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FRAUNHOFER INSTITUTE FOR BUILDING PHYSICS IBP

INDOOR CLIMATE

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RESEARCH AND DEVELOPMENT IN THE AREAS OF

- **INDOOR CLIMATE SYSTEMS**
- **SIMULATION**
- **SYSTEMS INTEGRATION**
- **PREVENTIVE CONSERVATION AND PRESERVATION OF MONUMENTS**
- **CONSERVATION OF CULTURAL HERITAGE AND BUILDING IN A HISTORIC CONTEXT**

The Fraunhofer Institute for Building Physics IBP's Indoor Climate department is divided into the working groups Indoor Climate Systems, Simulation, Systems Integration, Preventive Conservation and Preservation of Monuments as well as Conservation of Cultural Heritage and Building in a Historic Context. Here, researchers focus on developing the systems needed to analyze, monitor and optimize indoor climate. Our teams conduct research into creating user-friendly climates for enclosed spaces in the building construction, aviation and automotive sectors. As well as focusing on the relationship between the effects of indoor climate and people's sensation of comfort, we also investigate how to optimize indoor climates while using the minimum of resources so that they can be used in comfort without harming the environment. Key aspects are to include user acceptance, variations in user requirements and systems' energy efficiency. We consider architecture and technology as a single overarching system in order to improve the indoor climate while taking into consideration the thermal mass and hygroscopic properties of structural components.

With its multitude of interdisciplinary skills, our highly professional team is able to develop solutions that are precisely tailored to each customer's individual needs. We can perform an extensive range of analyses and evaluations. These include lab measurement systems such as the DressMAN test dummy, the experimental school environment and the mobile indoor climate reader. We conduct physical and psychophysical measurements of thermal comfort using test subjects in settings such as our controlled-environment room and flight test facility. We can also carry out additional comfort analyses, mathematical analyses of building components, building simulations as well as full-scale testing of building designs, building components and system components for HVAC and energy systems.

The predictive models we use are developed and validated at Fraunhofer IBP and are based on experimental results. They support the use of computational fluid dynamics for the study of ventilation and can simulate the way the human body regulates heat to help analyze thermal comfort. Building simulations allow us to perform energy analyses and to make sure that the surrounding structural fabric is not damaged in any way.

Customers that benefit from the services of the Indoor Climate department include international manufacturing companies as well as planners and developers from the public, commercial and private sectors. Our ultimate goal is always to collaborate with our customers to translate the results of our work into marketable innovations, products and services.

1

2

INDOOR CLIMATE SYSTEMS

This working group conducts research into energy-efficient systems, concepts and technologies designed to control indoor climate so that it can conserve resources while still meeting users' needs. Creating an efficient and sustainable indoor climate solution requires a perfectly dovetailed integrated system that encompasses both architecture and building systems. The climate design working group develops solutions to meet comfort specifications, energy efficiency and occupational safety requirements. Holistic planning measures for new or existing buildings use a minimum of energy and offer maximum comfort – even within mobile environments such as planes, trains or automobiles.

Indoor climate concepts for a climate- and user-oriented architecture

"Climate-adapted building design" means analyzing and establishing parameters for a building's outdoor climate, function, form, location, comfort specifications and usage requirements. This yields an integrated overall concept that includes environmentally friendly strategies for regulating indoor climates.

Indoor climate analysis, building monitoring and inspections

When users complain about dry air or drafts, manifold indoor climate analysis methods are used to assess and optimize the indoor environment. Measurements determine air exchange rates within a room or between parts of a building (via tracer gas method), air age and radiation temperatures, and this information can then be used to assess thermal comfort, air currents or humidity. Often the measurements will be supplemented with emissions tests by the "Chemistry and Sensory" group to create an optimized ventilation concept. Equipped with user survey results, the team can devise improvement strategies for renovations or for new living, office as well as commercial or industrial building space.

