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Swiss Federal Office of Energy SFOE
Energy Research

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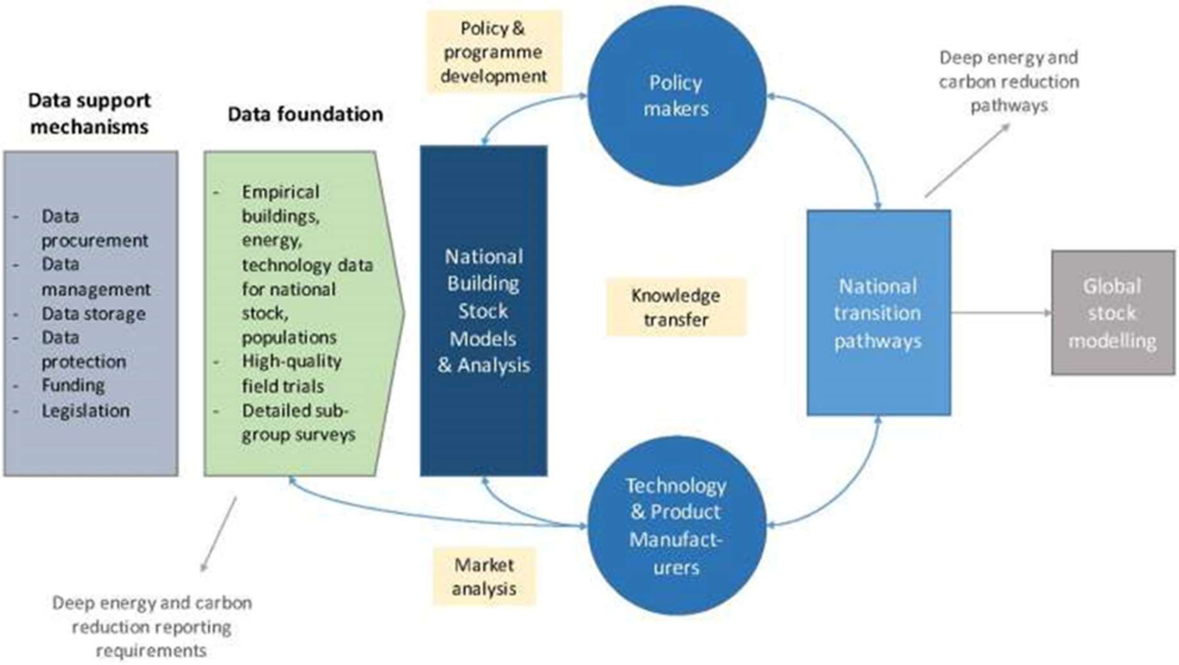
IEA EBC Annex 70: "Building Energy Epidemiology: Analysis of Real Building Energy Use at Scale"

Swiss contribution



Idealised Operation of a National Building Data and Stock Model. Source: https://energyepidemiology.org/annex-proposal/

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Zusammenfassung

TEP Energy hat die Schweiz im IEA EBC Annex 70: "Building Energy Epidemiology: Analysis of Real Building Energy Use at Scale" vertreten und trug aktiv zu dessen Zielen bei.

Motivation und Zielsetzung: Der IEA EBC Annex 70 "Building Energy Epidemiology: Analysis of Real Building Energy Use at Scale" zielt auf die grossmassstäbliche Analyse des (realen) Gebäudeenergieverbrauchs und die Energiemodellierung von grossen Gebäudebeständen ab. Mit Verweis auf das aufkommende Gebiet der Energy Epidemiology sollen robuste Ansätze für solche Analysen entwickelt werden. Das Verständnis der Wechselbeziehungen zwischen Gebäuden, Akteuren und dem Gebäudebestand bzw. dem Gebäudepark sowie der Auswirkungen der verschiedenen Einflussfaktoren (einschließlich politischer Massnahmen) wird durch einen multidisziplinären Ansatz verbessert. Zweck des Annexes ist es, die Mitgliedsländer dabei zu unterstützen, realistische Absenkpfade zu entwickeln, die zu einer drastischen Verringerung des Energieverbrauchs und der CO_2-Emissionen ihrer Gebäudesektoren führen.

Methodisches Vorgehen: Um die spezifischen Ziele des Annexes zu erreichen, werden die Forschungs- und Entwicklungsarbeiten in drei Teilaufgaben (Subtasks) unterteilt. Subtask A fokussiert auf den Einbezug der Nutzenden von Energie- und Gebäudedaten sowie Modellen. Daher wurde im Rahmen des IEA EBC Annex 70 eine Online-Umfrage entwickelt, um Informationen über den Bedarf an energie- und gebäudebezogenen Daten, die Häufigkeit der Nutzung und den Datenzugang zu erheben. Subtask B fokussiert auf Daten und Methoden. Es wurde ein Online-Datensatz-Repository für energie- und gebäudebezogene Datensätze entwickelt. Die damit referenzierten Datensätze werden beschrieben, klassifiziert und mit Metadaten versehen. Subtask C befasst sich mit der energetischen Modellierung von Gebäudebeständen und der damit verbundenen Analyse. Zunächst wird auf der Grundlage früherer Klassifizierungsstudien eine neue Systematik für die Klassifizierung von Gebäudeenergiemodellen geschaffen. Darüber aufbauend wird ein Leitfaden entwickelt, um Gebäudeenergiemodelle systematisch und vergleichbar zu beschreiben. Im Gegensatz zur Klassifizierungssystematik geht dieser Leitfaden in Bezug auf technische Aspekte der verschiedenen Energiemodelle mehr ins Detail. Um die verschiedenen Modelle zu vergleichen und zu bewerten, werden Sensitivitätsanalysen angewendet, um die Auswirkungen von Unsicherheiten auf die Ergebnisse aufzuzeigen.

Ergebnisse und Diskussion: Die Umfrage von Subtask A zeigt, dass eine grosser Teil der Datennutzenden nicht nur Daten verwendet, sondern auch selbst Daten sammeln und erzeugen. Gebäude- und energiebezogene Daten werden in einer Vielzahl von Disziplinen verwendet. Aufgrund ihrer Heterogenität ist es jedoch oft schwierig, sie über verschiedene Länder hinweg zu kommunizieren und zu vergleichen. Das in Subtask B entwickelte Online-Daten Repository soll diese Situation weiter verbessern. Zu diesem Zweck werden Metainformationen zu einer Vielzahl von Datensätzen, die von Energiemodellierern verwendet werden, systematisch gesammelt und beschreiben. Mehr als 1000 Datensätze wurden in das Datensatzarchiv aufgenommen, das in Zukunft noch erweitert werden könnte. Die in Subtask C entwickelte Modellklassifizierungssystematik schlägt ein Quadrantenschema mit mehreren nicht-hierarchischen Ebenen vor. Mit den Quadranten werden die Modellierungsansätze nach ihrem Design (Top-down oder Bottom-up) und dem Grad der Transparenz (Black box oder White box) klassifiziert. Dies ermöglicht den Einbezug neuer Modellierungstechniken (systemdynamische Modelle, agentenbasierte Modelle und maschinelles Lernen) und Modellattribute (z. B. Systemgrenzen, geografische und räumliche Auflösung, Unsicherheit usw.). Diese Klassifizierungssystematik und der von den IEA EBC Annex 70-Mitgliedern entwickelte Leitfaden für die Erstellung von Modellbeschrieben soll die Transparenz und das Verständnis von Gebäudeparkmodellen verbessern. Der Leitfaden erstreckt sich auf fünf Themenbereiche (Überblick, Modellkomponenten, Input und Output, Qualitätssicherung und zusätzliche Informationen). Die Unsicherheits- und Sensitivitätsanalysen geben einen Überblick über typische Unsicherheiten von Datensätzen und Parametern von Gebäudeparkmodellen und zeigen die Auswirkungen solcher Unsicherheiten auf die Ergebnisse der Modelle auf.

Schlussfolgerungen: Auf Basis der Ergebnisse des IEA EBC Annex 70 (und Basis der damit verbundenen und von TEP's generischen Gebäudeparkmodellierungsaktivitäten) können folgende Erkenntnisse festgehalten werden:

- Verschiedene Arten von Stakeholdern artikulieren einen zunehmenden Bedarf an Energie- und energierelevanten Gebäudedaten, die verschiedenen Zwecken dienen. Teilweise sind die Datennutzer auch Dateninhaber oder Datenlieferanten. Fehlende Daten, ungenügende Datenqualität, Fragen des Datenschutzes und der Datensicherheit sowie strategische Überlegungen behindern jedoch die Schaffung von konsistenten Datensätzen, die zu attraktiven Konditionen zur Verfügung gestellt werden. Wenn die Schweiz und andere Länder rasch ehrgeizige Dekarbonisierungsziele erreichen sollen, müssen Datenqualität und Datenverfügbarkeit verbessert werden, um eine effektive Planung und Umsetzung von Dekarbonisierungsmassahmen zu ermöglichen.
- Bis zu einem gewissen Grad können geeignete Energie- und Gebäudebestandsmodelle helfen, die Situation fehlender oder inkonsistenter Daten zu überwinden. In der Tat ermöglichen agentenbasierte oder gebäudespezifische Modelle die Verschneidung verschiedener Datensätze in unterschiedlichen Auflösungen. Außerdem können Modelle dazu verwendet werden, um Daten zu synthetisieren und damit Datenlücken zu schließen. So können Gebäudeparkmodelle und damit verbundene Datensätze je nach konkretem Bedarf für unterschiedliche Zwecke verwendet werden (z. B. Monitoring des Energieverbrauchs, Ausloten von Dekarbonisierungspfaden, Bewertung der Wirkungen von politischen Instrumenten).
- Um die Nützlichkeit von Gebäude- und Energiemodellen für die oben genannten Zwecke zu erhöhen, sollten verschiedene Aspekte verbessert werden. Insbesondere sollten die Modelle in Bezug auf Zweck, Funktionalität, Parameter und Datensätze usw. einheitlich und vergleichbar beschrieben werden. Der IEA EBC Annex 70 hat mit seinem Leitfaden für die Modellberichterstattung zu diesem Bedarf beigetragen. Zur Bewertung der Unsicherheiten der Modelle sind spezielle Unsicherheits- und Sensitivitätsanalysen nützlich, sowohl für Modellierer als auch für ihre Kunden. Der IEA EBC Annex 70 hat dazu beigetragen, das Bewusstsein für diese Aspekte zu schärfen.
- Die Unsicherheits- und Sensitivitätsanalyse erwies sich in der Tat als sehr nützlich und aufschlussreich. Einerseits konnte die relative Relevanz und Auswirkung der Unsicherheit der verschiedenen Variablen visualisiert werden, was einen grossen Mehrwert darstellt. Andererseits zeigte die Analyse, dass die Sensitivität davon abhängt, wie die Unsicherheiten spezifiziert werden (entweder als Skalierungsfaktor, als einzelne Variablen oder als Gruppe von Variablen) und welchen Unsicherheitsrange man festlegt. Dies ist für uns eine der wichtigen Erkenntnisse aus unserer Teilnahme am IEA EBC Annex 70 und sollte bei der Durchführung weiterer Unsicherheits- und Sensitivitätsanalysen in der Zukunft berücksichtigt werden.

Résumé

TEP Energy a représenté la Suisse dans l'IEA EBC Annex 70 : "Building Energy Epidemiology : Analysis of Real Building Energy Use at Scale" et a contribué activement à ses objectifs.

Motivation et objectif : L'IEA EBC Annex 70 "Building Energy Epidemiology : Analysis of Real Building Energy Use at Scale" vise l'analyse à grande échelle de la consommation (réelle) d'énergie des bâtiments et la modélisation énergétique de grands parcs de bâtiments. En référence au domaine émergent de l'épidémiologie de l'énergie, il s'agit de développer des approches robustes pour de telles analyses. La compréhension des interactions entre les bâtiments, les acteurs et le parc immobilier, ainsi que l'impact des différents facteurs d'influence (y compris les mesures politiques) seront améliorés par une approche multidisciplinaire. L'objectif de l'annexe est d'aider les pays membres à développer des trajectoires de réduction réalistes qui conduisent à une réduction drastique de la consommation d'énergie et des émissions de CO2 de leurs secteurs de la construction.

Approche méthodologique : Pour atteindre les objectifs spécifiques de l'Annexe, les travaux de recherche et de développement sont divisés en trois sous-tâches (Subtask). Subtask A se concentre sur l'intégration des utilisateurs de données et de modèles énergétiques et immobiliers. Une enquête en ligne a donc été développée dans le cadre de l'Annexe 70 de l'AIE EBC afin de recueillir des informations sur les besoins en données relatives à l'énergie et aux bâtiments, la fréquence d'utilisation et l'accès aux données. Subtask B se concentre sur les données et les méthodes. Un référentiel de jeux de données en ligne a été développé pour les jeux de données relatifs à l'énergie et aux bâtiments. Les jeux de données ainsi référencés sont décrits, classés et dotés de métadonnées. Subtask C est consacrée à la modélisation énergétique des bâtiments existants et à l'analyse qui en découle. Tout d'abord, une nouvelle systématique pour la classification des modèles énergétiques des bâtiments sera créée sur la base d'études de classification antérieures. Ensuite, un guide sera développé pour décrire les modèles énergétiques des bâtiments de manière systématique et comparable. Contrairement à la systématique de classification, ce guide entre davantage dans les détails en ce qui concerne les aspects techniques des différents modèles énergétiques. Afin de comparer et d'évaluer les différents modèles, des analyses de sensibilité sont utilisées pour mettre en évidence les effets des incertitudes sur les résultats.

