in dB during the day**
1	Quiet area	45
2	Residential suburb	50
3	City residential area	55
4	Downtown area	60
5	Commercial area	65

Source: ÖNORMB8115-2

If a building is erected on a site where there is an increased level of noise, it is important, if possible, to plan the „rest areas" such as bedrooms, children's rooms and living rooms away from the source of the sound. At the same time, good soundproofing of the building's outer shell reduces the noise level in the interiors.

Sound measurements in Viva Research Park

But which building material is best suited to withstand external noise and to ensure quiet interior spaces? The research conclusions from Viva Research Park demonstrated: solid houses have the best sound insulation values. Therefore, the scientists analyzed that external noise is only perceived half as much in solid houses compared to houses with wood frame construction. They investigated frequency ranges as they occur in everyday sources of sound (street traffic, children playing, etc.).



Sound insulation measurements depending on wall materials and thermal

In the measurements, the solid concrete house with 49 dB had the best soundproofing measurements. This means that in the solid house, noise from outside is only perceived half as loud as in the house with wood frame construction. Source: IBO

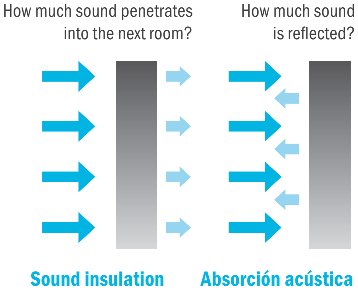
Thermal insulation reduces noise

Special thermal insulation also minimizes exterior sound. The sound measurements in the research park demonstrated that thermal insulation (especially phenolic foam insulation board) reduces noise. This is due to the higher elasticity of the insulation boards, which cushions the sound like a trampoline. Owners and builders can take advantage of these findings: if a wall has good sound behavior, you can install larger windows without increasing interior noise - which is a good solution, especially when building modern houses with many windows.

The topics of sound and acoustics currently receive barely any consideration when planning a home. In particular, in areas with higher traffic volumes, for example, the noise pollution can be noticeably reduced with the right choice of building materials, structural designs and geometry.

SOUND INSULATION AND SOUND ABSORPTION

The term sound insulation refers to how much sound energy can pass through a wall into an adjoining room. Sound insulation or sound absorption by a wall or ceiling, however, takes place during the reflection process by converting part of the sound energy into heat. The degree of sound absorption depends on the surface texture. A wall can have good soundproofing while still having a low level of sound absorption, and vice versa. The sound insulation is measured in decibels (dB). For sound insulation, the following applies: The higher the value, the better the sound insulation. 10 decibels plus means half the perceived noise level.



Room acoustics

At medium and high frequencies (e.g. music), there are no differences in the room acoustics for the different types of construction. In the low frequency range (e.g. a male voice), the timber block house and the house with wood frame construction achieved the shortest reverberation times. The concrete houses had the longest reverberation times. In the low-frequency range, furnishings can easily reduce reverberation.

The room acoustics have a decisive influence on the well-being in interiors, because rooms with bad room acoustics have a long reverberation period. The „echo effect“ of conversations or noises created in such reverberant rooms causes annoying background noise and reduces speech intelligibility.

INTERVIEW

»Noise is the sounds that others make.«

Bernhard Lipp, sound and acoustics expert from the Österreichischen Instituts für Baubiologie und Bauökologie (IBO) [Austrian Institute for Building Biology and Construction Ecology], performed the sound measurements at Viva Research Park. He explains the effects of noise on health and why it is so important to pay attention to good sound insulation in construction.

What is the significance of sound insulation for living quality?

Bernhard Lipp: An essential factor for describing the acoustic quality of a room is the sound insulation. Lack of sound insulation in the building can be stressful and can make people ill in the long run. That‘s why it‘s important to address the topic of sound as early as the planning phase of a construction project. Retrofitting a building due to its lack of sound insulation can often only be accomplished at the structural level at great expense. In terms of sound-proofing measures, footfall sound insulation also plays an important role, in addition to the sound insulation properties of the wall materials.

How does noise affect health?

Bernhard Lipp: Noise can interfere with our personal well-being and, depending on its volume and duration, can cause health issues. In addition to road traffic, construction sites, trades and industry, the most common sources of noise include neighborhood noise. This means that noise is not only harmful to health but also to interpersonal relationships, as it is the most common reason for conflict between neighbors.

How do you build for „noise reduction“?

Bernhard Lipp: To protect yourself from noise, you should choose building materials that have proven sound insulation properties. The sound measurements carried out in Baumit‘s Viva Research Park show that walls coated with plaster and constructed of concrete and bricks with the appropriate external insulation (Baumit Resolution) as well as solid wood perform the best in terms of sound insulation. The better the sound insulation, the higher the comfort level, as noise reduction of 10 dB is perceived as halving the volume.

INTERVIEW

REVERBERATION TIME

The best known measurement of room acoustics is the reverberation time. It refers to the period during which the sound level in a room decreases by 60 decibels (dB) when the sound source (e.g. a person's voice, music, etc.) suddenly stops. The length of the reverberation time in a given room depends on three factors: the size of the room, the surfaces in the room and the furnishings. The reverberation time is frequency-dependent, since stone, wood, carpet and textiles absorb sound differently at different frequencies.

The required reverberation time depends on the room acoustics purpose for which a room is used. For example, rooms that are planned for musical performances (concert halls, etc.) have higher reverberation times than rooms like classrooms, in which many people speak, because good speech intelligibility requires a short reverberation time. In addition to the volume of the room, the reverberation time affects the degree of absorption of the walls, ceilings, floors and other objects in the room. The sound absorption coefficient is frequency-dependent and reaches values from 0 (fully reflecting surface) to 1 (fully absorbing surface). The size of the room also influences the reverberation time: The larger the room and the more reverberant (reflective) the surface materials, the longer the reverberation time.

Acoustic measurements in Viva Research Park

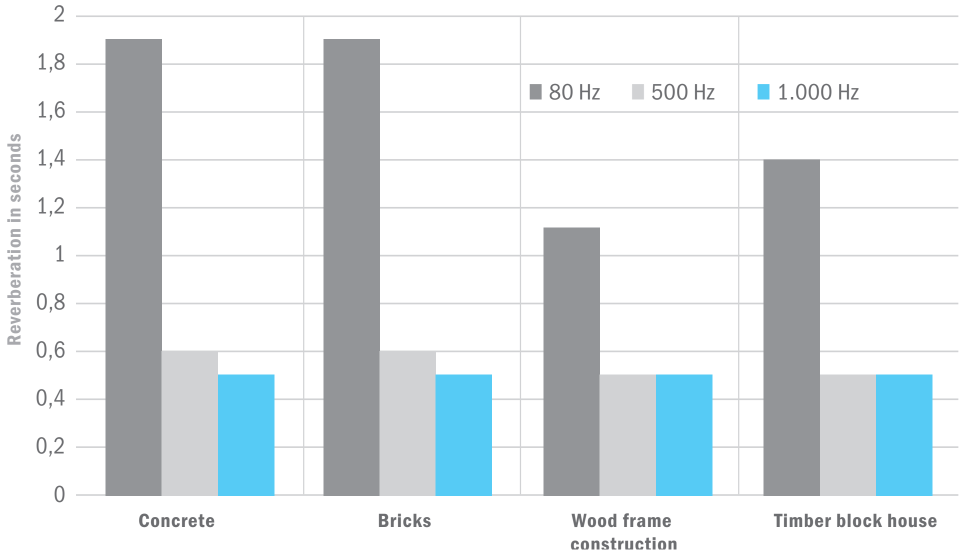
How much does the construction affect interior acoustics? The reverberation times were measured at 10 different measuring points per house at different frequencies in the range between 50 and 10,000 Hz. The scientists examined three frequency ranges in especial detail: the frequency range at 500 Hz, where the perception of human speech begins (when one understands spoken words), the middle range of speech perception between 500 and 1,000 Hz and the low frequency range from 80 Hz, in which one begins to perceive the voice (to hear the sound).

The acoustic measurements presented interesting results: While the middle and high frequencies (e.g. speaking voice, music) showed no particular differences for the different wall structures, there were clear differences in the low frequency range (e.g. voices).

There were few differences between the individual construction types for frequencies > 500 Hz. The average values ranged between 0.5 and 0.6 seconds of reverberation at both 500 Hz and 1,000 Hz. In these frequency ranges, the materials selected for the wall structures obviously plays a subordinate role in room acoustics.

Reverberation times of wall structures at different frequencies

The acoustic measurements at Viva Research Park only detected audible differences in the low-frequency range. At 80 Hertz, the houses with wood frame construction and the timber block house had the shortest reverberation times (average values for the individual house types). Source: IBO



Different results for the lower frequencies: The houses made of concrete and brick had the longest reverberation times of 1.9 seconds, while the scientists measured the shortest reverberation times in the timber block house (1.4 s) and the wood frame construction houses (1.1 s).

What to do in the event of intense reverberation in the low-frequency range?

In general, low-frequency areas in the living space are evaluated as non-critical, as the reverberation times are usually neutralized by furnishings such as boxes, carpets and/or curtains. However, in office spaces with many bare areas, an increased reverberation time can play an important role. Special acoustic plasters or room and ceiling panels can help in this regard.
The results of the building acoustics measurements match the subjective perception of reverberation times on site fairly well. Different groups of people were asked to individually rate the reverberation times. Here, too, the longest reverberation times were found in solid concrete houses.

3.4. HIGH-FREQUENCY FIELDS

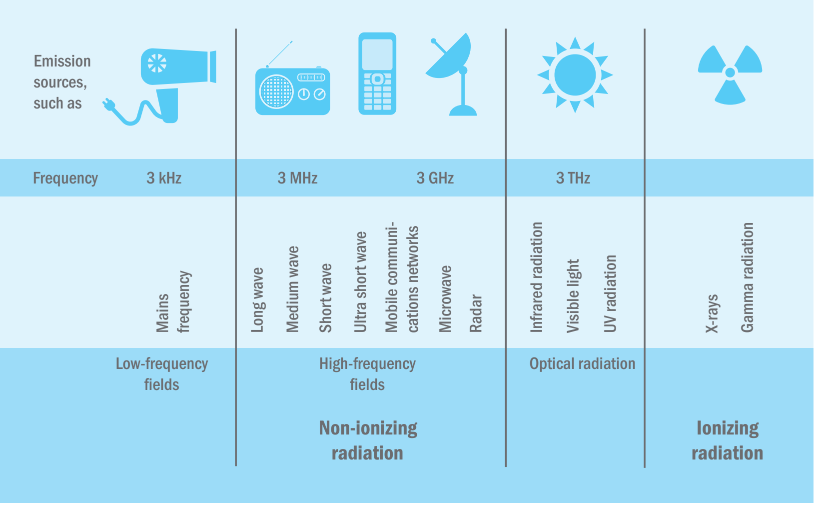
The best materials for attenuating electromagnetic fields are concrete and solid wood.