User behavior and comfort

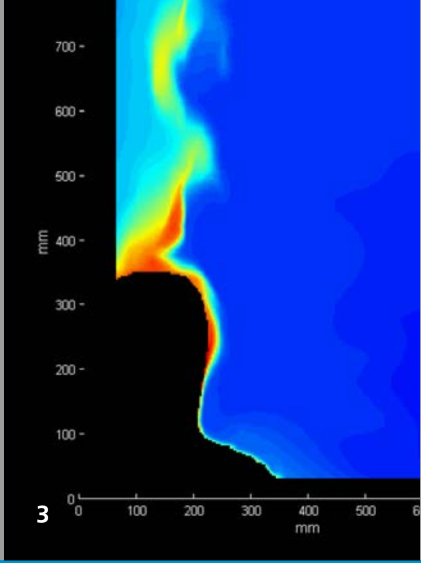
Many factors influence people's sensation of comfort in indoor spaces and affect their behavior as a result. Since achieving the required specifications can sometimes lead to mutually contradictory courses of action, the goal of successful indoor environmental conditioning should be to optimize user comfort while maximizing energy efficiency. User surveys and statistical analyses are carried out to ensure that user profiles and needs are met and then correlated with subjective assessments of comfort.

Customized and transient air conditioning systems

Developing customized and transient air conditioning systems that can even adapt themselves depending on whether a person is present enhances energy-saving measures and optimizes climate zones in buildings, vehicles and airplanes. The goal is to harness the potential of air conditioning required only on a temporary basis in order to ensure thermal comfort while taking advantage of the positive effects of reactive systems. Innovative possibilities are being researched to match radiation conditions to usage profiles, for instance through wall heating or cooled ceilings. These can be coupled with convective-cooling mechanical ventilation systems to achieve draft-free, energy-optimized regulation. Hybrid ventilation systems that are automatically supported by natural window ventilation can achieve huge improvements in air quality.

Industrial climate control

Industrial facilities and processes are already very efficient when it comes to technical and logistical procedures. Nevertheless, air conditioning, thermal management and indoor workplace ergonomics could all be vastly improved. Here, Fraunhofer IBP employs its own simulation models to optimize the relevant systems as early as the planning stage. This makes it possible to evaluate and compare any required airflows, air exchanges or heat transfer processes, and to consider the use of waste heat for heating and cooling in addition to local system solutions featuring surfaces cooled or heated by convection or radiation.



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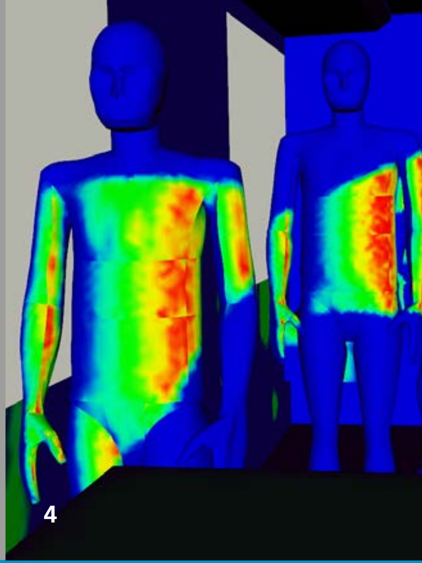

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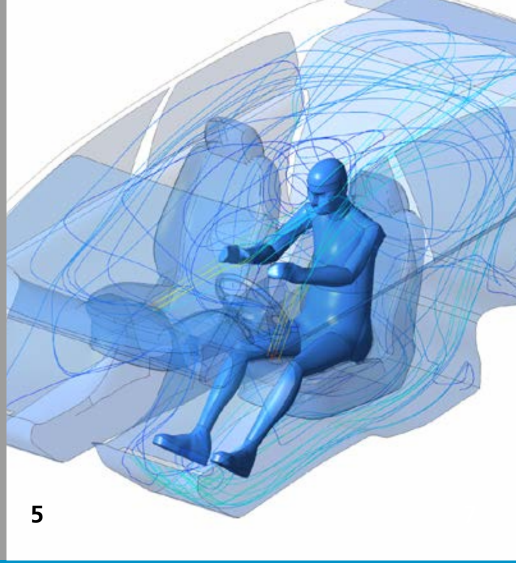

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Energy systems optimization
System optimization involves evaluating the energy efficiency potential of several different approaches and seeking out new solutions that cater to the specific outdoor climate in each case. Solutions might include the passive use of available energy sources (e.g. through natural cooling or ventilation) and the possibility of using excess heat from one system for a different system. Our researchers also develop solutions designed to prevent malfunctions such as a computer overheating in an aircraft. In this case, the goal is to keep the cooling system functioning long enough for the pilots to make a safe landing.