Résultats et discussion : l'enquête du Subtask A montre qu'une grande partie des utilisateurs de données ne se contentent pas d'utiliser des données, mais qu'ils en collectent et en génèrent eux-mêmes. Les données relatives aux bâtiments et à l'énergie sont utilisées dans une multitude de disciplines. Cependant, en raison de leur hétérogénéité, il est souvent difficile de les communiquer et de les comparer entre différents pays. Le référentiel de données en ligne développé dans Subtask B vise à améliorer cette situation. Pour ce faire, les méta-informations relatives à un grand nombre de jeux de données utilisés par les modélisateurs énergétiques sont systématiquement collectées et décrites. Plus de 1000 ensembles de données ont été ajoutés à l'archive de données, qui pourrait être élargie à l'avenir. Le système de classification des modèles développé dans Subtask C propose un schéma en quadrants avec plusieurs niveaux non hiérarchiques. Les quadrants permettent de classer les approches de modélisation en fonction de leur conception (top-down ou bottom-up) et de leur degré de transparence (« black box » ou « white box »). Cela permet d'intégrer de nouvelles techniques de modélisation (modèles de dynamique des systèmes, modèles basés sur des agents et apprentissage automatique) et de nouveaux attributs de modèle (par exemple, les limites du système, la résolution géographique et spatiale, l'incertitude, etc.) Ce système de classification et le guide de rédaction des modèles élaboré par les membres de l'AIE EBC Annex 70 visent à améliorer la transparence et la compréhension des modèles de parcs immobiliers. Le guide couvre cinq thèmes (aperçu, composants du modèle, entrées et sorties, assurance qualité et informations supplémentaires). Les analyses d'incertitude et de sensibilité donnent un aperçu des incertitudes typiques des ensembles de données et des paramètres des modèles de parcs immobiliers et montrent les effets de ces incertitudes sur les résultats des modèles.

Conclusions : Sur la base des résultats de l'annexe 70 de l'IEA EBC (et sur la base des activités de modélisation du parc immobilier de TEP en général), les messages suivants sont retenus :

- Différents types de parties prenantes expriment un besoin croissant de données sur l'énergie et les bâtiments pertinents pour l'énergie à l'échelle, servant des objectifs divers. En partie, les utilisateurs de données sont également des détenteurs ou des fournisseurs de données. Cependant, le manque de données, leur qualité insuffisante, les questions de confidentialité et de protection des données ainsi que des considérations stratégiques entravent la création d'ensembles de données cohérents qui sont mis à disposition à des conditions attrayantes. Si la Suisse et d'autres pays doivent atteindre rapidement des objectifs de décarbonisation ambitieux, la qualité et la disponibilité des données doivent être améliorées pour permettre une planification et une mise en œuvre efficaces des mesures de décarbonisation.
- Dans une certaine mesure, des modèles appropriés de l'énergie et du parc immobilier peuvent aider à surmonter la situation de manque de données ou d'incohérence. En effet, les modèles basés sur des agents ou spécifiques à des bâtiments individuels permettent de croiser différents ensembles de données à diverses résolutions. Les modèles peuvent également être utilisés pour synthétiser les données afin de combler les lacunes. En tant que tels, les modèles de parc immobilier et les ensembles de données connexes peuvent être utilisés à différentes fins, en fonction des besoins concrets (par exemple, pour surveiller la consommation d'énergie, explorer les voies de décarbonisation, évaluer l'effet des mesures politiques).
- Pour améliorer l'utilité des modèles de bâtiment et d'énergie aux fins susmentionnées, divers aspects doivent être améliorés. En particulier, les modèles doivent être décrits en termes d'objectif, de fonctionnalité, de paramètres et de jeux de données, etc. L'annexe 70 de l'EBC de l'AIE a contribué à répondre à ce besoin par sa directive sur les rapports de modélisation. En outre, pour évaluer les incertitudes des modèles, des analyses d'incertitude et de sensibilité spécifiques sont utiles à la fois pour les modélisateurs et leurs clients. L'annexe 70 de l'AIE EBC a contribué à sensibiliser à ces aspects.
- L'analyse de l'incertitude et de la sensibilité s'est en effet révélée très utile et instructive. D'une part, elle a permis de visualiser la pertinence et l'impact relatifs de l'incertitude des différentes variables, ce qui représente une grande valeur ajoutée. D'autre part, l'analyse a montré que la sensibilité dépend de la manière dont les incertitudes sont spécifiées (soit comme facteur d'échelle, soit comme variables individuelles, soit comme groupe de variables) et quel niveau d'incertitude on specifie. C'est pour nous l'un des enseignements importants de notre participation à l'Annexe 70 de l'AIE EBC et il devrait être pris en compte lors de la réalisation d'autres analyses d'incertitude et de sensibilité à l'avenir.

Summary

TEP Energy represented Switzerland in the IEA EBC Annex 70: "Building Energy Epidemiology: Analysis of Real Building Energy Use at Scale" and actively contributed to its goals.

Motivation and Goals: The IEA EBC Annex 70 "Building Energy Epidemiology: Analysis of Real Building Energy Use at Scale" aimed at the analyses of (real) building energy use at scale and the energy modelling of building stocks. Referring to the emerging field of energy epidemiology, it seeks to develop robust approaches to such analyses. The comprehension of the interrelations between buildings, actors, and the building stock as well as the impacts of various drivers (including policy measures) is improved adopting a multi-disciplinary approach. The purpose of the Annex is to support member countries in their task of developing realistic transition pathways to dramatic reductions in energy use and carbon emissions associated with their buildings.

Methodology and procedure: To address the specific Annex objectives, the research and development work in the Annex is divided into three subtasks. Subtask A focuses on user engagement (needs and provisions). Therefore, an online-survey was developed within the Annex 70 to collect information on needs of different energy and building related data, the frequency of use and the data access. Subtask B focuses on data and methods. An online dataset repository is developed which serves as central repository for energy and building related datasets. Each dataset is described and classified and characterized with metadata. In Subtask C building stock modelling and related analysis are addressed. Based on previous classification studies, a new building stock energy model classification framework that leverages international modelling expertise from the participants of the International Energy Agency's Annex 70 on Building Energy Epidemiology is set up. Further, a reporting guideline is generated by means of the aggregated knowledge of participating members of the IEA-EBC Annex 70. In contract to the classification framework, the reporting guideline is more precise on technical details of different energy models. Finally, in order to compare and evaluate different models, comparable methods for uncertainty and sensitivity analysis are applied.

Results and Discussion: The survey of Subtask A shows that a large amount of data users not only use data but also collect/generate data themselves. Building and energy-related data is used in a variety of disciplines. However due to its heterogeneity it is often difficult to communicate and compare across different countries. The online dataset repository developed in Subtask B should further improve this situation by collecting and describing meta information of a variety of datasets, used by energy modellers in a systematic way. More than 1000 datasets were added in the dataset repository which might further be expanded in the future. The model classification framework developed in Subtask C proposes a non-hierarchical multi-layer quadrant scheme that classifies modelling techniques by their design (top-down or bottom-up) and degree of transparency (black-box or white-box). This allows for the incorporation of emerging modelling techniques (system dynamics, agent-based and machine-learning) and model characteristics (e.g. system boundaries, geographical and spatial resolution, uncertainty etc.). Further, the reporting guideline designed by IEA EBC Annex 70 members expanding on five topics (overview, model components, input and output, quality assurance and additional information) will help to improve the transparency and understanding of building stock models. Finally, the uncertainty and sensitivity analysis gives an overview on typical uncertainties of datasets and parameter used in building stock modelling and revealed the impact such uncertainties have on the output of models.

Conclusions: Based on the outcome of the IEA EBC Annex 70 (and based on TEP's related and generic building stock modelling activities) the following take home messages are retained:

- Various types of stakeholders express an increasing need for energy and energy-relevant building data at scale, serving diverse purposes. Partly, data users are also data holders or data providers. However lacking data, insufficient data quality, data privacy and data protection issues as well as strategic considerations hinder the creation of consistent data sets that are made available at appealing conditions. If Switzerland and other countries should rapidly achieve ambitious

decarbonization goals, data quality and data availability should be improved to enable effective planning and implementation of decarbonization measures.

- To a certain extent suitable energy and building stock models may help to overcome the situation of lacking or inconsistent data. Indeed agent-based or individual-building specific models enable the intersection of different data sets at various resolution. Also, models may be used to synthetize data to fill data gaps. As such, building stock models and related data sets might be used for different purposes, depending on the concrete needs (e.g. monitoring energy consumption, explore decarbonisation pathways, appraise the effect of policy measures).
- To improve the usefulness of building and energy models for the above mentioned purposes various aspects should be improved. Particularly the models should be described in terms of purpose, functionality, parameters and datasets etc. The IEA EBC Annex 70 contributed to this need by its modeling reporting guideline. Also, to appraise the models' uncertainties dedicated uncertainty and sensitivity analysis are useful for both modelleres and their clients. The IEA EBC Annex 70 helped to raise awareness regarding these aspects.
- The uncertainty and sensitivity analysis indeed turned out to be very useful and insightful. One the one hand side the relative relevance and impact of the uncertainty of different variables could be visualized. On the other hand, the analysis revealed that the sensitivity depend on how uncertainties are specified/implemented (either as scaling factor, as individual variables or as group of variables) and on the magnitude of uncertainty ranges specified. This is one of the important learnings from our participation in the IEA EBC Annex 70 and should be taken into account when performing further uncertainty and sensitivity analysis in the future.

Contents

Abbreviations

BAFU	Bundesamt für Umwelt (*Federal Office for the Environment*)
BDR	Buildings and dwellings registry
BFE	Bundesamt für Energie (*Federal Office of Energy*)
BSM	Building stock model
EBC	Energy Buildings Community
EGID	Eidgenössischer Gebäudeidentifikator (*Federal building identifier*)
EPG	Energy Performance Gap
EWID	Eidgenössischer Wohnungsidentifikator (*Federal dwelling identifier*)
FeKo	*Feuerungskontrolle* (control / inspection of combustion systems)
FOEN	Federal Office for the Environment
FSO	Federal Statistical Office
GEPAMOD	Gebäudeparkmodell (*Building stock model*)
IBPSA	International Building Performance Simulation Association
IEA	International Energy Agency
IERC	International Energy Research Centre
MDB	Multi-dwelling building
NREL	National Renewable Energy Laboratory
NTNU	Norwegian University of Science and Technology
SDB	Single-dwelling building
SFOE	Swiss Federal Office of Energy
ST	Subtask
TEP	Technology, Economics, Policy
UASA	Uncertainty analysis and sensitivity analysis
UCL	University College London

1 Introduction

The transformation of the building stock with drastically reduced energy demand and carbon emissions requires a wide set of technology and policy interventions. To be truly effective, this transformation must be supported through comprehensive empirical evaluation, both ex-ante and ex-post. The data to support the design, implementation and evaluation of such interventions are often absent; consequently, many policies do not deliver the anticipated impact on energy demand and carbon emissions.

The collection of, and access to, reliable building and energy use data have historically been limited due to a lack of awareness, due the cost of collection, maintenance, and management as well as due to institutional or governmental structure such as the privatisation of utilities. In addition, the importance of access to high quality data has been underestimated. This situation is changing as new international treaties are agreed upon and countries implement legislatively controlled carbon budgets. Simultaneously, a data revolution is occurring driven by the introduction of high frequency and smart meters, the increasing use of low-cost sensors, and the combination and integration of many and varied data sets facilitated by the Internet.

A much better systems approach is needed to intersect such data sources, also to understand how energy demand and carbon emissions is changing over time, and the reasons therefore. A comprehensive and/or energy systems perspective can be obtained by bringing together energy data from large scale population (or building stock) based studies and adopting data management and analytical techniques similar to those applied to public health (e.g. health epidemiology). Insights from population-based empirically derived evidence can be used to inform the type, timing, and targeting of policies, as well as provide insights to assist development of technologies designed to manage energy demand and carbon emissions. For example, by linking together large databases of energy, buildings, and energy retrofits data to determine the efficacy of different technologies in reducing measured energy use. Such information is the tip of the iceberg of what can and should be achieved with future data sources and when these data are combined with data from more detailed field studies.