Electromagnetic fields are defined as radiation with a frequency between 100 kilohertz (kHz = 1,000 Hz) and 300 gigahertz (GHz = 1,000,000,000 Hz). Within this range, the electrical and magnetic fields switch direction several thousand times to billions of times every second.

High-frequency radiation is emitted by antennas and is primarily used for communication technologies. All radio and TV signals, all wireless technologies, mobile communication (GSM, UMTS, LTE), cordless telephones, WLAN and Bluetooth fall within the high-frequency range and span a wide frequency range. This ranges from a few MHz (short wave radio) through the FM radio range at about 100 MHz to the mobile network range, which is between approximately 800 MHz and a few GHz.

Electromagnetic fields in the environment

High-frequency fields fall within the range of 100 kilohertz and 300 gigahertz.



There are currently numerous studies running on the long-term effects of high-frequency electromagnetic fields on humans. The warming of tissue is now considered a safe effect of microwaves. However, observations show that, in addition to the warming effects, other biological effects occur in the so-called low-dose range.

In this regard, the classification by the World Health Organization (IARC, International Agency for Research on Cancer) of high-frequency mobile communications fields into Group 2B, which may have a carcinogenic effect in humans, should not be ignored. The present findings recommend the careful handling of electromagnetic fields in the mobile communications range.

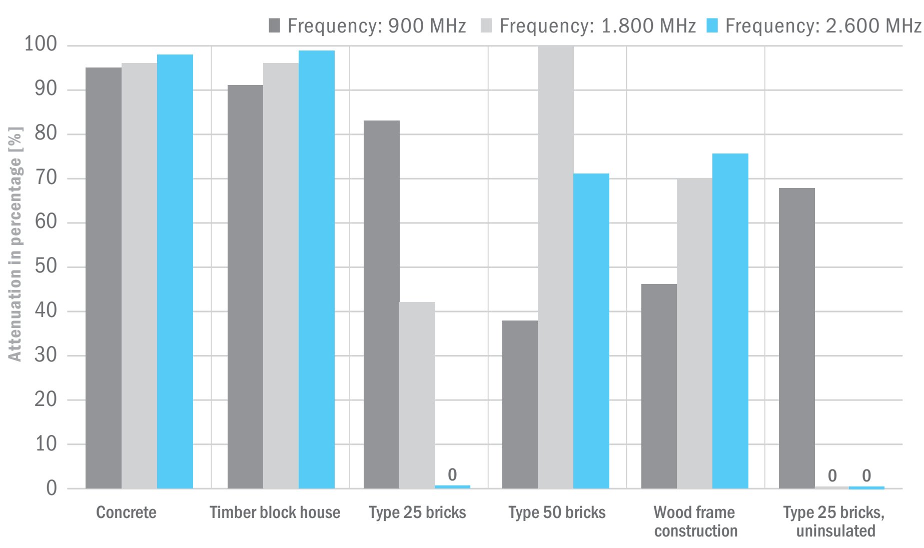
High-frequency electromagnetic fields in Viva Research Park

How much can different types of construction attenuate (or „dampen“) high-frequency fields?

In Viva Research Park, the scientists tested the shielding capability of the research houses in relation to the three most common mobile communications frequency bands (900 MHz, 1,800 MHz and 2,600 MHz). For this purpose, the scientists placed a transmitter antenna outside the respective research house at a fixed distance from the wall surface and at a height of one meter above the floor level. The receiving antenna was located in the house at a fixed distance from the transmitting antenna and at the same height.

Damping of high-frequency fields in different wall structures

Concrete and solid wood almost entirely attenuate different high-frequency fields. The uninsulated brick house performed the most poorly (average values of the individual house types). Source: IBO Innenraumanalytik OG



The measurement results drew a clear picture: The concrete houses attenuated almost 100% of all three frequencies, closely followed by the timber block house. For the two frequencies 1,800 MHz and 2,600 MHz, the uninsulated house (older construction, type 25 brick) performed the most poorly. Interesting differences came to light for the frequencies with other construction types: the house with type 50 bricks completely attenuated the frequency of 1,800 MHz. At the high-performance frequency of 2,600 MHz, attenuation was only 71%; while attenuation was only 38% at the 900 MHz frequency. In general, it can be said that the insulated houses with wood frame construction and the insulated brick houses gave average performances in terms of their damping efficacy for high-frequency fields. It should be noted that a high attenuation effect (damping) also means that the amount of radiation emitted by mobile phones used in strongly damped houses is higher.

3.5. WELL-BEING AND COMFORT

Thermal insulation and the type of construction affect health and comfort. The most comfortable houses are insulated brick houses with type 25 bricks and Baumit KlimaPutz as well as insulated concrete houses with Baumit KlimaPutz.

How do different methods of construction affect health? As a cooperation partner with Viva Research Park, the Medical University of Vienna dealt intensively with this question. After FH Burgenland and IBO Innenraumanalytik OG evaluated all of the measurement data, all data records were transmitted anonymously to the scientists at the Medical University of Vienna. The data was anonymized so that no conclusions could be drawn about individual houses. Afterwards, the results were evaluated based on health-related factors. The scientists primarily focused on the endpoints of well-being and comfort, which are also regarded as the basis for healthy living.

Indoor Air Quality analysis

Using a so-called Indoor Air Quality (IAQ) analysis, scientists at the Medical University of Vienna assessed the individual climatic and building physics factor bundles for each building type in terms of their effects on comfort and well-being.

In doing so, they tested the individual houses to determine which of the measured parameters created relevant differences in comfort levels. At the same time, all comfort parameters were evaluated for each house with the help of a specially developed „discomfort score“. This score is based on fundamental biophysical conditions according to Fanger, the so-called Fanger equation, and on ISO 7730 (2005).

As a basis, a room temperature of 21 °C and a relative humidity of 50% were assumed. All deviations from this base or this optimum were taken into calculation. If the room climate corresponds precisely to the specifications, the discomfort score is zero and fulfills the optimal conditions for our sense of comfort. The higher this value, the greater the deviations from the optimum.

DISCOMFORT SCORE

On the basis of the data on air temperature, air humidity and temperature of the enclosing surfaces, a discomfort score was determined every hour; these scores were then used to calculate a daily average value. ISO 7730 and the comfort criteria defined by Fanger were the starting point for the discomfort score. From this. the scientists developed their own formula, which they used for their calculations.

Discomfort score formula:

$$\text{Discomfort score} = \left|\frac{\Delta\text{vert}}{5}\right| + \left|\frac{\Delta\text{Wall, air}}{4}\right| + \left|\frac{\Delta\text{Wall}}{5}\right| + \left|\frac{T-21}{4}\right| + \left|\frac{F-50}{10}\right|$$

Δvalue:	Numerical value of vertical temperature gradients (floor, ceiling) in Kelvin (K)
ΔWall, air:	Numerical value of the temperature difference between the air temperature in the center of the room (T) and the average temperature of the enclosing surfaces
ΔWall:	Numerical value of the maximum temperature differences of the walls
T - 21 =>	Numerical value of the temperature minus 21; where 21 °C corresponds to the assumed optimum room temperature
F - 50 =>	Numerical value of the relative humidity minus 50; where 50% relative humidity corresponds to the assumed optimum relative humidity
	Source: MedUni Wien [Medical University of Vienna]

Evaluation results

Clear results of the residential medical analysis: The type of construction and the choice of building materials significantly affect comfort levels.

For example, if two buildings have the same thermal insulation properties, the solid structure performs better than the light-weight construction method. If the thermal insulation properties are different but the construction method is the same, the house with thermal insulation performs significantly better - which is also the biggest difference in terms of comfort: A brick house with 25 cm brick thicknesses and thermal insulation where the U-value = 0.15 W/m^{2}K demonstrated a very high degree of comfort; whereas the same type of construction without insulation performed the most poorly.

Overall evaluations for the Viva Research Park research houses				
Research houses	**House 4**	**House 2**	**House 1**	**House 10**
Wall materials	Type 25 bricks	Concrete	Concrete	Timber block house
Thermal insu-lation	Baumit open®air climate protection facade with Baumit open®air facade panel	Baumit open®air climate protection facade with Baumit open®air facade panel	Baumit WDVS XS 022 with Baumit facade insulation panel XS 022	Baumit WDVS Nature with Baumit solid soft wood fiber panel
Cleaning systems	Lime plaster Baumit KlimaPutzS	Lime plaster Baumit KlimaPutzS	Dispersion filler Baumit FinoFinish	No interior plaster, only timber block wall
Wall paint	Mineral paint Baumit KlimaColor	Special paint Baumit Ionit	Dispersion paint Baumit Divina Classic	No interior coating
Well-being and comfort				
Evaluation	high			
Score	1,4	1,4	1,5	1,7

When studying well-being and comfort, the primary focus was on temperature and humidity. All houses with a score up to 1.75 demonstrate a high level of comfort. Source: MedUni Wien [Medical University of Vienna]

Since all research houses - except for the uninsulated house (which corresponds to a renovated brick house with older construction) - meet the extremely high standards of Austrian building guidelines and standards, none of them demonstrated an extremely poor degree of living comfort. For this reason, the values for the degree of living comfort are relatively similar for all houses. All houses up to a score of 1.75 were classified into a comfort level; the houses scoring between 1.76 and 2.0 fell in the average comfort range. All wall structures with a score higher than 2 demonstrate a low level of comfort.

Overall evaluations for the Viva Research Park research houses				
Research houses	**House 9**	**House 6**	**House 7**	**House 3**
Wall materials	Type 50 bricks	Wood frame with gypsum plasterboard paneling	Wood frame with gypsum plasterboard paneling	Type 25 bricks
Thermal insulation	Insulation inside bricks - filled with mineral wool BaumitGrundPutz Leicht	Baumit WDVS ECO with Baumit facade insulation panel ECO plus	Baumit WDVS ECO with Baumit facade insulation panel ECO plus	No insulation for Baumit MPA 35
Cleaning systems	Lime plaster Baumit KlimaPutzS	No interior plaster, only gypsum plasterboard sheets	Gypsum plasterboard sheets + special plaster Baumit Ionit Spachtel	Gypsum plaster Baumit GlättPutz
Wall paint	Mineral paint Baumit KlimaColor	Dispersion paint Baumit Divina Classic	Special paint Baumit Ionit	Dispersion paint Baumit Divina Classic
Well-being and comfort				
Evaluation	average			low
Score	1,9	1,9	1,9	2,1

4. VIVA
THE HOUSES

DETAILED RESULTS AND TYPES OF HOUSES

4.1. OVERALL EVALUATION MATRIX FOR HOUSES

How do the individual houses compare? In order to provide a meaningful overview of the different types of houses, the scientists set themselves the goal of summarizing all individual measurement results of the research institutes in a comprehensive overall evaluation matrix. This had never been done before.