Flight Test Facility
The one-of-a-kind flight test facility at our Holzkirchen site comprises a low-pressure chamber housing an original front section of an airplane and space for up to 80 test subjects. As well as using the facility to study cabin air quality, the researchers also conduct studies of the aircraft as an overall system under realistic flight conditions, by investigating energy questions and usage requirements encompassing areas such as the cockpit, passenger cabin, avionics and cargo bay. The team also studies thermodynamic correlations and the build-up of condensation on aircraft components as part of international projects completed on behalf of both manufacturers and suppliers from the aviation industry.

SIMULATION

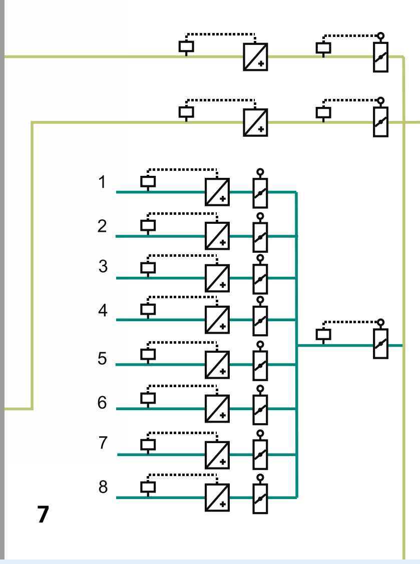
The researchers apply a computer-based simulation of the indoor climate and simulate complex thermodynamic systems to optimize it for both people and the requirements of technical facilities. Based on the relevant climate factors, model-based forecasts and analyses are carried out to optimize the indoor climate in the enclosed spaces of buildings, airplanes and vehicles according to usage and user requirements. The working group applies a combination of model development, simulation and experiment to gain a comprehensive understanding of the system under examination and follows a scale-adaptive approach.

Indoor climate building simulation
Building simulation provides an integral assessment of energy needs and indoor climate. Customized simulation models are created for the integral design optimization of interior spaces with respect to energy efficiency and comfort in buildings as well as for cars and airplanes. In addition to using established building simulation tools such as TRNSYS, EnergyPLUS and IDA-ICE, researchers also use model libraries and tools they have developed themselves, including efficient radiation solvers using graphics hardware, a refined zonal airflow model for confined spaces (VEPZO) and a Modelica library for the simulation of coupled heat and moisture transfer within building zones, envelopes and rooms (Indoor Climate Library). Depending on the degree of detail required, either simplified models (such as air node models) or complex spatial geometry models (CAD) are used to carry out computational fluid dynamics (CFD) simulations. The underlying purpose behind the stationary or transient analysis – such as the insights to be gained about temperature distribution, air exchange or ventilation strategies – determines the choice of the appropriate methods.

Indoor climate evaluation – development of simulation tools
So that indoor climate can be assessed, comfort models and verification procedures have been built into the tools. This includes the required parameters of norms and guidelines, such as PMV and draft rating (ISO 7730), radiation temperature (ISO 7726), operative temperature and humidity. The BNB tool "Thermal Comfort" developed by Fraunhofer IBP makes it possible to quickly investigate these parameters based on data from indoor climate and building simulations.

Thermoregulation models
For precise study, a 3D human model is used to evaluate positional and directional indoor climate conditions in respect to air currents, room temperature, heat exchange and so on. These thermoregulation models dynamically mirror the human body and its reactions so that thermal system

6



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influences such as variations in surface temperature, natural solar radiation or individual ventilation can be evaluated in detail.

Model integration and coupled simulation

The simulation of indoor climate in buildings and vehicle cabins must follow a holistic approach that describes the problem on different temporal and spatial scales. In the working group, the models are integrated or coupled by means of scale transitions. For this, the working group has developed its own co-simulation framework as middleware (CoSimA+).