1.1 Background information and current situation

Currently, energy related building data and energy building stock models are stored and used quite ad hoc and scattered over different data owners and research groups. In general terms data sources are getting more and more complete, for instance in terms of spatial (3D) data or in terms of data with high(er) temporal resolution (including high-frequency sampling). Yet, accessibility is still an issue in many respects, both with public and corporate data owners (albeit for different reasons).

Also, the state of the art and the scope of energy and building stock models is quite heterogeneous, especially across countries. This makes comparisons of model methodologies and data adoption approaches quite difficult.

1.2 Purpose of the project

The shift to a low carbon, built environment will require both a step change in the energy performance of buildings alongside more efficient provision of energy services, and an aggressive decarbonisation of the energy used. Yet the prerequisite data of building stocks needed to support this essential shift in energy performance of buildings are not necessarily available or are inaccessible or incomplete. Further, as more information on building energy use (and indoor environment) is collected through high frequency sensors and building form analytics become more sophisticated, the analysis methods applied to the myriad and diverse sub-sectors of the building stock ‘population’ need to be commensurate with the heterogeneity of the building stock.

In support of the principal aim of employing an energy epidemiological approach for the benefit of improving the transition to more energy efficient buildings and communities, and to take advantage of various experiences, an international approach is needed. For these reasons the IEA EBC Annex 70 was initiated to identify lessons that can be learned and shared between participants.

1.3 Objectives

The goal of the project is to represent Switzerland in the IEA EBC Annex 70: "Building Energy Epidemiology: Analysis of Real Building Energy Use at Scale" and to actively contribute to its goals:

1. To evaluate the scope for using real building energy use data at scale to inform policy making and to support industry in the development of low energy and low carbon solutions;
2. To compare across the national approaches to developing building stock data sets and building stock models, and to addressing the data analysis reliability in the calculation of the energy performance gap; and,
3. To establish best practice in the methods used for gathering and analysing real building energy use data, including the creation of models and the identification of determinants for energy demand/use.

The principle aim of the energy epidemiological approach is to put in place the methods that can improve the understanding of variation and causes of difference among the energy-using population. For Switzerland, the relevance of new evidence regarding the energy performance gap and of further uncertainties (from a methodical and data point of view) should be assessed through and with building stock modelling. Based on these findings methodological approaches and related data need to decrease uncertainties should be highlighted. Innovative validation and data gathering approaches should be developed. The agent-based approach described by Nägeli et al. (2018) should be investigated and further developed. The approach is particularly valuable due its potential ability to incorporate energy data at different scales (building technology, building, neighbourhoods, regions, countries etc.)

The Annex is principally about energy and building stock data and models (it is not the intention of the Annex to collect such data, instead the function of the Annex is to identify, describe and structure the data and models and to provide best practice guidance on their use). The Annex focuses on ‘populations’ of buildings and not on individual buildings and the goal is to:.

- Engaging with government, industry and technology manufacturers in order to identify user requirements for data and information upon which future strategy and policy can be based;
- Researching the requirements, needs, types, and uses of empirical building and energy data for both the residential and non-residential building stock;
- Developing best practice guidance for undertaking surveys and for analysing and reporting energy and building stock data and models; and,
- Developing metrics and methods for international comparisons of building stocks and their energy use.

2 Description of facility

The facility TEP Energy contributed with to the IEA EBC Annex 70 is its building modelling stock family, its experience of developing and applying various bottom-up models at various scales, and related empirical methods to fill data gaps.

Depending on the research topic and of the problem stated by clients such as the SFOE and other federal entities, Cantonal and municipal authorities, associations, utilities, and others, different functionalities are needed to address respective issues (see Jakob et al., 2019a; Jakob et al., 2019b; Reiter et al., 2019). Related to building stock modelling TEP Energy's models are all bottom-up models. They all adopt a hybrid approach (according to the model classification developed in this IEA EBC Annex 70, see description of results of Subtask C) in terms of modelling techniques: engineering, statistical, and economic methods are used (see Nägeli et al., 2018; Nägeli et al., 2020a; Nägel et al., 2020b for details). However, they serve different purposes, and also are different with respect to other dimensions (see Table 1).

Table 1: Overview of the Building stock model family by TEP Energy.

	Swiss BSM	**Swiss BSM**	**Cantonal BSM**	**Spatial BSM for Municipalities, Cantons, and Switzerland**
Purpose	Ex-ante analysis of scenarios and policy measures	Ex-post analysis of the drivers and use categories of past energy consumption	Ex-post analysis of energy indicators and CO_2-emissions	Ex-ante analysis of scenarios and policy measures
Modelling technique	Building agents characterized by attributes stemming from aggregated data or statistical distributions (pre-analyses), dynamics based on the simulation of decisions	Building agents characterized by attributes stemming from aggregated data or statistical distributions (from pre-analyses), dynamics based on the simulation of decisions and/or on assumptions	Cohorts of building archetypes characterized by attributes derived from registries, aggregate and statistical data (from pre-analyses) and surveys.	Alteration of buildings based on exogenous assumptions and on the simulation of decisions. Buildings are characterized by attributes stemming from registries and from aggregated data or statistical distributions,
Spatial resolution	Cantons, energy related topology (spatial potentials and restrictions)	Cantons, energy related topology (spatial potentials and restrictions)	Canton (could be extended to municipalities, energy related topology)	Geo-referenced individual buildings and parcels, related to georeferenced potentials and restrictions
Temporal resolution	Annual, monthly btw. 2010 and 2050/2060	Annual, monthly, btw. 2000 and 2020 (and subsequently beyond)	Annual, monthly, btw. 2016 and 2020 (and subsequently beyond)	Annual, monthly btw. 2010/2018 and 2050/2060
Considered dynamics	Construction of new buildings, demolitions and retrofit of existing ones (by element), reinstatement and replacement of heating systems, energy-efficiency options of building technologies (all			
System boundaries	Final energy and upstream primary energy and emissions, embodied energy and emissions	Final energy and upstream primary energy and emissions, embodied energy and emissions	Final energy and direct emissions, could be expanded to upstream primary energy and emissions, embodied energy and emissions	Final energy and upstream primary energy and emissions, embodied energy and emissions

3 Procedures and methodology

To address the specific Annex objectives, the research and development work in the Annex is divided into three subtasks, which are further divided in a number of research activities. The three main subtasks (ST) are:

- Subtask A: User engagement (needs and provisions);
- Subtask B: Data and methods;
- Subtask C: Building stock modelling and analysis.

The following section describes the methodology as well as the procedure in the three subtasks, referring to extra reports for more detailed descriptions.

3.1 Subtask A: User engagement (needs and provisions)

Lead: Ian Hamilton, University College London, UK

Co-Lead: Hannes Warmuth, ÖGUT, AT

In the context of this subtask, the different needs and interests are identified based on the identification of relevant stakeholders as well as data users and producers. The topic of "Big Data" poses different challenges for actors in the building and energy sector, although it can also be seen that attractive new business areas in the management and analysis of extensive data sets are emerging as a result. The prevailing needs and interests serve as a basis for the subsequent development of international benchmarks, which are much easier to implement if stakeholders are involved in the activities at an early stage.

In Subtask A potential users and producers of building and energy related data identified and the requirements of these users in various fields of application are investigated by an extensive online survey.

TEP Energy contributes to the

- structuring of the various user groups and provides content related as well as methodological input to the online survey.
- evaluation and communication of the Swiss-specific results by means of a short report.

More information on Subtask A as well as TEPs contribution can be found in Müller et al. (2021).

3.2 Subtask B: Data and methods

Lead: York Ostermeyer, Chalmers University, SE

In Subtask B data availability, data access and data fundamentals in the participating countries are being gathered and assessed. To this end, a methodology is developed, in order to classify, describe and evaluate data. Different aspects of data protection, data acquisition and data storage are also included.

The contribution and activities from TEP include:

- Methodological contributions, with a focus on data related to building stock modelling.
- Revision of the structure of the data registry activity (to make it more compatible with findings from Subtasks A and C)

- Input of energy and building related datasets into a dataset repository set up as part of the Annex. This includes the description of the data set as well as the metadata and the classification of the data sets.

3.3 Subtask C: Building stock modelling and analysis.

Lead: Jelle Laverge, Ghent University, BE

Co-Lead: Martin Jakob, TEP Energy, CH

In Subtask C the development and application of building stock models are recorded and described, as well as in classified and registered in a framework developed as part of ST C.

In order to compare and evaluate different models, an international validation method is being developed. The analysis of the effect of uncertainties is of particular importance in this context. Uncertainties can arise due to incomplete data, but also due to a lack of linkage possibilities. The overall procedure for the uncertainty and sensitivity analysis can be divided into 4 steps:

a) *Analyse uncertainties of various datasets* (and modellers' assumptions in case of lacking data) that serve as input tables or as parameters of calculation routines through a thorough literature analysis.

b) *Identify potentially sensitive parameters and identify groups of parameters that are common across different models.* The relevant parameters could vary depending on whether the current status or future scenarios are assessed. For this reason, the analysis has been divided into first evaluating variables that only influence the "initial state" (IS), and then the ones that influence the "dynamic state" (DS), and the "dynamic development" (DD). Furthermore, the analysis is also divided for "residential" and "non-residential" buildings, as not all parameters are pertinent for both.

c) *Define parameter ranges.* To further confine the scope of the Uncertainty and sensitivity analysis (UASA), both to make it meaningful and feasible (referring to computation time the number of runs must not be high), the range within a certain parameter is varied was specified. This specification of the parameter range is based on findings from the literature and on modellers' experience (see also presentations in the Cologne meeting in November 2019 (Jakob et al. 2019c) or Cork (Nägeli et al, 2019c)). The ranges for each parameter will be chosen for the two different building typologies mentioned in the previous point: "residential" and "non-residential" buildings. For some parameters, further specifications are made according with age, and some geometry considerations (single or multi-dwelling, roof type, etc.).

d) *Perform sensitivity analysis*. The sensitivity analysis was done following the Morris method, also called Elementary Effects. With this method, for each run one input parameter is changed and the ensemble of all runs explores the space of all combinations of parameters (Morris, 1991). The input values were assigned using distributions (mostly normal or lognormal) based on the typical range values for the group parameters (see previous point). The UASA will be focused on two output parameters: final energy demand and CO_2-emissions.

Contributions by TEP include:

- Demonstrate the impact of new knowledge at the level of individual buildings/samples of buildings on the building stock as a whole.

- Participation with the building stock model in the international activity among others with the aim to evaluate/improve it.

- Collaboration on the development of evaluation standards (performance indicators) for national building stock models to compare them across countries.

More information on the UASA as part of Subtask C as well as TEPs contribution can be found in Jakob et al. (2021b).

4 Results and discussion

Given the goal of this report, this chapter focuses on results and discussion of TEPs contribution to the IEA EBC Annex 70: "Building Energy Epidemiology: Analysis of Real Building Energy Use at Scale". For each Subtask A, B and C, the main results and outcomes are described and if available, further publications with more detailed descriptions are mentioned.

4.1 Subtask A: User engagement (needs and provisions)

The stakeholder survey about “access and use of energy and building stock data among different organization types and their views on how data is used to support the low carbon transition of the built environment” was finalized in 2018. After the finalisation of the English version together with the Annex lead and a small core team it was translated into German and implemented into the survey software (by the Austrian partner OEGUT). TEP Energy supported this activity and adjusted the survey to the Swiss context. The roll-out of the survey in Switzerland took place in the reporting year 2019, with a first wave end of September / beginning of October 2019. A reminder was sent in November 2019.

In 2020, the collected data was aggregated, descriptive results were generated and reported to the IEA EBC Annex 70 consortium. Combined with the survey results of other countries, a more comprehensive overview concerning the access and use of energy and building stock data can be given. In 2021 a short country report for Switzerland was drafted, where all important descriptive analyses and insights from the survey are presented (Müller et al. 2021). The most important results from the survey are presented in this report.

In Switzerland an impressive sample of 399 responses has been collected which corresponds to a response rate of 12%. Since the invitation to the survey was sent by email and regarding the period of the survey at the end of the year, the response rate is pleasing. The target group is composed of stakeholders from federal, cantonal and municipal authorities, energy utilities and other potential users of energy and building data from construction and building operation sectors. Almost all of the participants (> 97%) work for a company or organisation in Switzerland and only a minor part works in neighbouring (Germany and Austria) or other countries. All company/organisation sizes are well represented in the sample (more than 17% of the sample for each category).

Some of the survey results are presented here as examples. Figure 1 illustrates the relative frequency of each chosen answer regarding the benefits of access and using possibilities of energy and building data. More than 50% of the respondents indicated that they benefit in order to conduct analyses and research topics, they combine datasets to get better information or to improve efficiency of energy services. The results show that the demand for energy and building data is high and very heterogeneous, i.e. the interests are widely distributed over the different topics and no key interest is identified that would dominate other interests.