In doing so, the experts faced the challenge of defining comprehensible evaluation criteria for the sometimes very different parameters. This resulted in four evaluation classes:

1. Building physics parameters
2. Physical parameters
3. Chemical parameters
4. Well-being and comfort

These are the evaluation classes:

In the assessment matrix for building physics, physical parameters and chemical parameters, the research houses were evaluated according to relevant criteria such as heat storage behaviour, summer overheating, interior surface temperature, moisture buffering, sound and acoustics, attenuation of high-frequency fields, radon, odor, VOCs and formaldehyde. The building physics parameters were classified as „low“, „average“, „high“ and „very high“. The same classifications apply to the radon concentration. For the evaluation of the formaldehyde concentration and the volatile organic compounds (VOCs), classification was based on national and international guidelines and divided into 5 quality classes. Here, Class 1 designates the best and Class 5 the worst indoor air quality. In turn, the sensory odor tests were divided into „unremarkable“ and „remarkable.“ Classification for the parameters of sound insulation, room acoustics and the damping effect of high-frequency electromagnetic fields, classification was divided into „high“, „average“ and „low“. The same classification applies to the „well-being and comfort“ parameters, which were assessed using each house‘s discomfort score (Section 3.5).

VIVA RESEARCH PARK HOUSES

OVERALL EVALUATIONS

The overall evaluation matrix includes all tested research houses with their different wall structures and different building materials used. Some of the individual evaluation classes were developed specifically for this research project. Eight houses were included in the comprehensive overall evaluations.

Overall evaluations for the Viva Research Park research houses					
Research houses		**House 1**	**House 2**	**House 3**	**House 4**
Wall materials		Concrete	Concrete	Type 25 bricks	Type 25 bricks
Thermal insulation		Insulated	Insulated	Uninsulated	Insulated
Cleaning systems		Dispersion filler Baumit FinoFinish	Lime plaster Baumit KlimaPutzS	Gypsum plaster BaumitGlättPutz	Lime plaster Baumit KlimaPutzS
Wall colours		Dispersion paint Baumit Divina Classic	Special paint Baumit Ionit	Dispersion paint Baumit Divina Classic	Mineral paint Baumit KlimaColor
Building physics parameters					
Heat storage behaviour		high	high	low	average
Protection against summer overheating		high	high	low	average
Fluctuation of interior surface temperature		low	low	very high	average
Moisture buffering		low	high	low	high
Physical parameters					
Sound insulation		high	high	low	average
Room acoustics		average	average	average	average
Attenuation of high-frequency fields		high	high	low	low
Radon		low	low	low	low
Chemical parameters					
Odor	**after 7 months**	unremarkable	unremarkable	unremarkable	unremarkable
	after 14 months	unremarkable	unremarkable	unremarkable	unremarkable
VOC	**after 3 months**	Class 1	Class 1	Class 5	Class 4
	after 15 months	Class 2	Class 2	Class 3	Class 1
	after 19 months	Class 1	Class 1	Class 1	Class 1
Formal-dehyd	**after 3 months**	Class 1	Class 1	Class 1	Class 1
	after 15 months	Class 1	Class 1	Class 1	Class 1
	after 19 months	Class 1	Class 1	Class 1	Class 1
Well-being and comfort					
Evaluation		high	high	low	high

It should be noted that the results obtained indicate the room air hygiene, technical radiation and acoustic conditions using the respective products, but these results are not necessarily always representative of the respective wall structure or materials.

Research house number 5 was used for new product trials and is therefore not represented in the overall evaluation. House number 8 is also not in the matrix because it contains the central data acquisition and the measuring computer.

Overall evaluations for the Viva Research Park research houses

Research houses		House 6	House 7	House 9	House 10
Wall materials		Wood frames with gypsum plasterboard paneling	Wood frames with gypsum plasterboard paneling	Type 50 bricks filled with mineral wool	Timber block wall
Thermal insulation		Insulated	Insulated	Insulated	Insulated
Cleaning systems		No interior plaster, only gypsum plaster-board sheets	Gypsum plasterboard sheets + special plaster Baumit Ionit Spachtel	Lime plaster Baumit KlimaPutzS	No interior plaster, only timber block wall
Wall colours		Dispersion paint Baumit Divina Classic	Special paint Baumit Ionit	Mineral paint Baumit KlimaColor	No interior coating
Building physics parameters					
Heat storage behaviour		low	low	average	average
Protection against summer overheating		low	low	average	low
Fluctuation of interior surface temperature		high	high	average	average
Moisture buffering		low	average	high	high
Physical parameters					
Sound insulation		low	low	average	average
Room acoustics		high	high	average	high
Attenuation of high-frequency fields		average	average	average	high
Radon		low	low	low	low
Chemische Parameter					
Odor	after 7 months	noticeable	noticeable	unremarkable	noticeable
	after 14 months	noticeable	noticeable	unremarkable	noticeable
VOC	after 3 months	Class 4	Class 4	Class 2	Class 5
	after 15 months	Class 4	Class 2	Class 1	Class 4
	after 19 months	Class 2	Class 1	Class 1	Class 4
Formal-dehyd	after 3 months	Class 1	Class 1	Class 1	Class 3
	after 15 months	Class 1	Class 1	Class 1	Class 4
	after 19 months	Class 1	Class 1	Class 1	Class 4
Well-being and comfort					
Evaluation		average	average	average	high

Summary of results

Building physics parameters

In terms of building physics parameters, the insulated solid houses performed particularly well. Solid construction - whether with brick or concrete, plus thermal insulation - is the ideal construction method in terms of heat storage capacity, protection against summer overheating and low heating and cooling costs. The wood house also performed well in terms of building physics. The insulated wood frame construction houses with gypsum plasterboard sheets were not able to deliver comparable results due to their lower storage mass. The uninsulated brick house, which was modelled after non-renovated old stock, brought up the rear.

The moisture buffering capacity of the wall materials is critically related to the interior coating. The houses coated with Baumit KlimaPutz and Baumit Ionit had far higher moisture buffering abilities than the houses that were only treated with dispersion plaster and paint. The timber block house created an interesting effect: inside, the natural wood demonstrated excellent moisture buffering abilities.

Physical parameters

In terms of sound insulation and the attenuation of high-frequency electromagnetic fields, the concrete houses ranked first, followed by the wood house and the brick houses. In terms of room acoustics, the wood house and the houses constructed with wood frames did particularly well. The radon exposure was low in all research houses.

Chemical parameters

In terms of odor, the concrete and brick houses were neutral. However, in terms of odor, the two wood frame construction houses (damp, musty) and the wood house (intense, long-lasting wood odor) gave off conspicuous odors.

The formaldehyde loads - except for the timber block house - were in the very good Class 1 range for all research houses. This wood house was rated Class 4 due to its high formaldehyde emissions. This high formaldehyde concentration was most likely due to the formaldehyde-releasing glue that was used for the wood material of the wall structure.

Two years after the houses were completed, all were virtually VOC-free, with one exception: the wood house. Here too, the VOC content was still quite high after this time due to the wood-specific terpene emissions (Class 4).

Comfort parameters

In terms of comfort, the brick and concrete houses with external insulation and the timber block house performed particularly well. All demonstrated a high level of comfort. In this category, as expected, the uninsulated house (older construction, type 25 bricks) performed the worst.

4.2. THE HOUSES IN DETAIL

The concrete houses

Concrete is the most commonly used building material for houses - multi-story residential buildings are usually built with concrete. Single-family houses made of concrete are still fairly rare in our latitudes, although architects are increasingly resorting to concrete as a building material due to its wide range of design options.

Concrete

Concrete is a functional building material: limestone and clay cement is mixed with sand or gravel and water. Adding different materials creates specialized types of conncrete: Adding structural steel or prestressing steel creates reinforced concrete. The most important component of concrete is cement, because the so-called cement paste, which joins the aggregate, can only be formed in combination with water. Only then is a solid building material created.

Concrete as a building material

In order to optimally use small pieces of property, the current trend is compacted construction. The goal is to create as much living space as possible in the most compact square footage. Therefore, losing as little living space as possible to thick walls and additional heat, fire and sound insulation is ideal. In this case, concrete is an ideal building material; due to its good fire and sound insulation properties, it creates thinner walls than traditional masonry. This means that, for a house with 100 m^2 of floor space, building with concrete adds up to 6 m^2 of extra space.

In the case of concrete houses, system design (prefabricated concrete parts for walls, staircases, ceiling elements, etc.) and in-situ concrete are usually combined with formwork (fresh concrete placed on the construction site for floor slabs, etc.) - which saves both time and money.

Advantages and disadvantages of concrete	
Advantage	**Disadvantage**
Durability and resilience	Low moisture buffering capability - therefore no balanced room temperature due to lack of plaster
Good storage capacity for heat and cold	No special acoustics for living areas - long reverberation time
Good sound insulation	High weight relative to the compressive strength
Outstanding fire protection	Risk of cracking - concrete shrinks
High density makes thin walls possible	Demolition of concrete buildings is time-consuming and expensive
High degree of design freedom (structure, strength, color)	
Targeted adjustable properties for all demands and requirements	
Recyclable	

Profile of concrete houses

Two concrete houses made of precast concrete elements were constructed in Viva Research Park. Their only differences are their thermal insulation, the interior plaster and the wall paint.

Wall structure of concrete houses						
House	**Wall materials**	**Wall thickness (cm)**	**Insulation**	**Insulation thickness (cm)**	**Cleaning systems**	**Wall colours**
1	Concrete	18	Baumit facade insulation panel XS 022	14	Dispersion filler Baumit FinoFinish	Dispersion paint Baumit Divina Classic
2	Concrete	18	Baumit open®air climate protection panel	20	Lime plaster Baumit KlimaPutzS	Special paint Baumit Ionit

Research houses 1 and 2 in concrete: overview of building materials and insulation thicknesses

Strengths of concrete houses

The analyses in Viva Research Park demonstrate: due to their high storage mass, concrete houses have excellent heat storage behavior and, in combination with heat insulation, they adequately protect from summer overheating as well as rapid cooling.

In terms of sound insulation, the concrete houses performed very well due to their mass; the shielding (attenuation) of high-frequency electromagnetic fields was high. The houses made of concrete were unremarkable in terms of odor and the emission of pollutants.

Weaknesses of concrete houses

The two different concrete houses demonstrated differences in terms of moisture buffering. This is one of the weaknesses of concrete as a building material: its low moisture buffering capacity. The interior wall treated only with plaster and interior diffusion paint was able to buffer much less moisture than the wall with Baumit KlimaPutz and Baumit Ionit. An interesting finding was that merely a thin layer of Baumit KlimaPutz (1.5 to 2 cm) immensely improved the moisture buffering capacity in the interior. The acoustics in the concrete houses were mediocre due to relatively long reverberation times.