Building Information Modeling (BIM) and IT interfaces

An important part of our researchers' work is the deployment and development of information technology models and data exchange formats for the object-oriented representation of a building over its life cycle. A special focus is placed on the use of building information modeling to form a tool chain in which building physics simulation models are connected via platforms such as CoSimA+ or functional mock-up interfaces (FMI).

Validation and calibration

An essential step for the validation of simulation models is to measure and calibrate them at test facilities. The working group has adopted a common methodology for measurement and verification (M&V). Researchers use both methods of descriptive analysis, parametric and sensitivity studies as well as optimization techniques.

Integration of sensor technology and climate technology

In order to understand and objectively evaluate complex thermal parameters, an appropriate measurement principle is needed. DressMAN 2.0 is a newly developed climate measuring system that already provides all the interfaces for coupling into the simulation environment. The measuring points, which are distributed over the dummy's body, record information for equivalent temperatures, air temperatures, etc. and can be mapped in a localized comfort model. Only then it is possible to make accurate statements about temperature sensitivity and to correlate those with non-uniform or transient micro climates.

SYSTEMS INTEGRATION

The working group investigates the integration of structural, plant-specific and use-specific measures in the area of building control systems and automation. In order to achieve high energy efficiency even for complex buildings and to optimize the operation of different plant-specific systems, such as heating, ventilation and air-conditioning as well as light and sun protection systems, the systems have to be coordinated and integrated into a comprehensive system. To do this, the group develops components and control algorithms. One special focus is on the continuity of communication of bus systems and on implementation that allows components to be tested alongside "foreign" systems both in virtual tests and in the lab. This enables the development of procedures to identify and diagnose problems in facility management systems.

System design: Control algorithms for technical building services

The focus lies on the development of complex control and prediction algorithms for the interaction of various building systems technologies, the building itself and its users. Control scenarios for the connection of a virtual testing environment are modeled and tested with different building constraints, user scenarios and behavioral patterns. This results in improvements in comfort and energy efficiency.

Building automation: Component tests and development

At the Energie Campus Nürnberg a lab is formed for the development and testing of communication interfaces with various bus systems (such as BacNet or LON). Building automation components are integrated into a virtual test environment (such as SPS, sensors or controls) and tests on the components are carried out according to various operating scenarios. In the lab, tests are performed to investigate HVAC systems, building

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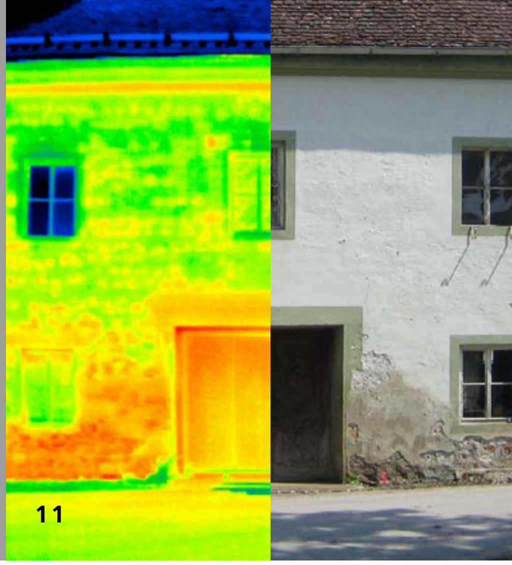

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control and automation components interactively using virtual scenarios. The evaluation of the usability and acceptance of the systems is validated by test subjects.

Human-technology-building interaction

The detection of user behavior in regards to new building automation systems is a primary focus. Human interaction with innovative building technology and user acceptance is evaluated and critical factors for improvements for new as well as existing systems are researched.

Data and knowledge management in building automation

With the increasing availability of data and information in building management systems, the corresponding data and knowledge management plays a progressively more important role. The group performs meta-analyses of measured values to identify a building's relevant characteristics and develops methods for error detection. These lead to techniques for the automated identification and optimization of control settings.