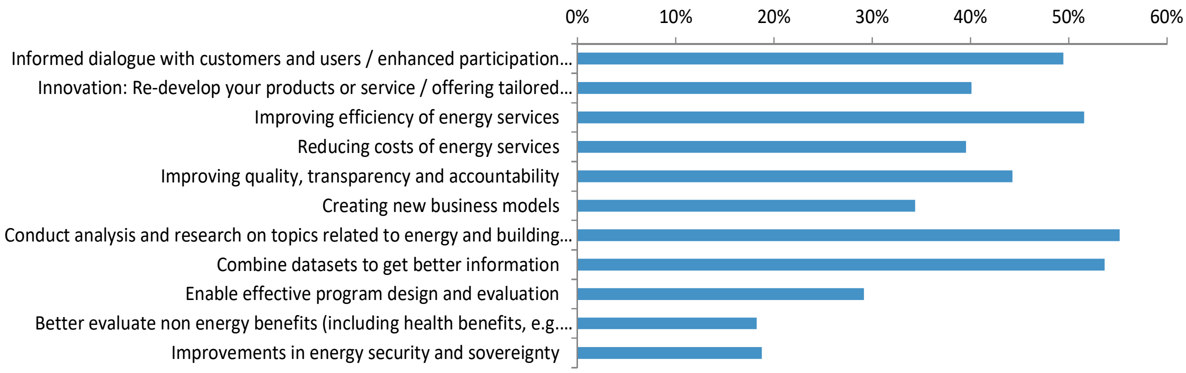


Figure 1: Answers to question "What are (or could be) the benefits of accessing and using buildings and energy data in your organization?". A total of N = 207 answers were collected.

The frequency by which energy data is used varies a lot by data type (see Figure 2Figure 2). Low temporal resolution fuel data is a lot more used than high resolution data regarding fuel use. However, a higher amount of respondents also indicated, that they don't have access to high resolution data. Furthermore, carbon intensity as well as billing and tariff data are also widely used.

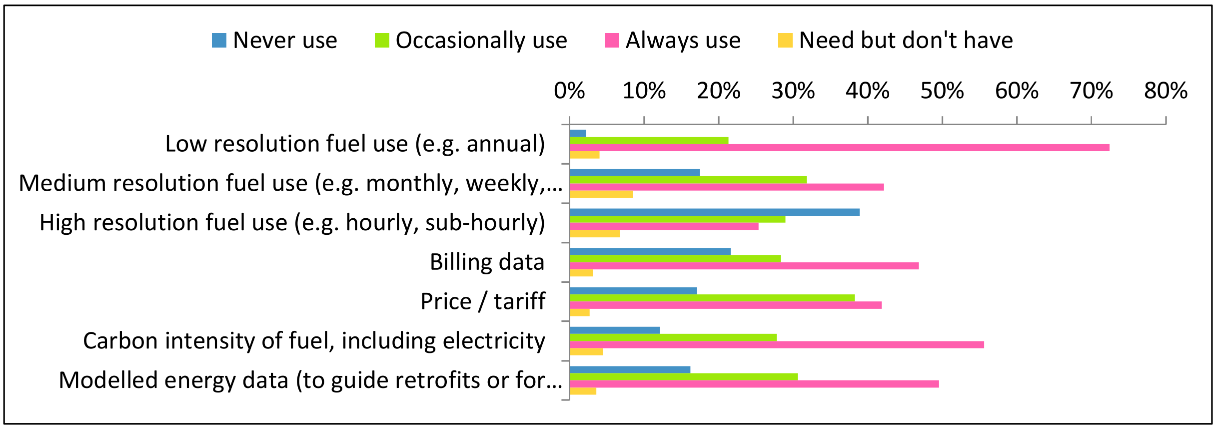


Figure 2: Frequency by which energy data is used. A total of N = 227 answers were collected.

Similar patterns are visible for building data (see Figure 3). Especially data regarding building age, floor area, heating/cooling/ventilation/storage systems, renewable technologies or activity type are very often used. Compared to the energy data, the respondents more often indicated that they would need the here listed data although they do not have access.

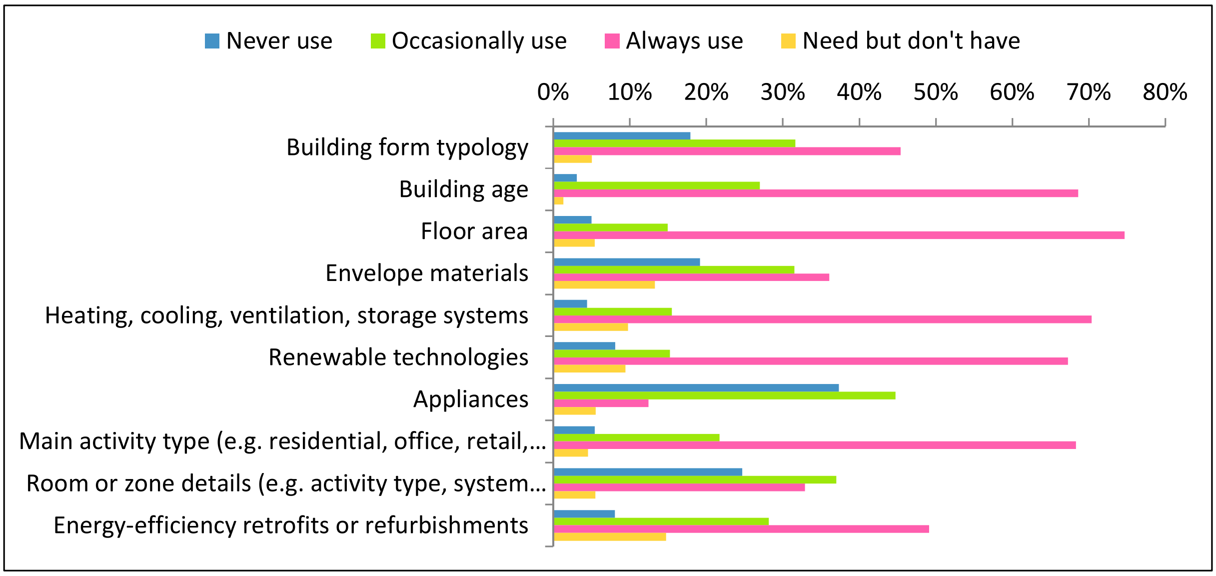


Figure 3: Frequency by which building data is used. A total of N = 227 answers were collected.

The extensive survey shows that a large part of the users of energy and building data also collect/generate data themselves. Energy and building data are most frequently used for the analyses of building performance, for measuring, verifying or evaluating energy savings as well as for communicating energy measures and for planning purposes. Respondents use building data (year built, typology, materials, heating and hot water) more frequently than energy data (e.g., consumption, billing, or tariff data).

Besides lack of resources and budget, stringent privacy protections are most commonly indicated as barriers to collecting, accessing, and using energy and building data. Publicly available data is important to many institutions, but at the same time presents several challenges. The compliance with the present data protection, including confidentiality and storage of the data as well as the competitiveness, represent possible challenges.

A majority of respondents see the benefits of accessing and using energy and building data when merging datasets for detailed analysis. This linking of data sets allows new analysis possibilities. For this, however, improved, uniform data registers are desirable both nationally and at the European or global level.

Further, the survey showed, that Smart meter data and other building performance data are also being used more and more frequently. The latter are available from building certificates, for example.

The survey was also conducted in other countries as part of the IEA EBC Annex 70, for which an aggregated summary is produced in a different form. For certain countries (Japan, Canada, Norway, Austria, USA), specific results are also published in report form. The comparison of Switzerland with Austria shows that the usage of data but also the advantages of the use of energy and building data is estimated very similar. Especially with regards to data protection, the distribution of answers is very similar to that of Switzerland (Warmuth et al. 2021).

4.2 Subtask B: Data and methods

Research projects often involve the collection and analysis of data, the collection of meta-information and the subsequent publication of the results. However, finding appropriate data sets is often a very time-consuming task. Accordingly, in this project repository with structured information about building and energy related data and models is created.

Within the scope of Subtask B and in collaboration with the other IEA partners, TEP contributed to the development of the data registry (Palacios, 2018; IEA EBC Annex 70, 2021). The data registry includes a wide range of different data sets related to energy and building relevant data. By advanced search methods the datasets can be filtered by different attributes (country, publisher, building type and theme (categories: people, building, energy, environment or other).

New data registry entries are inserted by an online form (see Figure 4). Each dataset consists of general information such as title, description, and data type (raw data, cleaned raw data, processes/aggregated data, model output etc.) and is categorized by different attributes:

- **Main theme**: categories: people, building, energy, environment or other
- **Sub theme**: further specification based on the theme (e.g. for theme "energy": consumption/energy use, energy carrier / fuels, end use type, costs and prices, sector)
- **Typology (related to buildings)**: agricultural, commercial, residential, medical, educational, government, industrial, military, parking structures and storage, religious, transport, non-buildings, infrastructure, power providers, institutional, non-residential, others
- **Unit of observation**: building, cluster, household, person, component, province, national, international
- **Time resolution**: static/constant, annual, monthly, weekly, daily, hourly, minute, second
- **Language**: variety of languages
- **Country**: variety of countries

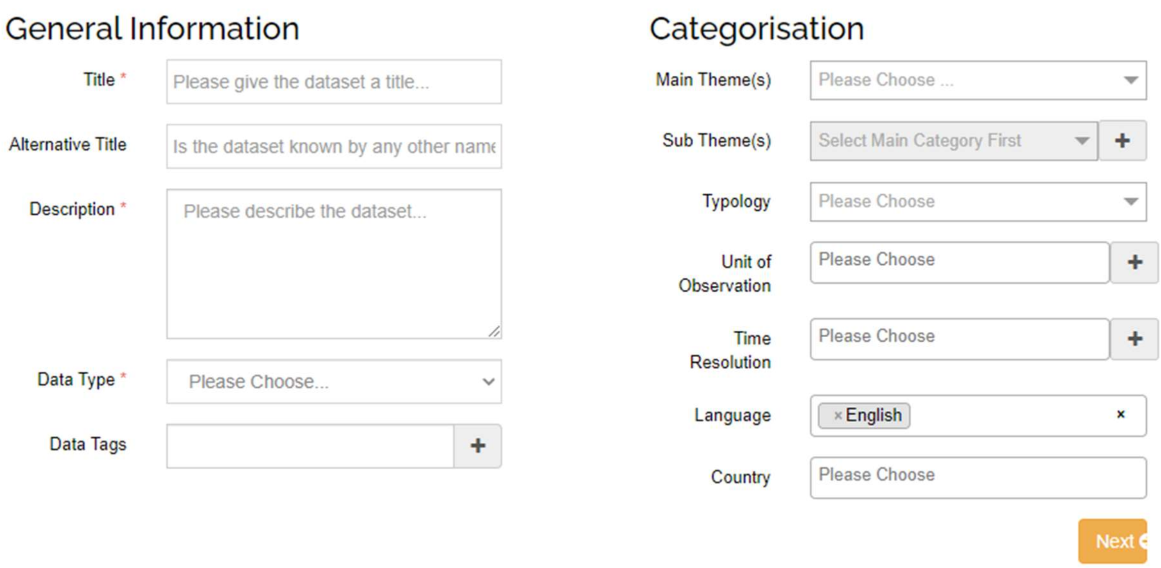


Figure 4: Online form to create a new entry in the data registry (IEA EBC Annex 70, 2021).

Further, access information (access type, open data license, source, contact details) and owner details (author, publisher, maintainer, harvested from, creation and publication date) are indicated for the datasets. The model registry further allows for data import by URL.