Evaluation matrix for concrete houses			
Research houses		**House 1**	**House 2**
Wall materials		Concrete	Concrete
Thermal insulation		Insulated	Insulated
Plaster system		Dispersion plaster	Lime plaster
Wall paint		Dispersion paint	Baumitlonit
Building physics parameters			
Heat storage behaviour		high	high
Protection against summer overheating		high	high
Fluctuation of interior surface temperature		low	low
Moisture buffering		low	high
Physical parameters			
Sound insulation		high	high
Room acoustics		average	average
Attenuation of high-frequency fields		high	high
Radon		low	low
Chemical parameters			
Odor	**after 7 month**	unremarkable	unremarkable
	after 14 month	unremarkable	unremarkable
VOC	**after 3 month**	Class 1	Class 1
	after 15 month	Class 2	Class 2
	after 19 month	Class 1	Class 1
Formaldehyde	**after 3 month**	Class 1	Class 1
	after 15 month	Class 1	Class 1
	after 19 month	Class 1	Class 1
Well-being and comfort			
Evaluation		high	high

The concrete houses performed very well in the areas of heat storage, sound insulation, VOCs, formaldehyde and attenuation of high-frequency fields. Sources: FH Burgenland, IBOInnenraumanalytikOG, MedUni Wien

How healthy and comfortable is a concrete house?

Concrete houses with an internal diffusion-open and moisture-buffering interior coating, such as Baumit Ionit and Baumit KlimaPutz, are more comfortable than concrete houses without interior plaster. This was demonstrated by the evaluations in Viva Research Park. Climate-active interior coatings provide better moisture buffering effects and thus create a balanced and healthy indoor climate. In general, the concrete house with Baumit KlimaPutz and Baumit Ionit performed very well in terms of comfort. In terms of VOCs and formaldehyde pollution, concrete houses achieved the highest Class 1 (evaluation: Classes 1-5; for details see the Houses overall evaluation matrix).

The brick houses

Single-family brick houses are the most common construction in our latitudes. Almost 70% of all single-family homes in Austria are made of bricks. Brick houses are regarded as stable in value; they are cost-effective and have good room climate properties.

Bricks as a building material

Bricks are among the oldest building materials used by humans. The first find of unfired clay bricks is more than 6,000 years old. The first bricks made of fired clay were made around 3000 B.C. Until well into the middle of the 20th century, brick houses were built entirely from solid bricks. However, when Porotherm brick - the first perforated brick - hit the market in the 1970s, the brick industry changed rapidly. Today, the originally dense solid brick is mostly only used as facing material for double-shell wall structures. The actual masonry in brick buildings consists of perforated or hollow bricks.

Your benefits: The holes reduces the weight of the bricks as well as the thermal conductivity, creating an improved thermal insulation effect. A further development of recent years is thermal insulation tiles whose cavities are filled with insulating material such as mineral wool. As a result, energy-efficient brick houses meeting the passive house standard are possible.even without additional insulation.

Their contact surfaces are smoothed in order to improve the installation process. This is why we also refer to flat bricks or precision blocks. The smooth surfaces mean that only small amounts of mortar are required in masonry. In order to work more efficiently and more economically, especially for multi-story residential construction, large-scale brick plan elements have also been developed in recent years. There are also specialized types of brick which are used for areas such as basements or interior walls.

Advantages and disadvantages of bricks	
Advantages	**Disadvantages**
Good insulation and thermal insulation	Longer construction time
Outstanding fire protection	Load capacity of walls is not as high
More robust and stable building material	
Long service life	
Natural and sustainable	
Easy to process	
Good price-performance ratio	
Good moisture storage capacity	
Good sound insulation	
High degree of flexibility during construction and renovation	

Profile of insulated brick houses

In Viva Research Park, three different brick houses were analysed - a traditional brick house with type 25 bricks and exterior insulation, a brick house with type 50 bricks filled with mineral wool - dispensing with the need for additional exterior insulation - and a house with type 25 bricks and no thermal insulation.

Wall structure for insulated brick houses						
House	**Wall materials**	**Wall thickness (cm)**	**Insulation**	**Insulation thickness(cm)**	**Cleaning systems**	**Wall colours**
4	Wienerberg Porotherm 25 N+F bricks	25	Baumit open®air climate protection facade with Baumit open®air facade panel	18	Lime plaster Baumit KlimaPutzS	Mineral paint Baumit KlimaColor
9	Wienerberg Porotherm 50 W.i object plan (filled with mineral wool)	50	Insulation in bricks filled with mineral wool Baumit GrundPutz Leicht	0	Lime plaster Baumit KlimaPutzS	Mineral paint Baumit KlimaColor

Research house 4 made of type 25 bricks and house 9 made of type 50 bricks: overview of building materials and insulation thicknesses

The brick house with type 25 bricks received 18 cm-thick exterior insulation made of EPS. The combination of type 25 bricks and exterior thermal insulation with EPS is the most common construction method for single-family homes in Austria.
In order to take new developments in the brick sector into account, a brick house with type 50 bricks filled with mineral wool was also erected in Viva Research Park. Baumit KlimaPutz and the mineral paint Baumit KlimaColor were used in the interiors of both brick houses.

Strengths of insulated brick houses

In terms of heat storage behavior and protection against summer overheating, the insulated brick houses fell in the middle range, as did the interior surface temperatures of the exterior walls. This is due to the solid construction of the brick. However, the concrete houses have even more mass - a square meter of brick wall (including interior plaster, exterior insulation and exterior coating) with type 25 bricks weighs approximately 248 kg/ m^2; with type 50 bricks, filled with mineral wool, a square meter weighs approximately 370 kg/m^2; a square meter of concrete wall (including interior plaster, exterior insulation and exterior coating), on the other hand, weighs approximately 487 kg/m^2 - thus demonstrating better values in comparison. The moisture buffering capability of both brick houses is very high. In addition to the moisture-regulating properties of bricks, this is also due to the use of Baumit KlimaPutz and the mineral paint Baumit KlimaColor, which also have moisture-buffering and vapor-permeable effects. Sound insulation and room acoustics were deemed „average“ in insulated brick houses. The odor and emission of pollutants were unremarkable.

Weaknesses of insulated brick houses

The insulated brick houses were not especially noteworthy in any particular area. Only the attenuation of high-frequency electromagnetic fields was low for the type 25 bricks; it was moderately pronounced with the type 50 bricks.

Evaluation matrix for insulated brick houses			
Research houses		**House 4**	**House 9**
Wall materials		Type 25 bricks	Type 50 bricks filled with mineral wool
Thermal insulation		Insulated	Insulated
Plaster system		Lime plaster	Lime plaster
Wall paint		Mineral paint	Mineral paint
Building physics parameters			
Heat storage behaviour		average	average
Protection against summer overheating		average	average
Fluctuation of interior surface temperature		average	average
Moisture buffering		high	high
Physical parameters			
Sound insulation		average	average
Room acoustics		low	low
Attenuation of high-frequency fields		low	average
Radon		low	low
Chemical parameters			
Odor	**after 7 month**	unremarkable	unremarkable
	after 14 month	unremarkable	unremarkable
VOC	**after 3 month**	Class 4	Class 2
	after 15 month	Class 1	Class 1
	after 19 month	Class 1	Class 1
Formaldehyde	**after 3 month**	Class 1	Class 1
	after 15 month	Class 1	Class 1
	after 19 month	Class 1	Class 1
Well-being and comfort			
Evaluation		high	average

In terms of moisture buffering, both brick houses performed especially well; in all other areas, they fell solidly in the middle range. Sources: FH Burgenland, IBO Innenraumanalytik, MedUni Wien

How healthy and comfortable is an insulated brick house?

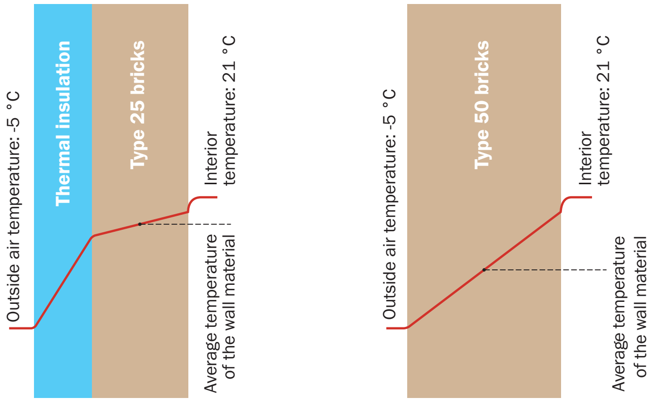
The results of the comfort analysis were an interesting point. Here, the brick house with type 25 bricks and exterior insulation, together with the concrete house with Baumit Klima Plaster and Baumit Ionit performed better than all other research houses. This is due to the solid construction and the moisture-buffering interior coating, which created a well-balanced interior climate.

This result is also consistent with the subjective evaluation of 200 visitors to Viva Research Park. The majority of visitors felt most comfortable in the brick house with type 25 bricks and exterior insulation.

The brick house with type 50 bricks filled with mineral wool was on par with the houses with wood frame construction, but performed less well than the type 25 brick house. This is due to the average temperature of the storage-effective masses: If the insulation external, the average temperature of the storage-effective masses is significantly higher than for the type 50 bricks filled with mineral wool. In addition, if massive materials with high density, specific heat capacity and thermal conductivity are used, the heat energy can be stored better and released into the room quickly. This means that the building does not cool down so quickly, such as in the event of a heating failure in winter.

Comparison of average temperature for type 25 bricks with exterior insulation and type 50 bricks filled with mineral wool.

The average temperature of the storage-effective masses is higher for type 25 bricks with exterior insulation than for type 50 bricks filled with mineral wool. Source: FH Burgenland



The formaldehyde emissions were low immediately after construction for the type 25 brick house and the type 50 brick house. The VOC concentration in the interior air was low immediately after completion, aside from the first test. The high value during the first test was due to the fact that an aromatic-containing adhesive was used to seal the measurement sensors during the construction phase. Normally an adhesive of this type is not used in a brick house. After 15 months, both brick houses were judged Class 1 - best interior air quality.

Profile of uninsulated brick house

In order to have a good basis for comparison between modern construction with thermal insulation and older construction, there is one uninsulated house in Viva Research Park. It consists of type 25 bricks and corresponds to the traditional, non-renovated older construction. Inside, the house received a coating of gypsum smoothing plaster and traditional dispersion paint.

Wall structure of the uninsulated brick house						
House	**Wall materials**	**Wall thickness (cm)**	**Insulation**	**Insulation thickness(cm)**	**Plaster system**	**Wall colours**
3	Wienerberg Porotherm 25 N+F bricks	25	No insulation	0	Gypsum plaster Baumit GlättPutz	Dispersion paint Baumit Divina Classic

Comparison object: Research house 3 is the only house in Viva Research Park with no insulation.