PREVENTIVE CONSERVATION AND PRESERVATION OF MONUMENTS

The Preservation of Cultural Heritage and Preventive Conservation working group deals with all the issues related to the preservation of buildings and monuments that form part of our cultural heritage. This field includes the effects of climate change on historical buildings, the establishment of new solutions for museum depots, the sustainable renovation of museums and research into preventive conservation.

Preventive conservation for art and national treasures

Preventive conservation is at the heart of an enduring preservation of art and national treasures. It is geared toward the general improvement of environmental conditions and the avoidance of damage to art works, fixtures and buildings without direct intervention on the object. By means of a comprehensive analysis of a building and the collection it houses, researchers are able to draw up individual risk evaluations that then form the basis for developing concepts.

Climate concepts for historical spaces, museums and depots

The indoor climate in historic buildings and museums is of great interest to the preservation of objects and collections because an unfavorable climate – such as excessive humidity or significant temperature fluctuations – would destroy works of art step by step. The starting point for developing a climate concept for historical spaces is the analysis and simulation of buildings, collections and climatic influences. These climatic parameters are determined by measurements, which together with the documentation of historical materials, techniques and conservation serve as the basis for the individual risk assessment of a collection.

Risk assessment for works of art

To keep valuable exhibits in good condition, it is essential to maintain the right air quality and climate. Factors that can cause exhibits to age and decay include temperature, humidity, light exposure and air pollution. Calculating the potential damage that could be triggered by these factors enables a risk assessment for the works of art. Image monitoring plays an essential role for the documentation of damage processes. Concerns about building and object security are also dealt with as part of a holistic approach.

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CONSERVATION OF CULTURAL HERITAGE AND BUILDING IN A HISTORIC CONTEXT

By combining tradition, innovation and an interdisciplinary approach, researchers create and implement practical solutions at the Fraunhofer Center Benediktbeuern in a way that reaches out to the wider public. The goal is to provide a rigorously scientific demonstration of the issues involved in the energy-saving renovation of historic buildings and the preservation of monuments.

Fraunhofer Center for Energy Efficiency of Historic Buildings and Conservation of Cultural Heritage Benediktbeuern
As part of the renovation of the Old Cooperage at Benediktbeuern Abbey, practical research on building is taking place. Research and studies into innovative materials and building systems are presented with reference to a historic, listed building. Exhibits, training and further education events make it possible to pass on knowledge and to learn independently.

Methods and technologies for the preservation of historic buildings
Taking into account such aspects as reversibility and avoiding damage, innovative materials and technologies for historic conservation as well as the energy efficient renovation of older buildings are explored, existing systems are questioned and new solutions are developed. Studies on the use of materials and constructions are carried out which are both traditionally applied in construction and are characterized by their innovative nature.

Concepts for historic buildings, existing buildings and historic urban districts
The development of concepts includes the holistic view of historic buildings and urban districts, based on energy efficiency, renewable energies and user involvement. Individual expert's reports provide an assessment and analysis of the results as well as specific recommendations for how best to implement concepts within the established parameters.

Knowledge transfer between building practice, research, industry and preservation of historic monuments
The Fraunhofer Center Benediktbeuern provides comprehensive information relating to questions of building physics, historic preservation and energy efficiency. It offers a broad network for professional exchange and is active in collaborating on the development of guidelines. This makes it possible for partners from the building industry, administration, industry and crafts to work on research projects carried out on an actual historical building.

1 *DressMAN 2.0 measuring equivalent temperature.*
2 *Fraunhofer Flight Test Facility.*
3 *Visualisation of thermal plume over a heated human manikin after post-processing the flow field from Particle Image Velocimetry (PIV).*
4 *Heat input by short-wave radiation in public transportation.*
5 *Computational fluid dynamics in a vehicle.*
6 *Person simulator for studying indoor climate.*
7 *Installation layout for personal ventilation.*
8 *Heating manifold.*
9 *Renatus Chapel, Lustheim Palace.*
10 *Renovated exhibition space (© Kunsthalle Mannheim).*
11 *Old Cooperage, Benediktbeuern Abbey.*

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