In terms of providing content to the data registry TEP Energy add meta data about several building and energy related data sets. An important starting basis of this activity was the report "Bestandes-aufnahme Energie- und CO_2-Daten – Grundlagen für die Bestimmung von Energie- und CO_2-Daten des Gebäudeparks in den Kantonen” (Jakob et al. 2015). In addition to this inventory TEP Energy researched and compiled additional data sets and fed its meta information into the dataset repository. In the following, some key registries are listed including descriptions for some of them:

a) Federal Register of Buildings and Dwellings, published by the Federal Statistical Office (FSO), Switzerland
The federal register of buildings and housing contains the most important basic data about buildings and housing. It is used for statistical, research and planning purposes and allows the cantons and municipalities to fulfil their statutory tasks. The register is updated in coordination with the construction and housing statistics. Every building and every dwelling has a clear and unique identification number (federal building ID (EGID) or federal dwelling ID (EWID)) and a geocoded address, standardised according to the SNV 612040 standard. Plot numbers, building numbers and metric building coordinates allow the exact geographic location of the buildings to be identified. It provides an up-to-date view of the building and dwelling stock of Switzerland, thanks to the quarterly update. Licence to use geodata A licence is required for the use of official survey and geological data. The Geoinformation Act distinguishes between private and commercial use. A licence for private use is issued when the map or data are ordered and the corresponding fee has been paid. A special licence is required for commercial use. However, swisstopo also makes certain geodata available for downloading or within the scope of its geoservices without charge.

b) Buildings and Dwellings Statistics 2017 and subsequent years, published by the Federal Statistical Office (FSO), Switzerland *Buildings by canton, building category, use, number of floors, number of dwellings and time of construction. Mostly residential buildings so far. Dwellings by canton, building category, number of rooms, occupation and ownership and time of construction. The Buildings and Dwellings statistic (BDS) is based on the Federal Register of Buildings and Dwellings (RBD) in combination with data from the Population and Household Statistics (STATPOP) and from the FPC's Structural Survey (SS). It provides information on the structure of the whole buildings and dwellings stock and on the population's living conditions (e.g. occupation density per room or dwelling, floor space per person).*

c) Structural Statistics of Enterprises, published by the Federal Statistical Office (FSO), Switzerland. *STATENT provides central information on the structure of the Swiss economy (eg number of enterprises, number of establishments, number of jobs, etc.) and provides an overview of Switzerland's economic landscape. It is based on the records of the AVS compensation funds and thus represents a methodological change, since it is no longer based on an exhaustive survey, but on the basis of register data. The STATENT replaces the Business Census (BR), last carried out in 2008. The use of the AVS registers in particular makes it possible to reduce the investigation burden of the companies.*

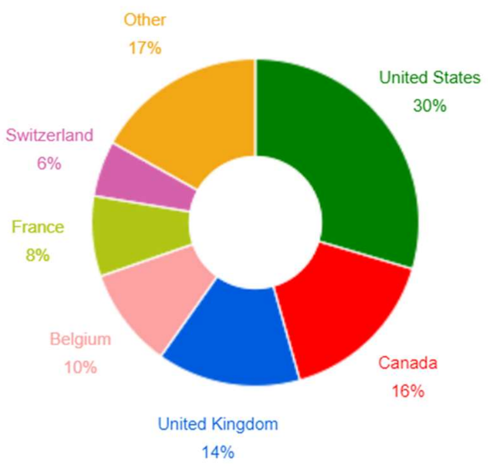
d) STAT-TAB - interactive tables (FSO), published by the Federal Statistical Office (FSO), Switzerland
STAT-TAB enables the interactive creation of customised tables on numerous official statistics topics. The tables produced can be exported in various formats. The basis for the creation of tables are the data cubes. The search for the appropriate data cube is carried out using the various options in the left-hand column or by a random search in the search box. Tables are produced by using individual combinations of the characteristics (variables) of the selected data cubes. You will find general information on STAT-TAB with a link to the filter list of all cubes, a user guide and a contact form here:
https://www.bfs.admin.ch/bfs/en/home/services/recherche/stat-tab-online-data-search.html

e) swissBUILDINGS3D 2.0, published by Swiss Federal Office of Topography swisstopo
According to swisstopo, the swissBUILDINGS3D 2.0 is a vector-based dataset which describes buildings as 3D models with roof geometries and roof overhangs. The high degree

of detail in all three dimensions, together with the high coverage and realistic rendering of the building volumes, make this product a valuable basic dataset for a large range of applications. swissBUILDINGS3D 2.0 is updated every six years. Technical details and information on how to get the dataset in different formats can be found here: https://shop.swisstopo.admin.ch/en/products/landscape/build3D2

f) Final annual energy consumption by energy agent and by sub-sector for the sectors Industry and Services, report and analysis about an annual survey of energy consumption of public and private enterprises (Del Taglia et al. 2019, Stamm and Kost, 2019)
g) Electricity production and demand by technology and by sector (Swiss electricity statistics), published by the Swiss Federal Office of Energy
h) Swiss global energy statistics, published by the Swiss Federal Office of Energy
i) Emission Information System in Switzerland (EMIS)
j) Final consumption of renewable energy, by energy agent and by technology
k) Swiss statistics for renewable energy, Swiss Federal Office of Energy

The data registry gives an overview of 1094 datasets. TEP Energy contributed by adding information of a total of 59 datasets from Switzerland (IEA EBC Annex 70, 2021). The shares of added items differentiated by country and theme are illustrated in Figure 5.



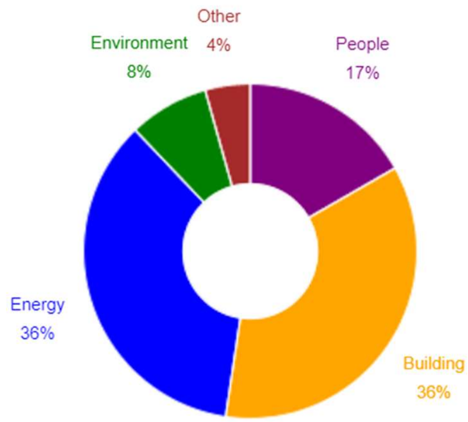


Figure 5: Share of added items differentiated by countries (left) and themes (right).

4.3 Subtask C: Building stock modelling and analysis.

4.3.1 Model classification

To develop a common understanding, a meaningful model classification system has been an important part of the Subtask C activity in 2018. The classification should consider themes (building, people, environment [context], energy) and the main classification dimensions were chosen to be:

- Model type (bottom-up vs. top-down)
- Modelling techniques (engineering, statistical, economic etc.)
- Model purpose (descriptive, predictive, ex-ante vs. ex-post etc.)

Additional dimensions such as spatial resolution, temporal resolution, considered dynamics, system boundaries, uncertainty aspects (provenance, assessment approaches) are considered as further classification variables.

In 2019 the model classification was restructured, revised and further developed. In 2020 the article on model classification “Developing a common approach for classifying building stock energy models” (Langevin et al., 2020), to which TEP Energy contributed, was published.

Models that represent the energy use of the building stock at scale under various scenarios of technology deployment have become essential tools for the development and assessment of sustainable development goals. Within the past decade, the capabilities of building stock energy models have improved considerably, while model transferability and sharing has increased. Given these advancements, a new scheme for classifying building stock energy models is needed to facilitate communication of modelling approaches and the handling of important model dimensions (Langevin et al., 2020).

Due to the development in modelling, hierarchical classification trees (e.g. into bottom-up and top-down branches) can no longer capture the variety of the energy models. Hence, within the IEA EBC Anenx 70 a new building stock energy model classification framework has been developed. It leverages international modelling expertise from the participants of the International Energy Agency’s EBC Annex 70 on Building Energy Epidemiology (see Figure 6) (Langevin et al., 2020).

The proposed building stock energy model classification scheme (Figure 6) establishes a flexible framework for high-level model classification that:

a) builds from existing classification frameworks while accounting for emerging simulation-based, data-driven, and hybrid modelling techniques;

b) recognizes the potential sub-layers of a building stock energy model; and

c) encourages the description of additional model dimensions that are not readily captured by a high-level classification.

In place of the hierarchical organization of existing classifications, the classification diagram in Figure 6 groups building stock energy modelling techniques into one of four quadrants based on their design (top-down/bottom up) and degree of transparency (black-box/white- box). The four classification quadrants are thus: top-down/black box (Q1), top-down/white-box (Q2), bottom-up/black-box (Q3), and bottom-up/white-box (Q4) (Langevin et al., 2020).

To illustrate how this new classification approach addresses gaps in the coverage of building stock energy modelling techniques in existing classifications, Figure 6 includes examples of emerging data-driven and simulation-based techniques alongside established techniques: machine learning (Q4: bottom-up/white-box), system dynamics (Q2: top-down/ white-box), agent-based modelling (Q4: bottom-up/white-box), and physics-simulation (Q4). Additionally, the new classification designates an area between each of the four classification quadrants for hybrid modelling techniques that combine techniques across (but not within) the quadrants (Langevin et al., 2020).

Figure 6 shows three additional modelling layers that support the main energy layer of the classification. These supporting layers concern the representation of key energy use determinants: occupants energy-related behaviours within the modelled building stock, the characteristics of the building stock itself, and environmental context (physical conditions such as outdoor temperature and solar intensity as well as socio-economic conditions). Modelling techniques that directly represent such variables are expected to map to the same four quadrants shown in Figure 6 for the energy layer, though specific techniques within each quadrant may be unique to the supporting layer. Where these supporting layers are only implicitly addressed in a building stock energy model, this should be noted alongside the model’s classification (Langevin et al., 2020).

Finally, Figure 6 identifies four additional modelling dimensions that should be described as a complement to the high-level classification: dynamics, system boundaries, spatio-temporal resolution, and model uncertainty. Each of these dimensions represents an axis along which modelling approaches may vary independently of the high-level classification quadrants and layers. While such dimensions are not readily captured by a high-level classification, their description provides important context about a model that further facilitates its assessment by the research community and comparison with similar building stock energy models (Langevin et al., 2020).

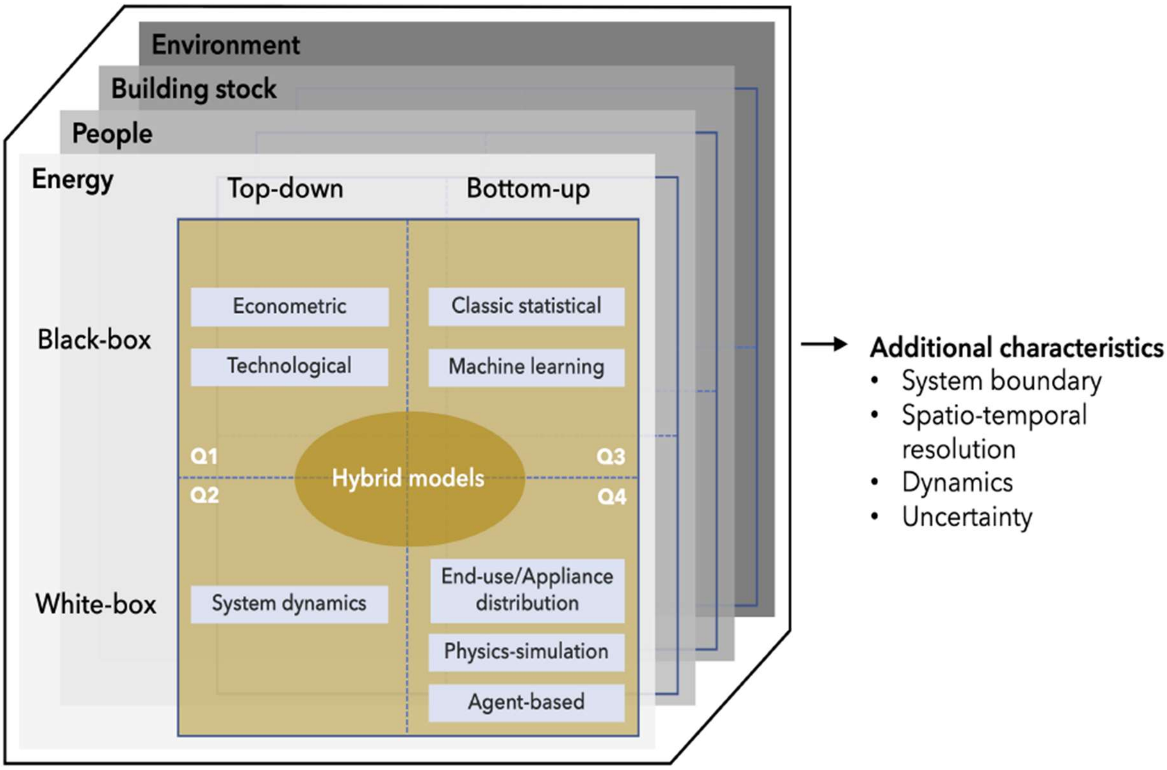


Figure 6: An updated classification scheme for building stock energy models (Source: adopted from Langevin et al., 2020).

Table 2 summarizes the approach as well as strengths and limitations of models in each of the four quadrants (Top-down/Black-box, Top-down/White-box, Bottom-up/Black-box, Bottom-up/White-box) and hybrid models (multiple quadrants).

Table 2: Summary of classification quadrants (Langevin et al., 2020).

Classification Quadrant	Approach	Strengths	Limitations
Q1 (Top-down /Black-box)	Estimate aggregate building energy use from sector-wide socio-economic and/or technological variables	Simple and computationally tractable, readily paired with other modeling frameworks (e.g., with bottom-up representations of energy demand in Integrated Assessment Models)	Typically unable to represent impacts of specific technology or operation improvements/ measures; unable to represent disruptive changes to building stock energy use due to reliance on historical data
Q2 (Top-down /White-box)	Represent physical causality at the aggregate building and technology stock level	Able to represent the complexity of building stock energy use and its components at the aggregate level, including technology and building stocks, stock flows, and the evolution of the system over time	Unable to link aggregate building energy use to building-level operations; unable to represent spatial dimension; may require extensive data, time, and expert knowledge to fully represent system components and causal flows
Q3 (Bottom-up /Black-box)	Attribute building-level energy use to particular energy end uses utilizing statistical analysis of historical data	Able to reveal important relationships between energy end use outputs and relevant input variables; relatively simple models with low data requirements may yield high explanatory or predictive performance	Unable to explicitly represent key dynamics influencing energy end uses in buildings (e.g., occupant behavior, heat transfer through the envelope); in certain cases require large datasets to yield good predictive performance (e.g., machine learning models)
Q4 (Bottom-up /White-box)	Simulate the physical relationships of proccesses at the building or energy end-use level	Able to explicitly represent key dynamics influencing building energy end uses, building stock diversity, and the aggregate energy effects of changes to operations at the individual building level	Require extensive data to represent detailed characteristics of the building stock and drivers of its end use patterns, computationally intensive, potentially challenging to pair with other modeling frameworks
Multiple Quadrants (Hybrid)	Combine elements of the modeling approaches across the four classification quadrant	May address the limitations of one modeling approach by complementing with the strengths of another; potentially more flexible in application and able to answer a broader set of analysis questions	Often more complex in design and implementation – and by extension, more difficult to communicate and replicate – because of the need to harmonize multiple modeling approaches that may concern disparate scales and variables of focus

The article also highlights that with new modelling approaches the here proposed classification framework needs to be revised in the future. Within the IEA EBC Annex 70, the here proposed classification scheme is used to generate metadata for organizing energy models in an online model repository.