Strengths of the uninsulated brick house

In terms of odor, the values of the uninsulated brick house were unremarkable. The acoustics were average.

Weaknesses of the uninsulated brick house

The heat storage behavior in uninsulated brick house was low due to the lack of thermal insulation as well as the lack of protection against summer overheating. The fluctuations of the interior surface temperatures of the exterior walls were also high. All of these factors create a situation in which the costs for heating and cooling are exponentially higher than for a insulated brick house.

In order to maintain a comfortable temperature of 21 °C in the interior during the long-term measurements throughout the past several winters, 150% more energy had to be expended in the uninsulated brick house than in the insulated brick house. The fact that the moisture buffering capacity in an uninsulated brick house is low is partly due to the lack of thermal insulation and the resulting cooler interior surface temperature of the exterior walls as well as to the use of gypsum plaster, which can buffer less moisture than a lime plaster such as Baumit KlimaPutz.

The sound insulation was also low due to the lack of insulation. Similarly, the shielding ability of high-frequency electromagnetic fields was also low.

Evaluation matrix of the uninsulated brick house		
Research houses		**House 3**
Wall materials		Type 25 bricks
Thermal insulation		Uninsulated
Plaster system		Gypsum plaster
Wall paint		Dispersion paint
Building physics parameters		
Heat storage behaviour		low
Protection against summer overheating		low
Fluctuation of interior surface temperature		very high
Moisture buffering		low
Physical parameters		
Sound insulation		low
Room acoustics		average
Attenuation of high-frequency fields		low
Radon		low
Chemical parameters		
Odor	**after 7 month**	unremarkable
	after 14 month	unremarkable
VOC	**after 3 month**	Class 5
	after 15 month	Class 3
	after 19 month	Class 1
Formaldehyde	**after 3 month**	Class 1
	after 15 month	Class 1
	after 19 month	Class 1
Well-being and comfort		
Evaluation		low

The uninsulated house performed poorly in all building physics parameters. Sources: FH Burgenland BO Innenraum-analytikOG, MedUni Wien

How healthy and comfortable is an uninsulated brick house?

In terms of comfort, the uninsulated brick house (older construction, type 25 bricks) was the worst of all assessed research houses. The cause: in comparison to an insulated house, the room climate is not balanced. There are severe temperature differences between the center of the room and the interior surface temperature of the exterior walls. In addition, there are often phases with extremely low ambient humidity or dry air during the winter months. This creates an uncomfortable ambient atmosphere. Although the VOC values increased during the first two measurements (Measurement 1: Class 5, measurement 2: Class 3), this was due to the accidental use of an aromatic-containing adhesive to seal the measurement sensors during the construction phase. Normally an adhesive of this type is not used in a brick house. During the following tests about 1.5 years after the house was completed, the adhesive no longer impaired the values and the VOC concentration had fallen sharply. Therefore, it was classified into Quality Class 1. The formaldehyde concentrations were already low during the first measurements taken after 3 months.

WOOD FRAME CONSTRUCTION

The body of a wood frame house will be constructed with a wood carrier structure. Then the areas between the walls are filled with thermal insulation, such as rock wool or mineral wool The inside of the wall is made of a layer of chipboard, a vapor barrier and plasterboard paneling. The outside can be covered with a variety of materials. The simplest construction involves wood formwork, but metal panels can also be used. The walls are usually prefabricated, which is why the actual construction on-site is extremely fast.

The houses constructed with wood frames

About one third of all single-family homes in Austria are made with prefabricated wood frame construction. This is generally due to the short construction time and the more affordable construction costs.

Wood frame construction as a building material

For wood frame construction, planked wooden frames in walls and ceilings are used for the support structure. The walls are made of wood frames, which are placed at intervals of about 50 cm and reinforced with diagonally arranged planks of wood or chipboard. The ceilings are constructed analogously: a board or panel is nailed to the top and bottom of the wood frames.

Designed by the pioneers in the US, this method is still the cheapest and easiest way to build a house. No traditional woodworking joints are used; all wood joints are nailed. If the studs are higher than several floors, the construction is called „balloon framing“. If each separate floor is framed with its own studs, this method is called „platform framing“. This design is still used today; most of the houses in the USA are built this way and are characterized by their good stability.

Advantages and disadvantages of a wood frame wall

Advantages	Disadvantages
Short construction time	Poor room temperature
Custom-fit factory prefabrication.	Low tendency towards heat storage
Takes up less floor space due to low wall thickness	Tendency towards summer overheating
Fixed price guarantee from the manufacturer	Poor sound insulation
Economical	Architecture and floor plan are usually fairly limited
	Lower resale value

Profile of wood frame construction

Two research houses were built in wood frame construction with gypsum plasterboard paneling; their only difference is their interior coating. In one house, the walls were only treated with one type of dispersion paint. The other house, however, was filled with Baumit Ionit Plaster and coated with Baumit Ionit.

The wall structure of houses constructed with wood frames						
House	**Wall materials**	**Wall thickness (cm)**	**Insulation**	**Insulation thickness(cm)**	**Cleaning systems**	**Wall colours**
6	Vario construction wood frame wall with gypsum plasterboard paneling	18	Baumit WDVS ECO with Baumit facade insulation panel ECO plus	6	No interior plaster, only gypsum plasterboard sheets	Dispersion paint Baumit Divina Classic
7	Vario construction wood frame wall with gypsum plasterboard paneling	18	Baumit WDV-S ECO with Baumit facade insulation panel ECO plus	6	Gypsum plasterboard sheets + special plaster Baumit Ionit Spachtel	Special paint Baumit Ionit

Research houses 6 and 7 in wood frame construction with gypsum plasterboard paneling: overview of building materials and insulation thicknesses used

Strengths of wood frame construction

The room acoustics were good due to the significantly lower reverberation times; the attenuation of the high-frequency electromagnetic fields was in the middle range.

Weaknesses of wood frame construction

For wood frame construction houses, heat storage behaviour as well as protection from overheating in the summer is low. The fluctuation of the interior surface temperature is high. However, the room temperature can be changed for the better with diffusion-open and moisture-buffering wall coatings. Therefore, only the wood frame house with dispersion paint performed poorly in terms of moisture buffering capacity; however, the house coated with Baumit Ionit Plaster and Baumit Ionit wall paint fell in the middle range.

The smell was striking in both houses and was classified as „unpleasant“ in the sensory tests and described as „moist and musty“ in the detailed description. These results coincide with the subjective evaluations by visitors.

The majority of the visitors found the smell in the two wood frame construction houses remarkable and unpleasant. The sound insulation of the two houses with wood frame construction was low due to the lack of density.

Evaluation matrix of wood frame construction with gypsum plasterboard paneling			
Research houses		**House 6**	**House 7**
Wall materials		Wood frames with gypsum plasterboard paneling	Wood frames with gypsum plasterboard paneling
Thermal insulation		Insulated	Insulated
Plaster system		No interior plaster, only gypsum plasterboard sheets	Gypsum plasterboard sheets + Ionit plaster
Wall paint		Dispersion paint	BaumitIonit
Building physics parameters			
Heat storage behaviour		low	low
Protection against summer overheating		low	low
Fluctuation of interior surface temperature		high	high
Moisture buffering		low	average
Physical parameters			
Sound insulation		low	low
Room acoustics		high	high
Attenuation of high-frequency fields		average	average
Radon		low	low
Chemical parameters			
Odor	**after 7 month**	noticeable	noticeable
	after 14 month	noticeable	noticeable
VOC	**after 3 month**	Class 4	Class 4
	after 15 month	Class 4	Class 2
	after 19 month	Class 2	Class 1
Formaldehyde	**after 3 month**	Class 1	Class 1
	after 15 month	Class 1	Class 1
	after 19 month	Class 1	Class 1
Well-being and comfort			
Evaluation		average	average

The ambient temperature in both houses built with wood frames is not balanced. Interestingly, the odor in both houses was classified as remarkable. Sources: FH Burgenland, IBO Innenraumanalytik OG, MedUni Wien

How healthy and comfortable is a house in wood frame construction with gypsum plasterboard paneling?

The comfort values for the wood frame houses were at the lower end of the rating scale. This is due to the unbalanced room climate.

An interesting aspect was that, in the first VOC tests in spring 2015, a relatively high VOC load was detected in both houses with wood frame construction with gypsum plasterboard paneling. Cause: an aromatic-containing adhesive used for repair work in both research houses. However, this type of adhesive is a common system adhesive in the wood frame construction industry and was also used by the manufacturer in both houses to adhere the vapor barrier. However, during further VOC measurements, the VOC load dropped significantly. One and a half years after completion, the VOC values had fallen so far that house 6 achieved Quality Class 2 and house 7 actually achieved Quality Class 1 for best interior air quality. The formaldehyde concentration was low in both houses and corresponded to the best Quality Class 1 shortly after completion.

WOOD

Wood consists of cellulose and lignin and contains resins, waxes, fats, oils, starch, sugar, various minerals, tanning and coloring as well as alkaloids. It is primarily the lignin which turns a normal plant cell into a wood cell. 20 to 40 percent of the dry weight of wood consists of this „lignification“; the proportion is higher in coniferous wood than in hardwoods. The complex and highly polymeric material is chemically and physically firmly bound to the cellulose, making the wood stable and pressure-resistant.

The timber block house

In addition to stone, wood is the oldest building material used by humans, and it is a renewable resource. Recently, timber block houses have become more fashionable for single-family homes. In particular, the sustainability of timber block houses makes environmentally-conscious builders resort to wood as a building material.

Timber block wall construction material

Wood construction is stable, tough and elastic and has enormous load capacity with low net weight. A four-cm-square cube of fir wood can carry four tons of weight. This makes wood stronger than concrete and thus perfect for building houses.

In the timber block house, wall, ceiling and roofing panels are prefabricated at the factory and assembled at the construction site. For this purpose, the wood components are manufactured as single-layered as well as multi-layered, doweled, nailed or crosswise glued elements. For most solid wood houses, the insulation is applied externally. In the interior, the solid wood elements either remain visible or are covered with paneling.

Advantages and disadvantages of a timber block wall	
Advantages	**Disadvantages**
Good moisture storage capacity	Settlement and shrinkage
Good room climate	Susceptible to pests
Natural renewable building material	Expensive
Short construction time	Outgassing of VOCs and possibly formaldehyde
High pressure resistance and therefore high load capacity	

Profile of timber block house

The timber block house in Viva Research Park is a timber block house built with square timber in spruce and pine, with 5 layers of glue and 20 cm of wood fiber insulation. Inside, the timber block wall remained natural.

Strengths of the timber block house

The moisture buffering capacity of the unsealed wood surfaces in the timber block house was outstanding. It is comparable

wall structure of the timber block house						
House	**Wall materials**	**Wall thickness (cm)**	**Insulation**	**Insulation thickness(cm)**	**Plaster system**	**Wall colours**
10	Timber block wall	20	Pavatex Pavawoll Bloc wood fiber insulation	20	No interior plaster, only timber block wall	Without interior coating

The timber block house was constructed of solid wood elements and provided with exterior insulation.

to concrete coated with plaster and bricks. The heat storage behavior and the fluctuations of the interior surface temperatures fell in the middle range. However, the timber block house only demonstrated moderate protection against summer overheating. Overall, wood houses can be said to create a good, balanced room climate. In terms of sound protection, the wood house fell in the middle range; however, the acoustics were quite good due to the short reverberation times. The attenuation of the high-frequency electromagnetic fields was also very good.

Weaknesses of the timber block house

The significantly noticeable wood odor in the house was classified as remarkable due to its intensity. However, whether this odor is deemed pleasant or unpleasant is highly subjective. For this reason, the odor testers gave accordingly different evaluations. This assessment match with subjective visitor perception: some of the interviewees found the smell of wood pleasant, the others found it too intense and therefore unpleasant.

How healthy and comfortable is a timber block house?

In terms of comfort, the wood house performed very well with a score of 1.7. The formaldehyde-ambient air concentration was still very high in the timber block house 1.5 years after its construction. Therefore, the wood house was ranked in the next-to-last Quality Class 4. The cause of this high formaldehyde concentration was most likely the wood glue used. Such a high formaldehyde load would not be expected for wood materials with formaldehyde-free adhesives.
The concentration of VOCs and especially of terpenes was also conspicuously high. Terpenes are natural components of raw wood material. In addition to spruce wood, pine wood was also used in the timber block house. Pine has a tendency to emit intense amounts of terpenes for a particularly long time.

Evaluation matrix of the timber block house		
Research houses		**House 10**
Wall materials		Solid wood
Thermal insulation		Insulated
Plaster system		No interior plaster, only timber block wall
Wall paint		No interior coating
Building physics parameters		
Heat storage behaviour		average
Protection against summer overheating		low
Fluctuation of interior surface temperature		average
Moisture buffering		high
Physical parameters		
Sound insulation		average
Room acoustics		high
Attenuation of high-frequency fields		high
Radon		low
Chemical parameters		
Odor	**after 7 month**	noticeable
	after 14 month	noticeable
VOC	**after 3 month**	Class 5
	after 15 month	Class 4
	after 19 month	Class 4
Formaldehyde	**after 3 month**	Class 3
	after 15 month	Class 4
	after 19 month	Class 4
Well-being and comfort		
Evaluation		high

The timber block house has ideal moisture buffering properties. It also does very well in terms of comfort. However, opinions differed when it came to the wood odor - for some, it was much too much, while others found it pleasant. Sources: FH Burgenland, IBO Innenraumanalytik, MedUni Wien

4.3. VISITOR RESPONSES

In addition to the analyses and evaluations by researchers, more than 200 visitors rated the research houses according to their subjective opinions.

Visitor evaluation of research houses								
Research houses	**House 4**	**House 2**	**House 1**	**House 3**	**House 9**	**House 10**	**House 6**	**House 7**
Wall materials	Type 25 bricks	Concrete	Concrete	Type 25 bricks	Type 50 bricks	Solid wood	Wood frames with gypsum plasterboard paneling	Wood frames with gypsum plasterboard paneling
Thermal insulation	Baumit open®air climate protection facade with Baumit open®air facade panel	Baumit open®air climate protection facade with Baumit open®air facade panel	Baumit WDVSXS 022 with Baumit facade insulation panel XS 022	No insulation for Baumit MPA 35	Insulation in bricks filled with mineralwool Baumit GrundPutz Leicht	Baumit WDVS Nature with Baumit solid soft wood fiber panel	Baumit WDVS ECO with Baumit facade insulation panel ECO plus	Baumit WDVS ECO with Baumit facade insulation panel ECO plus
Cleaning systems	Lime plaster Baumit KlimaPutzS	Lime plaster Baumit KlimaPutzS	Dispersion filler Baumit FinoFinish	Gypsum plaster Baumit GlättPutz	Lime plaster Baumit KlimaPutzS	No interior plaster, only timber block wall	No interior plaster, only gypsum plasterboard sheets	Gypsum plasterbo-ard sheets + special spatula Baumit Ionit Spatula
Wall paint	Mineral paint Baumit KlimaColor	Special paint Baumit Ionit	Dispersion paint Baumit Divina Classic	Dispersion paint Baumit Divina Classic	Mineral paint Baumit KlimaColor	No interior coating	Dispersion paint Baumit Divina Classic	Special paint Baumit Ionit
Subjective perceptions and evaluations by visitors								
Comfort	high	average	average	average	average	average	low	low

200 visitors rated the individual research houses according to their subjective feelings and subjective level of comfort

Overall opinion of the visitors: „Who would have thought that you'd feel so different in every house! It smells different, it feels different and even the acoustics are different." The majority of the visitors felt particularly comfortable in the insulated type 25 brick house with Baumit KlimaPutz and Baumit KlimaColor - this result also largely coincides with the researchers' evaluations.

5. HEALTHY BUILDING

TIPS AND SERVICE

5.1. HOW DO YOU BUILD HEALTHY?

Construction methods and building materials have a significant impact on health and quality of life - which is the conclusion of the most comprehensive comparative analysis of building materials in Viva Research Park. Thanks to the knowledge gained by scientists specializing in construction physics, construction chemistry and medicine, we now know which parameters are relevant for a healthy home and which permanently improve quality of life. So what should you look for if you want to build a healthy home?

3 prerequisites for a healthy home:

No matter which architecture you choose when building a house, all houses have one thing in common. in order to build a healthy structure, the following areas must be taken into consideration in terms of room humidity and temperature:

Insulation first

Warm in winter, cool in summer for better health

Good thermal insulation not only contributes significantly to the energy efficiency of your building but also ensures pleasantly warm walls during the winter and pleasantly cool walls in the summer. This makes the living space a place where you feel comfortable without experiencing drafts. Living becomes more comfortable and healthy.

INSULATION FIRST

Solidity counts

Sustainable energy storage for healthy living

Solid walls can be protected from the outside by good insulation, storing heat in the winter and retaining cooler temperatures in the house in the summer. The more density, the better this storage process works and the more stable, pleasant and healthy the indoor climate remains.

SOLIDITY COUNTS

Interior values

Moisture storage for a healthy indoor climate

A good mineral cleaning system can even buffer moisture peaks within the first few centimeters by absorbing excess moisture and releasing it. A guaranteed constant level of humidity thus ensures a healthy indoor climate.

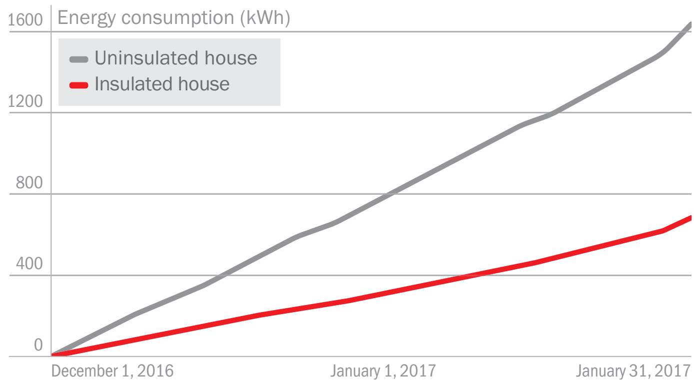
INTERIOR VALUES

Insulation first

An essential step in creating a healthy living space is optimally insulating the facade. The better the insulation, the higher the level of comfort. This has a positive impact on health while also reducing energy consumption. With efficient thermal insulation, the walls are kept warm during the colder months, while in the summer, the perfect insulation acts as a natural cold buffer. The rooms remain pleasantly cool because the exterior walls no longer heat up thanks to the insulation. In almost all building physics and comfort evaluations in Viva Research Park, the uninsulated house performed much more poorly than the insulated houses. And don‘t forget: an uninsulated house consumes significantly more heating energy than an insulated house.

Comparison of energy consumption for insulated and uninsulated houses

The energy consumption of an uninsulated house is about 2.5 times that of an insulated house.



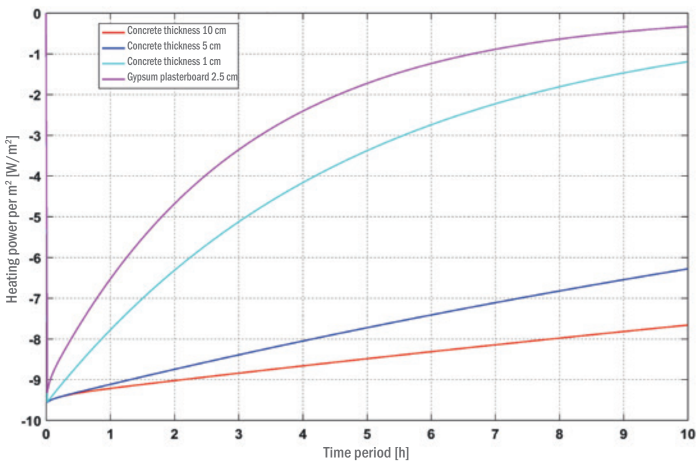
Solidity counts

In their analysis, the FH Burgenland scientists intensively addressed the construction physics effects of the different construction methods. In doing so, they observed the following: Houses with good external thermal insulation, large storable masses (high density and specific heat capacity) as well as high thermal conductivity of the wall materials are best capable of storing heat energy, optimally compensating for short-term temperature fluctuations. Components with pronounced heat storage capacity, such as solid walls, screeds or plasters, can absorb heat energy well, store it and quickly return it to the room when it gets cooler.

The components act like a heat accumulator which is integrated into the building's shell. In return, the rooms stay pleasantly cool for longer periods of time in the summer. The better the thermal insulation, the better the components can use their storage-effective masses.