4.3.2 Model registry

Besides the classification framework in section 4.3.1, a reporting protocol for building energy stock models was developed within the IEA EBC Annex 70 (Nägeli et al, 2021). In contrast to the classification scheme, this reporting protocol has a stronger emphasis on the technical details of different models.

The high heterogeneity in the models, together with a lack of consistency in the description and reporting of the models often hinders the understanding of the models, impeding an accurate interpretation and/or comparison of the results.

The aim of the reporting guideline is to structure the information about a given BSM always in the same manner (see Table 3). This will help researchers structure the information about their model in a consistent way and thereby help reviewers find relevant information about a model and thereby facilitate interpreting model results. The guideline is structured into six topics:

1. Overview: The overview section gives general information and context of the model and its aim and scope.
2. Model Design: The Model Design section delves deeper into the different aspects of the model and their underlying methodologies. This section follows the structure of the building stock model classification according to Langevin et al. (2021).
3. Input and Output: The main model input and output is described, giving readers a detailed view on what it takes to apply the model and what results they might get.
4. Quality Assurance: Results from sensitivity and uncertainty assessments of the model are presented as well as main model limitations are documented.
5. General: In this section, 25 general details about the model such as implementation, access as well as funding are documented.
6. Detail: Last but not least, the guideline offers the writer to give a detailed (technical) documentation of the model in the last section "Detail".

The six topics (Overview, Model Design, Input and Output, Quality Assurance, General and Detail) are broken down into individual subtopics (see Table 3) which are linked to guiding questions to help researchers to interpret the content of different sections (Nägeli et al., 2021). Each of the topics and subtopics summarized in Table 3 are described in more detail in the article. Moreover, for each subtopic a guiding question and an example are given.

This model reporting guideline should be used as a tool by authors, reviewers, and journal editors, in order to promote best practices in reporting building stock models and their results. We hope that through the application of the guideline we improve the transparency and understanding of BSMs and their results and thereby improve the reliability of results. In addition to that, using the guideline also comes with benefits for the modeler as it provides a clear framework for reporting, which should make it easier to write as well as read model documentation as it always comes in the same form. Moreover, using the guideline as a checklist will make sure that no important information is omitted in the reporting. Last but not least, once written, using a standardised format for model documentation will make reporting for future publications faster as (parts of) the documentation can be reused.

Based on the output from the model classification (Langevin et al., 2020) and the reporting guideline (Nägeli et al, 2021) also the model registry has been revised by the IERC (with some input of TEP Energy provided during the physical meetings). So far, 16 models have been registered in the model repository developed by the IEA EBC Annex 70 consortium (IEA EBC Annex 70, 2021).

Table 3: Structure and guiding questions of the different aspects of the reporting guideline (Nägeli et al., 2021).

Topic	Sub-topic	Guiding questions
Overview	Aim and scope	What is the overall aim and scope of the model? What are the main use cases addressed?
	Model structure	What is the general modeling approach and how is it structured? What are the main model parts and components included in the model and how do they relate to each other? What are the key steps in the modelling workflow?
	System boundary	What are the system boundaries (temporal, geographical, building types, energy services, economic sectors, etc.) of the model?
	Spatio-temporal resolution	What is the spatio-temporal resolution of the model?
Model design	Buildings	How are buildings and the building stock represented and characterized in the model? What building attributes are used to characterize buildings on either an individual or archetype basis?
	People	How are people (e.g. in terms of occupant behavior) represented in the model?
	Environment	How is the environment (e.g., climatic, policy, economic, context) represented in the model? How does the model account for spatial differences in these environmental aspects?
	Energy	How is the energy demand (useful, final, primary) and related indicators (e.g., GHG emissions) assessed?
	Costs	How are costs (capital and/or operational) assessed?
	Dynamics	How are building stock dynamics (i.e., changes of the stock over time) modeled? Which of the above aspects are modeled dynamically? Which of these dynamics are endogenously defined, what is modeled endogenously?
	Other aspects	Are there other relevant aspects of the model not covered by the above?
Input and output	Data sources	What are the primary data sources used for the model and how they are structured?
	Data processing	How has the data been cleaned, matched or otherwise processed to become input into the model?
	Key assumptions	What are the main input assumptions made to address any information gap in the data?
	Scenario	What model inputs are introduced or modified to describe a typical scenario?
	Output parameters	What are the main model outputs and the available levels of aggregation for each?
Quality assurance	Calibration	With what method(s) and sources of information has the model been calibrated? What was the outcome?
	Validation	With what method(s) and sources of information has the model been validated? What was the outcome?
	Limitations	What are the (current) limitations of the model and its results? How do modelling assumptions or data limitations affect the model application and/or interpretation of the model results?
	Uncertainty	What are key sources of uncertainty in the model? With what method(s) has the uncertainty of the model and results been assess? What was the outcome?
	Sensitivity	"With what method(s) and sources of information has the uncertainty of the model and results been assessed ? What was the outcome? What was the outcome?
General	Implementation	What software, programming language, packages, libraries or other models are used in or necessary for the model to be used?
	Access	Who owns the model? To whom and under what licence/condition is the model and the necessary data available?
	Transparency	How has the model development and/or underlying research been funded?
	Areas of application	In which geographical areas and for what use cases has it been applied?
	Key references	What are key references showing previous applications and documentations of the model or parts of the model?
Detail (Optional)	Detailed description	How does the model work in detail?

4.3.3 Uncertainty analysis and sensitivity analysis

Uncertainty analysis and sensitivity analysis provide powerful tools for the validation and comparison of models. As an input to this discussion TEP Energy prepared the presentation "Comparing uncertainties and sensitivities across building stock models" (Jakob et al., 2018) which was discussed in 2018 in Gothenburg (Hamilton, 2018).

Another starting point for the work in this subtask was a review to which TEP Energy contributed (Fennel et al., 2019a). The review was presented at the International conference on building simulation 2019 in Rome (Fennel, 2019b). The review finds that in only a very small proportion of studies model uncertainties are even considered. This fundamental flaw is due to the computational demands of exploring the output space of such complex models. A more detailed assessment was then undertaken of the identified studies in which uncertainty analysis (UA) and sensitivity analysis (SA) had been applied to BSEMs. The adequacy of the applied methods is discussed, and recommendations proposed for the application of best practice techniques based on the underlying form of the model (Fennel et al., 2019a).

In the reporting year 2019, an extensive list of variables was compiled by a selection of participants of the IEA EBC Annex 70 (UCL, Chalmers, TEP Energy, NTNU/Sintef, TU Vienna, IVL, NREL, TU Gent, and others) with different types of building stock energy models. In the reporting year 2020, the impact of some key parameters on final energy demand and CO_2-emissions have been estimated with very rough "back-on-the-envelope" estimates: building energy retrofit rates and energy carrier substitution rates. The list of parameter groups and parameters was then further processed in close collaboration with Chalmers University and finalized for initial state and dynamics, respectively. The following list shows the considered parameter groups for the UASA for the case of residential buildings.

Table 4: Parameter groups considered in the uncertainty and analysis (Jakob et al., 2021b) for the case of residential buildings

Initial state	**Dynamics**
Floor area	
	Prices of final energy carriers
	CO_2.tax
	Subsidy amount (currently per m^2, kW, etc.)
Geometry (ratio envelope to floor area)	
U-values (a.o. technical parameters) by element and by typology, e.g. based on past building energy code requirements	Envelope energy performance standard
Past retrofit activity: Share of retrofitted buildings (envelope) or building elements (%) and energy performance improvement (%, kWh/m^2, W/m^2K)	Component life times
Air tightness	
Correction function of energy performance gap	
Internal and external heat gains	
Hot water consumption	
Indoor temperature	
Annual conversion efficiency of heating and hot water systems	Heating system efficiency (fuel based heating systems, heat pumps)
Outdoor temperature	Outdoor temperature

For the case of non-residential some similar general parameters were considered, but also some specific ones (e.g. percentage of cooled, ventilated floor area, efficiency of the heat recovery systems). A comprehensive report as part of this Subtask C has been drafted by TEP Energy and Chalmers University (Jakob et al., 2021b), which describes in details the procedure and methodology as well as the parameter ranges, results from the UASA and their subsequent discussion.

5 Summary and conclusions

The activities pursued within the IEA EBC Annex 70 has turned out to be very useful. On the one hand, TEP Energy has been able to get to know various interesting modelling approaches and increase its network in the community. On the other hand, TEP Energy has been able to actively contribute to various activities which is useful for the other participants.

The whole setting within the IEA EBC Annex 70 was a very fruitful and stimulating environment. In the beginning, the project work focused mainly on sharpening the objectives and approaches, developing a common understanding of the project goals and structuring the exchange between the IEA EBC Annex 70 participants. For this purpose, knowledge and planned approaches were shared and refined in various workshops.

Based on this groundwork a broad online-survey targeting users and providers of energy and building data conducted in 2019. Results revealed a large diversity of the stakeholders and of data application fields. The survey showed that there is a rising demand for smart-meter and building performance data. Further, a majority of respondents see the benefits of accessing and using energy and building data when merging datasets for detailed analysis. This linking of data sets allows new analysis possibilities. For this, improved, uniform data registers are desirable both nationally and, at the European or global level. Such a register has been developed within the framework of the Annex. In Subtask B an online dataset repository was created, where more than 1000 different data sets are described and classified. TEP could contribute with about 60 datasets from energy and building related fields in Switzerland.

The findings from the survey were able to show well which data needs exist and where possibly cutbacks can be made. However, with the increasing use of even higher-resolution data and more complex models, the need for data will undoubtedly continue to grow in the future. In this context, it is important to maintain an overview. For this purpose and for the provision and exchange of different data in energy modelling, so-called data repositories are a good possibility. The repository created in the IEA EBC Annex 70 demonstrates the large variety in data sets that are used in the energy and building sector. For this reason (and other good reasons) the dataset repository of the IEA EBC Annex was implemented in the form of a meta and reference repository. Thus, rather than collecting, managing and providing data the repository offers references to and comparable meta-information about existing data sets. The repository is by no means complete and will require constant updating in the future which is considerable challenge. It remains open who could do this and at what expense this task could be accomplished.

Regarding activities related to the building stock modelling (Subtask C) the following conclusion covering both the meta-level (repording guideline, model classification and model repository) and the object level (actual modelling uncertainties and sensitivities) are drawn:

- The reporting guideline for reporting practices of building stock energy models closes a veritable gap which consists in insufficient transparency of most model related scientific articles and policy advising reports: a lack of comparable, comprehensive and complete description in terms of methodology and data fundamentals. To close this gap, experts from the IEA EBC Annex 70 developed a guideline which partly builds upon reporting guidelines from other elds. The guideline includes five topics (Overview, Model Components, Input and Output, Quality Assurance and Additional Information), which are further subdivided into subtopics. The article demonstrates which of the model aspects should be described in each subtopic. Further illustrative examples are given on how to apply the guideline. Finally, the developed reporting guideline is consistent with other activities from ST C such as the model classification framework and the online model registry.
- A model classification framework was developed with the aim of improving comparability and rapid comprehension and characterisation of models. This eases the selection of appropriate models for

a given purpos and also the communication between model users and their non-peer target group, particularly stakeholders adiced by modelleres. The classification developed might serve as a basis to improve the classification of current energy models and to incorporate emerging modelling techniques such as system dynamics, agent-based or machine-learning models. Besides the theoretical development of proposed multi-layer approach, the new classification scheme could be applied within the IEA EBC Annex 70 in order to classify different energy models in an online model repository. The classification framework was deliberately designed to be dynamic, and the authors are aware that this classification scheme will have to be adapted in the future.

A major part of TEP's contribution to the IEA EBC Annex 70 was allocated to the analysis of uncertainties related to data and models and the sensitivity of models (with a focus of uncertain data and parameters). The activity focused on assessing the sensitivity and uncertainty of the BSM for Switzerland as well as on investigating methodological issues in the application of UASA methods to BSMs. For this purpose, different analysis were conducted on different aspects of the model such as the initial state of the building stock vs dynamic aspects (future state and development of the building stock over time) and residential sector vs. non-residential sectors). As the problem could be broken up into different aspects and hence the number of parameters (and with it the total model run time) could be reduced.