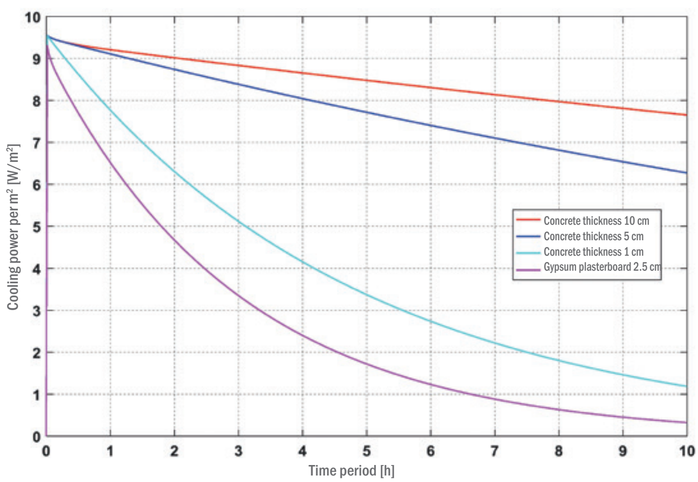
Heat storage capacity during a temperature drop from 21 °C to 15 °C

Solid components with pronounced heat storage capacity release the stored heat into the room over a long period of time if the interior temperature drops. A decrease in the building component density therefore also leads to the rapid reduction of the heat output emitted per m^2 . Source: FH Burgenland



Heat storage capacity during a temperature increase from 21°C to 27°C

The storable mass and the thermal conductivity also affect the cooling behavior of a component. When the interior temperature rises, it is evident that, as the component thickness decreases, the cooling capacity per m^2 falls rapidly. Source: FH Burgenland



Interior values

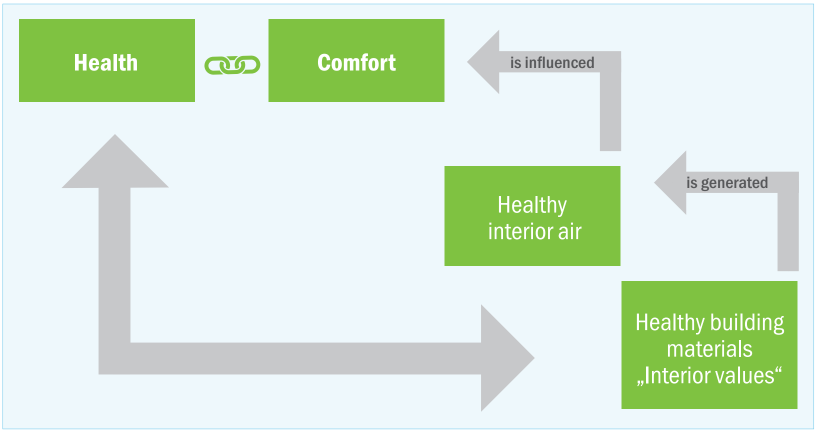
Energy-efficient construction always means airtight construction. This means that if ventilation is insufficient, any pollutants present can remain in the room for longer periods of time.

The exchange with the outside air is much lower in modern structures than in older buildings. Modern buildings therefore place much higher demands on building materials than older structures. That's why choosing the right ones is all the more important: Building materials should be free of pollutants, should be permeable and have good moisture storage capacity.

Just a thin layer (1.5 to 2 cm) of an interior plaster significantly contributes to improving the indoor climate. The conclusions drawn at Viva Research Park demonstrate how well a good interior coating can influence and improve the indoor climate and thus the quality of life, both for new buildings and renovated buildings.

Healthy building materials

Connection between healthy building materials - healthy room air - health



Other findings

In addition to the three relevant areas - „Insulation first“, „Solidity counts“ and „Interior values“, the scientists found even more informative connections for healthy building. Here‘s what you need to know if you‘re building a house:

Health and comfort

The Department of Environmental Hygiene and Environmental Medicine at MedUni Wien [Medical University of Vienna] analyzed the effects of different construction methods and materials on well-being and comfort. The scientists paid special attention temperature and humidity, in addition to odors and chemical parameters. Here, the insulated houses - especially the insulated houses made of brick and concrete with mineral, permeable interior coatings (interior plaster and wall paint) - received the best ratings.

VOCs, formaldehyde and odors

The pollutants experts from IBO Innenanalytik OG repeatedly measured VOCs (volatile organic compounds), formaldehyde and odors in the research park.

Conclusion: After two years, the concentration of VOCs was harmless in almost all houses. The timber block house with its high concentration of terpenes occupies a special position - a special feature of wood houses. The timber block house was built of 5-fold glued squared spruce and pine timbers. Resin-rich woods, such as pine, emit a particularly high amount of terpenes - therefore, when selecting wood for the wood house, select wood species containing less resin, such as pure spruce wood.

With the exception of the timber block house, the formaldehyde loads fell within the completely harmless range in all research houses just a few months after completion. The unusually high levels of formaldehyde in the timber block house were most likely emitted from the type of wood glue used. Therefore, when building a wood house, make sure to use adhesives that do not contain pollutants. As before, there are noticeable differences in odors: houses with wood frame construction with gypsum plasterboard paneling still have a noticeable odor after two years, despite daily ventilation.

Noise stays outside

In houses made of concrete, exterior noise is perceived as only half as loud compared to houses with wood frame construction and gypsum plasterboard paneling. Thermal insulation systems also contribute to sound insulation.

Insulation in the system

A wall structure with exterior insulation and interior density can make optimal use of the mass with storage capacity.

Shielding from radiation

High-frequency electromagnetic fields from outside are best attenuated (damped) by concrete and solid wood. Disadvantage: If many phone calls are placed from inside the house, the radiation inside is increased because mobile phones function with higher power levels.

Careful with ancillary construction products

Ancillary products (such as seals) can introduce harmful VOCs into the house. For example, in some of the research houses, inexplicably high VOC levels were found until researchers discovered after a long search that the source of the VOCs was a sealant adhesive - which no one had expected. Summary: When choosing ancillary construction products, always make sure they do not contain pollutants or emissions.

5.2. WHICH HOUSE IS RIGHT FOR WHOM?

Building your own house is generally one of the most challenging projects you could undertake. But how do you decide which house is right for you? What do you have to take into consideration, and where can you make compromises?

The right construction always depends on the owner‘s personal life situation. How big is my budget? Where is the property? How important is a good room climate to me? What do I want to pay special attention to as part of healthy building and living? Are good sound insulation, acoustics and protection from electromagnetic fields very important to me? All of these questions need to be discussed and compared in order to select the most suitable construction method.

Which house is right for whom?			
Houses	**Strengths**	**Weaknesses**	**Perfect for**
Concrete + thermal insulation	Solid construction - very good heat storage capacity and very good cooling effect, good sound insulation and good shielding of RF fields, no VOCs or formaldehyde loads, pleasant odor, high value stability	Higher construction costs, average acoustics, low moisture buffering capacity → this can be noticeably improved by using permeable mineral internal plaster with moisture buffering capability	**Owners who value healthy, solid and value-stable construction and who are looking for a large amount of design freedom**
Type 25 bricks + thermal insulation	„Classic“ design in Austria, good heat storage capacity and good cooling effect, in combination with permeable mineral internal plaster with moisture buffering capability = best room climate control, no VOCs or formaldehyde loads, pleasant odor, very good price-performance ratio, high value stability	Average sound insulation and average acoustics	**Owners who are looking for a very good price-performance ratio for their solid, healthy house**
Type 50 bricks (filled with mineral wool)	Simple construction - no additional thermal insulation necessary, solid construction, good heat storage capacity, in combination with interior plaster = best room climate control, no VOCs or formaldehyde loads, pleasant odor, high value retention	More expensive than conventional bricks, temperature buffer is worse than with type 25 bricks + external insulation	**Owners who are committed to a combination of innovation and proven techniques and who are ready to spend more money for it**
Wood frame construction with gypsum plasterboard paneling	Fast and inexpensive construction, good acoustics, average attenuation of HF fields	Low moisture buffering, low heat storage capacity and low cooling effect, VOC exposure in the first few months after completion, possible noticeable odor	**Owners who want to build quickly and inexpensively and for whom the indoor climate is not a primary focus**
Timber block house	Good room climate control, very good acoustics and very good damping of HF fields	High construction costs, noticeable wood odor, wood-specific terpenes → not optimal for sensitive people, possible high formaldehyde values → when selecting wood glue, use formaldehyde-free or low-formaldehyde adhesives	**Owners who want to build as naturally as possible and who like the smell of wood or tolerate it and are ready to spend more money for it**

5.3. HOW DO I MAKE MY HOUSE HEALTHIER?

There is one general truth that applies to all the research houses that were investigated in Viva Research Park: there is no such thing as a bad house, because all houses (with the exception of the uninsulated, non-renovated house corresponding to older construction styles) correspond to the current building regulations and thus are based on very good standards and norms. However, each type of construction has its strengths and weaknesses.

It is important to be aware of the advantages and disadvantages of each construction method in order to consciously choose the right house for your personal life and requirements. In many cases, the weaknesses of a construction method can be reduced by selecting the right building materials.

Optimization options in new construction and renovation

90 percent of our time is spent indoors. Therefore, a balanced indoor climate is immensely important for our overall health and well-being. All measures aimed towards improving the indoor climate when building new structures or performing renovations directly improve our quality of life.

Thermal insulation

New construction: The most important prerequisite for a well-balanced and healthy indoor climate is low fluctuations in the interior surface temperature of the exterior walls. This is achieved with good thermal insulation. In general, new structures aim towards a U-value of U = 0.15 W/m^{2}K - which corresponds to the lowest energy house standard. Therefore, thermal insulation is essential for every newly built home.

Renovation: When renovating uninsulated houses, whether they are made of concrete, brick, wood or wood frame construction, thermal insulation in particular can improve the indoor climate immensely. In addition, thermal insulation significantly reduces heating costs.

Room climate

New construction: All wall structures need a good functional interior coating or coating combination to create a healthy and balanced room climate. The right interior coating can create good moisture buffering and regulate the indoor climate, even with a layer only a few centimeters thick. For a brick wall, this requirement can usually be met by a mineral interior plaster with a vapor-permeable mineral interior paint. Lime-containing and lime cement-bound interior plasters with high open porosity work very well in this regard. They are suitable in combination with wall paints with a high vapor diffusion capability, such as mineral paints and dispersion silicate paints.

Unfortunately, concrete walls are often only filled and painted. Although this type of coating provides a smooth surface, it does little for moisture regulation. Here, using an interior plaster creates a significant improvement. For wood frame construction with gypsum plasterboard paneling, the situation is comparable to concrete. Here, thin layers of mineral putties measuring several millimeters thick create a noticeable improvement. For solid wood structures, the wood building material takes care of the moisture-buffering and moisture-regulating functions.

Renovation: Houses undergoing extensive renovations become denser through the use of thermal insulation and by replacing old windows. Therefore, moisture caused by cooking, washing or showering is usually subject to less ventilation, which creates strong fluctuations in the interior relative humidity. This has a negative effect on the indoor climate and can also increase the likelihood of mold growth during colder seasons. Increased surge ventilation, the use of dehumidifiers or the installation of a ventilation system helps to counter this effect. However, even in this case, the room climate can be sustainably improved by the subsequent coating with thin layers of mineral plaster and interior plaster.

Conclusion

When planning buildings, the process is generally based on standardized building materials as well as fast and cost-effective solutions. Once the building is standing, it only takes a short time to demonstrate whether the chosen construction method has healthy living properties. If this is not the case and the user is dissatisfied with the room climate, improvements are expensive. The expense of renovations is usually much higher than the investment costs that would be incurred if healthy aspects had been taken into account during the planning process. Here, Viva Research Park presents an overview of the construction methods and evaluates their effects on room climate and comfort.

LEXICON

BECQUEREL(BQ)

Becquerel (Bq) is the international unit of radioactivity (symbol A). The unit is named after French physicist Antoine Henri Becquerel, who, together with Marie Curie, received the Nobel Prize in 1903 for their discovery of radioactivity. The Becquerel indicates the number of atoms that decay per second.

Chapter 3/Page 86

CONCRETE

Concrete is a functional building material: limestone and clay cement is mixed with sand or gravel and water. Adding different materials creates specialized types of conncrete: Adding structural steel or prestressing steel creates reinforced concrete. The most important component of concrete is cement, because the so-called cement paste, which joins the aggregate, can only be formed in combination with water. Only then is a solid building material created.

Chapter 4/Page 110

FORMALDEHYDE

Formaldehyde is not a VOC due to its volatility. It is a colorless irritant gas that can lead to health impairments, even in very low concentrations. Today, formaldehyde is primarily used in the production of synthetic resins. They are contained in chipboard, adhesives and insulating foams. The slow decomposition of these resins leads to the prolonged release of formaldehyde into the air. Shorter but significantly higher loads may occur after the use of acid-cured parquet seals. Formaldehyde is also contained in tobacco smoke. It has a strong irritant effect on the mucous membranes of the upper respiratory tract and the eyes with stinging in the nose and throat, coughing, and burning eyes. Prolonged exposure can cause bronchitis and asthma. Formaldehyde can be measured relatively easily and reliably in the interior air. Initial irritant effects, especially around the eyes, begin to occur at concentrations of 100µg/m3 . For sensitive persons, these can begin at lower concentrations. There is no risk of cancer in this low concentration range.

Chapter 3/Page 84

FREQUENCY

The frequency indicates the number of oscillations per second The unit of frequency is called hertz (Hz). One hertz is 1 oscillation per second. For building acoustics, the frequency range from 50 to 5,000 Hz and the room acoustics range from 63 to 8,000 Hz are key. Sound which is completely undetectable by the human ear - ultrasound - starts at 20,000 Hz.

Chapter 3/Page 92

HEALTH

„Health is a state of complete physical, mental and social well-being, not just the absence of illness or ailments.“ (definition of the World Health Organization, or WHO)

Chapter 1/Page 11

GLOBAL RADIATION

Global radiation is understood to mean the total solar radiation arriving on a horizontal receiving surface on the earth‘s surface. It consists of direct solar radiation - direct radiation - and diffuse radiation, which reaches the Earth‘s surface by being scattered through clouds, particles of water and dust.

Chapter 2/Page 47

WOOD

Wood consists of cellulose and lignin and contains resins, waxes, fats, oils, starch, sugar, various minerals, tanning and coloring as well as alkaloids. It is primarily the lignin which turns a normal plant cell into a wood cell. 20 to 40 percent of the dry weight of wood consists of this „lignification“; the proportion is higher in coniferous wood than in hardwoods. The complex and highly polymeric material is chemically and physically firmly bound to the cellulose, making the wood stable and pressure-resistant.

Chapter 4/Page 125

WOOD FRAME CONSTRUCTION

The body of a wood frame house consists of a wood support structure. Then the areas between the walls are filled with thermal insulation, such as rock wool or mineral wool The inside of the wall is made of a layer of chipboard, a vapor barrier and plasterboard paneling. The outside can be covered with a variety of materials. The simplest construction involves wood formwork, but metal panels can also be used. The walls are usually prefabricated, which is why the actual construction on-site is extremely fast.

Chapter 4/Page 123

AIR IONS

Air ions are electrically charged molecular particles that carry either a positive or negative charge. These charged particles can consist of clusters of H_2O molecules, O_2, N_2 and CO_2 and measure approximately 1-50 nanometers in size. In nature, air ions are formed when charge shifts generate high polarization fields. This happens during electrical discharges such as lightning, piezoelectric effects and waterfalls. Air ions are also produced by radioactive, cosmic radiation and open fire (plasma), among other things. Technicologically, air ions are produced by generating very high charge densities on small needles with high electrical voltage.

Chapter 3/Page 89

LEXICON

REVERBERATION TIME

The best known measurement of room acoustics is the reverberation time. It refers to the period during which the sound level in a room decreases by 60 decibels (dB) when the sound source (e.g. a person's voice, music, etc.) suddenly stops. The length of the reverberation time in a given room depends on three factors: the size of the room, the surfaces in the room and the furnishings. The reverberation time is frequency-dependent, since stone, wood, carpet and textiles absorb sound differently at different frequencies.

Chapter 3/Page 96

RADON

Radon is a natural, common radioactive noble gas that is colorless, odorless and tasteless. It is an intermediate product of the decay series of the radioactive heavy metal ^{238}uranium, which occurs naturally in soils and rocks, while radon is directly produced from ^{226}radium. Radon can escape relatively easily from soils and rocks and can spread through soil vapor or by dissolving in water. It can also get into the interior air of buildings. The EU-wide reference value for radon concentration is 300 Bq/m^3. In new buildings, a medium radon concentration of 200 Bq/m^3 should not be exceeded (planning reference value) The medium value for residences is 60 Bq/m^3.

Chapter 3/Page 86

RELATIVE HUMIDITY

The relative humidity is calculated as follows:

$$\varphi[\%] = \frac{\text{Partial pressure of water vapor } \times 100\%}{\text{Saturation vapor pressure of the water}}$$

The relative humidity is the ratio between the actual water vapor pressure in the air and the maximum possible vapor pressure.

Chapter 3/Page 68

SOUND

Sound that reaches our ear is a physical vibration of the air molecules that leads to small pressure fluctuations. The strength of the sound is accordingly characterized by fluctuations in air pressure. Since the fluctuations fall within a large range of one to one billion, the sound level in daily use in a logarithmic system is expressed in decibels (dB). Increasing or decreasing the sound level by 10 dB means that the volume is either doubled or halved.

Kapitel 3/Seite 91

SOUND INSULATION AND SOUND ABSORPTION

The term sound insulation refers to how much sound energy can pass through a wall into an adjoining room. Sound insulation or sound absorption by a wall or ceiling, however, takes place during the reflection process by converting part of the sound energy into heat. The degree of sound absorption depends on the surface texture. A wall can have good soundproofing while still having a low level of sound absorption, and vice versa. The sound insulation is measured in decibels (dB). For sound insulation, the following applies: The higher the value, the better the sound insulation. 10 decibels plus means half the perceived noise level.

Chapter 3/Page 94

SORPTION ISOTHERMS

The sorption isotherms represents the material-specific relationship between the relative humidity and the moisture content of a material in its equilibrium state. This relationship makes it possible to determine the moisture content based on the relative humidity. The figure on page 34 illustrates the sorption isotherm for the Baumit KlimaputzS and a gypsum plasterboard sheet. This demonstrates that, with a relative humidity of 50%, the gypsum plasterboard sheet can absorb approximately 3.2 g water/kg of solid content, while the Baumit KlimaPutzS can absorb approximately 6.0 g water/kg of solid content.

Chapter 2/Page 34

DISCOMFORT SCORE

On the basis of the data on air temperature, air humidity and temperature of the enclosing surfaces, a discomfort score was determined every hour; these scores were then used to calculate a daily average value. ISO 7730 and the comfort criteria defined by Fanger were the starting point for the discomfort score. From this. the scientists developed their own formula, which they used for their calculations.

Chapter 3/Page 101

U-VALUE

The U-value (also called the heat transfer coefficient) is a unit measuring the transmission heat losses of a wall. The U-value describes the quantity of heat per second and square meter of wall surface that is lost when the room temperature is one degree higher than the outside temperature.

Chapter 2/Page 19

LEXICON

VOC

VOCs (volatile organic compounds) are irritants and odors that are found in many products, including building materials. They can evaporate easily or outgas at low temperatures. The VOCs include aliphatic compounds, alicyclic compounds, aromatics, chlorinated substances, esters, aldehydes, ketones and terpenes. Many are used to make plastics, solvents, dyes, tannins, perfumes and medicines. In higher concentrations, VOCs can lead to health problems.

Chapter 3/Page 80

EXTERNAL THERMAL INSULATION COMPOSITE SYSTEM (ETICS)

A system for insulating the exterior walls of buildings. The structure consists of the type of attachment (glued and/or dowelled or a track system), an insulating material, a base layer of plaster (reinforced, in-wall) and a surface layer (top coat).

Chapter 2/Page 32

HEAT CAPACITY

The heat capacity describes how well a substance can store thermal energy. The specific heat capacity corresponds to the amount of heat needed to heat 1 kg of a substance by 1 °C. The unit of specific heat capacity is given in J/(kg.K).

Chapter 2/Page 34

THERMAL CONDUCTIVITY

The thermal conductivity describes how well a material can conduct heat. Thermal conductivity A indicates the amount of heat which is conducted through 1 m^2 of a 1 m thick layer if the temperature gradient is 1 K (1 °C). The smaller the value of A, the better the insulating capacity of a building material.

Chapter 2/Page 35

WATER VAPOR DIFFUSION RESISTANCE

The water vapor diffusion resistance (also known as vapor barrier value) expresses to what degree the diffusion of water vapor in the building material is prevented. The characteristic value for water vapor diffusion resistance is the water vapor diffusion resistance coefficient μ. This expresses the factor by which the material in question reduces the diffusion of water vapor in relation to an equally thick layer of air. The greater the water vapor diffusion resistance coefficient μ , the more vapor-tight the building material.

Chapter 2/Page 35

We would like to thank all of our cooperation partners and participants
as well as the Österreichischen Forschungsförderungsgesellschaft mbH
[Austrian Research Promotion Agency mbH],
with whose support this research project could be realized.

Imprint:

Published by: Viva Research Park of Baumit Beteiligungen GmbH.
2754 Waldegg, Wopfing 156, Tel.: +43 (0) 501 888-0, www.baumit.com/viva-forschungspark

Edited by: Mag. Julia Posch

Experts: DI Bernhard Damberger, Prof. (FH) Dr. Christian Heschl, OA Assoz.-Prof. Priv. Doz. Dipl.-Ing. Dr. med. univ. Hans-Peter Hutter,
DI(FH) DI Stefan Langerwisch BSc, DI Dr. Bernhard Lipp, Dr. Jürgen Lorenz, Hans-Peter Schweiger, Univ. Lecturer DI Peter Tappler, DI Felix Twrdik.

Photos: Baumit, wahrheit.com (unless otherwise specified)

Printed in Austria. Misprints and printing errors reserved.
2st issue: January 2019