The analysis highlighted issues several issues around applying UASA to large scale models such as the BSM (and some of these issues might be related to the fact that the BSM applies some stochastic approaches):

- A large set of uncertain parameters implies a large number of model runs if advanced sensitivity analysis (such as Morris) covering the whole parameter space were to be implemented. Due to a relatively long computation time for one model iteration the number of investigated parameters had to be reduced and/or the different parameters grouped in order to limit the total number of required model runs. This, together with the issues stemming from the stochasticity of the model output, caused problems for the investigation of the model dynamics for which no stable results could be obtained in case of the residential stock.
- Grouping variables allows for reducing the number of necessary model runs. However it should be noted that results of grouped parameters have to be interpreted with care as the sampling method applied in the Morris method allows for parameters with a group to be adapted in different directions. Hence, the results reflect an average of the individual effects rather than a combined total effect of the individual parameters. If parameters within a group should be correlated with each other a different sampling strategy would have to be applied (e.g. using a meta-parameter based on which all other parameters are adjusted).

The UASA conducted in this analysis helped to better understand the sensitivity of different model inputs as well as the model behavior. As such, the analysis could be expanded at a later stage to investigate further issues and parameters not addressed in the current study (e.g. effect of availability of different heating system options, uncertainty in costs of different technologies or the development of the GHG-intensity of different energy carriers (primarily electricity or district heating). For this purpose, furthermore targeted analysis could be conducted to assess these issues. Moreover, by reducing the computation costs of the model through optimization and parallelization of the computation, the range of the analysed parameters could be expanded

6 Outlook and next steps

First ideas were discussed on how to sustain and further develop the main outcome of the IEA EBC Annex 70, i.e. the data registry, the model registry, and the modelling uncertainty best practice guide.

Current developments show that energy models will be even more high-resolution, both spatially and temporally. This results in further uncertainties. Accordingly, it will be important in the future to apply the UASA approach to models with higher temporal resolution, such as eLOAD. Also building physics models mostly have a high temporal resolution in their calculation routine and data output (cf. Müller et al., 2019a), which are associated with uncertainties that have not been studied to date.

TEP Energy and its partners have the ambition to consider uncertainty and sensitivity issues in their model related activities in order to raise awareness of potentials and limitations related to model-based decision making. Moreover we will use the model guideline to describe the different types of models in use at TEP Energy, in order to raise transparency and foster the dialog between model users and recipients of model-based results and advise.

7 National and international cooperation

7.1 National collaboration

7.1.1 Reporting of the Swiss Cantons about CO_2 emissions and energy indicators of buildings

As from 2016, the Swiss Cantons are requested to report about the CO_2-emissions from the buildings on their territory. Due to missing empirical energy consumption data in most of the Cantons, the reporting needs to be based on survey and modelling data. TEP Energy GmbH was mandated by the Swiss Federal Office of Environment and by the Cantons to develop a methodology to calculate CO2-emissions from the buildings sector based on a building stock modelling approach. The approach is based on data from the federal buildings and dwellings registry (BDR), the 3D-model of Swisstopo, the statistics of enterprises (STATENT) and on data which is gathered through a survey of building owners. In this approach the specific energy consumption is based on building characteristics (e.g. from the BDR), on geometry data, and on surveyed data about past retrofits. Similarly, the shares of the heating systems in the different segments of the building stock are estimated based on data from the BDR and on surveyed data (due to the fact that the respective attribute in the BDR is barely updated), see Jakob et al. (2020) und Jakob et al. (2021).

Due to the considerable lack of data, due to a large amount of out-dated data, and also because available data are associated with uncertainties the results from these model calculations are expected to be associated with uncertainties as well. The potential range of these uncertainties were roughly estimated and visually illustrated and presented to the contracting authorities and to the advisory board of the project (Jakob et al. 2020b), see Figure 7.

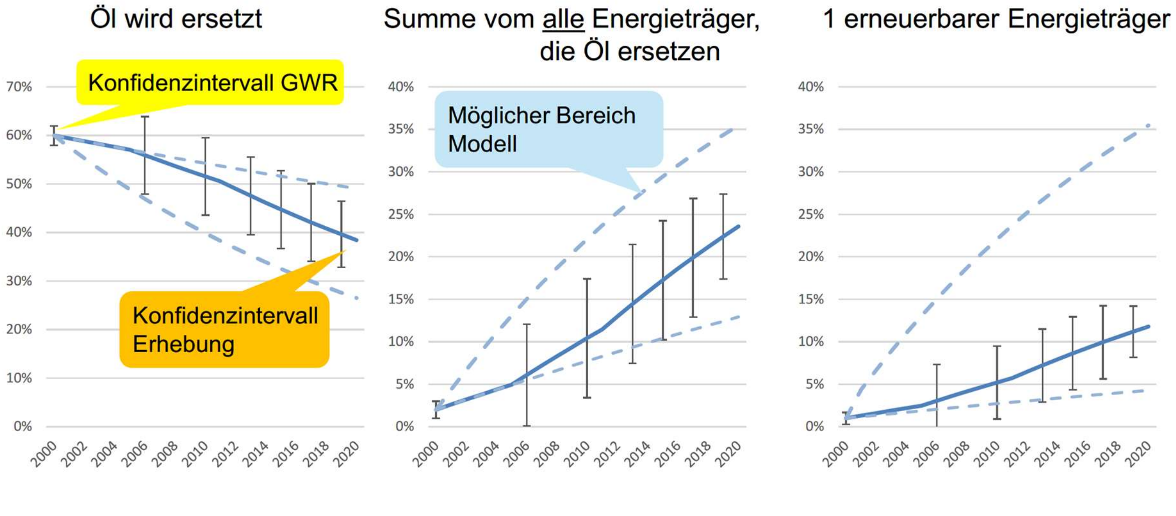


Figure 7: Comparison of uncertainties between model and survey for different cases (rough estimates for illustration purposes).

7.1.2 Using the agent-based approach to determine the top 15% of buildings

In order for Switzerland to achieve its Paris climate goals, the building stock must become significantly more “climate compatible”. To achieve this, investments are needed. TEP Energy, together with Raiffeisen Schweiz, is defining clear criteria for identifying environmentally sustainable buildings so that investments can increasingly flow in their direction.

With reference to the work of the EU Technical Expert Group on Sustainable Finance and the international Climate Bond Initiative (CBI), a "best in class" approach is used. CBI defines a benchmark of the best 15% of the buildings (in terms CO_2-emissions per square meters) as being climate-compatible (top 15%). In order to determine this benchmark of the best buildings (top 15%), TEP Energy's Swiss Building Stock Model is used.

Clear and practical criteria are defined that distinguish climate compatible buildings. The criteria are based on two dimensions: requirements in building regulations (MuKEn, Minergie, GEAK) and the energy sources used to produce space heating and hot water. For the financing of energy-efficiency renovations, criteria are defined for improvements of GEAK classes.

Thanks to the agent-based approach, the Swiss BSM is able to generate not only average or aggregate results, but also distributions of specific CO_2 emissions (kg/m^2) or primary energy consumption (kWh/m^2), see Figure 8 for an example. From this model results it is concluded that the direct CO_2 emissions of the top 15% is 0 kg/m^2, i.e. more than 15% of the building don't use fossil energy for heating and hot water purposes (but biomass, heat pumps and district heating instead). In fact, more than 40% of the single-family houses and about one third of the multi-dwelling buildings don't have direct CO_2-emissions.

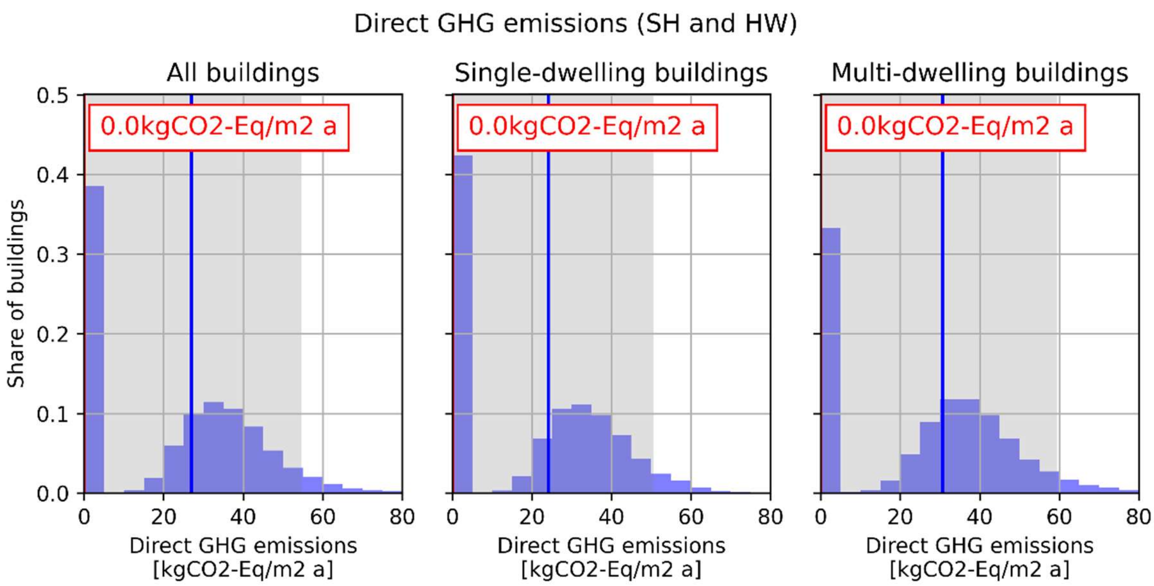


Figure 8:Frequency distribution of direct CO_2 emissions per m^2, median (vertical blue line), top 15% (red text box) and 90%-percentile (grey shaded area) for all residential buildings (left), single family houses (middle), and multi-dwelling buildings (right)

Two key lessons learned can be taken away from this collaboration with the financial sector:

- The generation and use of synthetic data in a building stock model to overcome data gaps and to model the heterogeneity of building stocks rather than simplified averaged archetypes (Nägeli 2018) and the agent-based approach clearly yields a value added. Next to identifying thresholds for ambitious benchmarks (as in this case), the approach could also use by authorities and label organizations to define minimal requirements or targets or to systematically interact with specific groups of building owners. For instance, the proposed revision of the CO_2-law (which was rejected in June 2020) set CO_2-emissions limits and with the BSM the number of affected buildings could be estimated.
- The current building related codes, standards, and labels are not suitable to define criteria for climate-compatible buildings. Indeed, given a certain energy-efficiency standard, direct (and also indirect) CO_2-emissions could still be very different, depending on the heating system and energy carrier used. For this reason additional criteria need to be considered, particularly a combination of energy-efficiency and feasible energy carriers (see Jakob et al. 2021c for details).

7.1.3 Gathering empirical data that is potentially useful for the decision module of the BSM

Further collaboration resulted from the MISTEE (Motivations for Investments in smart technologies and energy efficiency: The case of residential buildings) project. Within the framework of two choice experiments, data and findings could be collected regarding the investment decisions for energetic renovation work on the building envelope and heating replacement. Such data might provide further insights on the investment trade-offs between energy efficiency and renewable energies and might be used in e.g. the decision module of the current building stock model.

7.2 International collaboration

The fruitful exchange and discussions between the IEA EBC Annex 70 members have especially contributed the achievement of the project goals. Besides several online-Meetings, especially the well-organized workshops have enormously contributed to the outcomes described above.

TEP participated in most of the workshops:

- London (February 2017)
- Berkeley (August 2017)
- Ghent (December 2017)
- Gothenburg (June 2018)
- Washington (November 2018)
- Delft (March 2019)
- Cork (June 2019)
- Cologne (November 2019)
- Zurich (January 2020)

8 Publications (as part of the IEA EBC Annex 70)

Fennell P. J., Ruyssevelt P. A., Mata E., Jakob M (2019a). A Review of the Status of Uncertainty and Sensitivity Analysis in in Building-stock Energy Models. Article submitted to and accepted by 16th International Building Performance Simulation Association (IBPSA) Conference.

Fennell P. J., et al. (2019b). The Application of Uncertainty and Sensitivity Analysis in large scale Building Stock Energy Models. Presentation at the16th International Building Performance Simulation Association (IBPSA) Conference.

Fennel et al. (2019c). Model parameters (full details). Google spread sheet (Link available to the members the IEA EBC Annex 70 members.

Hamilton I. (2018). Workshop minutes (Workshop Report) about the IEA EBC Annex70 Meeting in Gothenburg, June.

IEA EBC Annex 70 (2021). Data Registry. Retrieved from: http://www.iea.ierc.info/testing/advanced_search.php

Jakob, M., Weinberg, L., Nägeli, C., Catenazzi, G., Palacios, A. (2021b). Report on the analysis of uncertainties and sensitivities using the Swiss building stock model. Contribution to the Common Exercise on uncertainty analysis and sensitivities analysis (UASA) of the Subtask C of the IEA EBC Annex 70 (in press). Zürich.

Jakob, M., Weinberg, L., Nägeli, C., Catenazzi, G., Palacios, A. (2021b). Analysis of uncertainties and sensitivities using Swiss building stock models – Contribution to the Common Exercise on uncertainty analysis and sensitivities analysis (UASA) of the Subtask C of the IEA EBC Annex 70. TEP Energy on behalf of the SFOE, Final draft as of 31 December 2021, Zurich.

Jakob, M., Catenazzi, G., Sunarjo, B., Nägeli, C., Wallbaum, H., Ostermeyer, Y., (2019a). CREATE: A toolbox to develop, implement and monitor advanced energy and climate goals and strategies. In: Proceedings of eceee summer study 2019.

Jakob, M., Catenazzi, G., Sunarjo, B., Reiter U., Nägeli, C., Wallbaum, H., Ostermeyer, Y. (2019b). The Building Stock Model (BSM). An element of CREATE: Carbon, Resource, Energy and Adaption Modelling Toolbox Europe. A tool to assist authorities, urban energy planners, branche associations and utilities. Presented at the ENERCONF, Cork, 19 June 2019

Jakob M., Catenazzi G., Nägeli C. (2019c). *Common Exercise: UA/SA for BSM (Version 1.2). Presentation held at the meeting of the IEA Energy in Buildings and Communities Programme (EBC) Annex 70* in Cologne on 9. November 2019.

Jakob M., Catenazzi G., Nägeli C. (2018). Comparing uncertainties and sensitivities across building stock models. Presentation held at the 4th meeting of the IEA Energy in Buildings and Communities Programme (EBC) Annex 70 in Gothenburg on 18-19 June 2018.

Langevin J., Reyna J.L., Ebrahimigharehbaghi Sh.; Sandberg N., Fennell P., Nägeli C., Laverge J., Delghust M., Van Hove M.; Webster J.; Federico F., Jakob M., Camasara C. (2019). Developing a common approach for classifying building stock energy models. Submitted to: Renewable & Sustainable Energy Reviews (Manuscript Number: RSER-D-19-04569).

Müller J., Meyer M., Reiter U., Jakob M. (2019a). Simulation of Pre-cooling Strategies in Office Buildings: Deriving Demand Side Management Potentials. Paper submitted to and accepted by 16th International Building Performance Simulation Association (IBPSA) Conference, Rome, 2nd of September 2019.

Müller J., Meyer M., Reiter U., Jakob M. (2019b). Simulation of Pre-cooling Strategies in Office Buildings: Deriving Demand Side Management Potentials. Presentation at the 16th International Building Performance Simulation Association (IBPSA) Conference, Rome, 2nd of September 2019.

Müller, J. & Jakob, M. (2021). IEA EBC Annex 70 – Building Energy Epidemiology. Resultate zur Erhebung Energie- und Gebäudedaten (in press). Zürich.

Nägeli, C., Jakob, M., Catenazzi, G., & Ostermeyer, Y. (2020a). Policies to decarbonize the Swiss residential building stock: An agent-based building stock modeling assessment. Energy Policy, 146. https://doi.org/10.1016/j.enpol.2020.111814

Nägeli, C., Jakob, M., Catenazzi, G., & Ostermeyer, Y. (2020b). Towards agent-based building stock modeling: Bottom-up modeling of long-term stock dynamics affecting the energy and climate impact of building stocks. In Energy and Buildings (Vol. 211). https://doi.org/10.1016/j.enbuild.2020.109763

Nägeli, C., Camarasa, C., Delghust, M., Fennell, P., Hamilton, I., Jakob, M., Langevin, J., Laverge, J., Reyna, J.L., Sandberg, N.H., Webster, J. (2021). Best practice reporting guideline for building stock energy models (Preprint submitted to Energy and Buildings).

Nägeli C., Jakob M., Catenazzi G. (2019c). *Common Exercise: UA/SA for BSM.* Presentation held at the meeting of the IEA Energy in Buildings and Communities Programme (EBC) Annex 70 in Cork on 20 June 2019.

Nägeli C., Camarasa C., Jakob M., Catenazzi G., Ostermeyer Y. (2018). Synthetic Building Stocks as a Way to Assess the Energy Demand and GHG-Emissions of National Building Stocks. Energy and Buildings, 173: 443-460. http://dx.doi.org/10.1016/j.enbuild.2018.05.055

Palacios A., (2018). Annex 70 Subtask B Energy and Building Stock Data Registry – Test Report. Prepared by TEP Energy. Zurich, November.

Reiter U., Jakob, M., Catenazzi, G., Sunarjo, B., Nägeli, C., Wallbaum, H., Ostermeyer, Y., (2019). CREATE: A toolbox to develop, implement and monitor advanced energy and climate goals and strategies. Presented at the eceee summer study, Presqu’île de Giens, 4th of June 2019.

9 References

Ascione, F., Bianco, N., Stasio, C. De, Mauro, G. M., & Vanoli, G. P. (2017). Addressing large-scale energy retrofit of a building stock via representative building samples: Public and private perspectives. Sustainability (Switzerland), 9(6), 1–18. https://doi.org/10.3390/su9060940

AWEL. (2018). Energie in Wohnbauten 2018. Kanton Zürich, Baudirektion.

Booth, A. T., Choudhary, R., & Spiegelhalter, D. J. (2012). Handling uncertainty in housing stock models. Building and Environment, 48, 35–47.

Carisch, L., Ménard, M., Mühlebach, M., & Talattad, M. (2018). SolarGap – Auswirkung von Sonnenschutzsystemen auf den Heizwärmebedarf von Gebäuden. Lemon Cosult i.A. Bundeamt für Energie BFE.

Caucheteux, A., Gautier, A., & Lahrech, R. (2016). A meta model-based methodology for an energy savings uncertainty assessment of building retrofitting. International Journal of Metrology and Quality Engineering, 7(4). https://doi.org/10.1051/ijmqe/2016016

Cozza, S., Chambers, J., Geissler, A., Wesselmann, K., Gambato, C., Branca, G., Cadonau, G., Arnold, L., & Patel, M. K. (2019). GAPxPLORE: Energy Performance Gap in existing, new, and renovated buildings.

Davila, C. C. (2017). Building Archetype Calibration for Effective by Signature redacted Signature redacted. 1–156.

Del Taglia C., Scherer R., Ferster M., Stamm N. (2019). Energieverbrauch in der Industrie und im Dienstleistungssektor - Resultate 2019. Helbling Beratung + Bauplanung AG, Polyquest AG and Swiss Federal Office of Statistics on behalf of the Swiss Federal Office of Energy (SFOE), Bern, July.

Hartmann Chr., Jakob M. (2018). Methodik ECOSPEED Immo – Berechnung der CO2-Emissionen im Gebäudebereich auf Basis der Gebäude- und Wohnungsstatistik (GWS) und des Gebäudeparkmodells (GPM). Zurich, May.

Hartmann Chr., Jakob M. (2016). Methodik zur Berechnung der kantonalen CO2-Emissionen im Gebäudebereich auf Basis des Gebäude- und Wohnungsregisters (GWR). ECOSPEED and TEP Energy on behalf of the Federal Office for the Environment (FOEN), Zürich, December.

Hässig, W., Wyss, S., & Staubli, J. (2015). Untersuchung Wärmeverbrauchsdaten von Neubauten. Hässig Sustech GmbH i.A. AWEL Kanton ZH.

Hoffmann, C., Geissler, A., & Carisch, L. (2016, September). Warum stimmt das nie? – Fragen beim Einsatz der SIA 380/1 als Prognoseinstrument bei Bestandsgebäuden (Wohnen). 19. Status-Seminar "Forschen Für Den Bau Im Kontext von Energie Und Umwelt", ETH Zürich.

Hoffmann, C., Geissler, A., Ménard, M., & Carisch, L. (2017). PRO380: Offene Fragen beim Einsatz der SIA 380/1 als Prognoseinstrument bei Bestandsgebäuden (Wohnbauten). Fachhochschule Nordwestschweiz FHNW und Lemon Consult AG i.A. Bundesamt für Energie.

IEA EBC Annex 70 (2021). Data Registry. Retrieved from: http://www.iea.ierc.info/testing/advanced_search.php

Jakob, M., Catenazzi, G., Sunarjo, B., Müller, J., & Weinberg, L. (2021a). Kantonale Energiekennzahlen und CO2-Emissionen im Gebäudebereich. TEP Energy i.A. BAFU. Zürich.

Jakob, M., Hofer C., Weinberg, L., Catenazzi, G., Nägeli, C., (2021c). Kriterien für klimaverträgliche Gebäudefinanzierung in der Schweiz. TEP Energy und Raiffeisen Schweiz, Zürich und St. Gallen April.

IEA EBC Annex 70 (2017). Building Energy Epidemiology: Analysis of Real Building Energy Use at Scale. https://energyepidemiology.org/annex-proposal/ Retrieved 19 November 2017.

Jakob M., Catenazzi G., Sunarjo B. (2020). Energiekennzahlen und CO_2-Emissionen des Gebäude-bereichs pro Kanton (*Energy indicator and CO_2-emissions of the buildings sector by Canton*). Presentation to the advisory group. Bern, August.

Jakob M., Catenazzi G., Sunarjo B., Müller J., Weinberg L. (2020). Kantonale Energiekennzahlen und CO2-Emissionen im Gebäudebereich. Zwischenbericht zuhanden BAFU, EnDK, KVU sowie kantonale Energie- und Umweltfachstellen, April.

Jakob, M., Catenazzi, G., & Looser, R. (2019). IEA-EBC Annex 70: “Building Energy Epidemiology: Analysis of Real Building Energy Use at Scale” – Schweizer Beitrag im ersten Projektjahr. TEP Energy i.A. Bundesamt für Enerige (BFE).

Jakob M. et al. (2019a). Entwicklung und Anwendung einer Methode zur Erhebung kantonaler Energiekennzahlen und Energieträger im Gebäudebereich”. Offerte zuhanden des Bundesamts für Umwelt und der Energiefachstellenkonferenz (EnFK) der Kantone.

Jakob M., Catenazzi G., Looser R. (2019b). IEA-EBC Annex 70: Building Energy Epidemiology: Analysis of Real Building Energy Use at Scale – Swiss contribution. Annual report 2019. TEP Energy i.A. Bundesamt für Energie (BFE), Bern, Dezember.

Jakob M., Catenazzi G., Looser R. (2017). IEA-EBC Annex 70: Building Energy Epidemiology: Analysis of Real Building Energy Use at Scale – Schweizer Beitrag. Jahresbericht 2017. TEP Energy i.A. Bundesamt für Energie (BFE), Bern, Dezember.

Jakob et al. (2016). Erweiterung des Gebäudeparkmodells gemäss SIA-Effizienzpfad Energie. TEP Energy und Lemon Consult i.A. Bundesamt für Energie (BFE), Bern.

Jakob M., Nägeli C., Martius G., Forster R. Vogel U.; (2015). Bestandesaufnahme Energie- und CO2-Daten – Grundlagen für die Bestimmung von Energie- und CO2-Daten des Gebäudeparks in den Kantonen. TEP Energy, Amstein+Walthert; Bundesamt für Umwelt (BAFU); Zürich/Bern

Jakob M., Bossmann T., Kallio S. (2014). Generating electricity demand-side load profiles of the tertiary sector for selected European countries. 8th International Conference Improving Energy Efficiency in Commercial Buildings (IEECB’14

Jakob M., Sunarjo B., Martius G. (2013). Thermischer Energiebedarf in Zürich-Altstetten. Ist-Zustand (2010) und Entwicklungsszenarien bis 2050. TEP Energy on behalf of Departements der Industriellen Betriebe. Zürich, September.

Khoury, J., Alameddine, Z., & Hollmuller, P. (2017). Understanding and bridging the energy performance gap in building retrofit. Energy Procedia, 122, 217–222. https://doi.org/10.1016/j.egypro.2017.07.348

Langevin, J., Reyna, J. L., Ebrahimigharehbaghi, S., Sandberg, N., Fennell, P., Nägeli, C., Laverge, J., Delghust, M., Mata, Van Hove, M., Webster, J., Federico, F., Jakob, M., & Camarasa, C. (2020). Developing a common approach for classifying building stock energy models. Renewable and Sustainable Energy Reviews, 133. https://doi.org/10.1016/j.rser.2020.110276

Lehmann, U., Khoury, J., & Patel, M. K. (2017). Actual energy performance of student housing: Case study, benchmarking and performance gap analysis. Energy Procedia, 122, 163–168. https://doi.org/10.1016/j.egypro.2017.07.339

Lim, H. (2017). Prediction of Urban-Scale Building Energy Performance with a Stochastic-Deterministic-Coupled Approach. Civil Engineering Graduate Theses & Dissertations, 268. https://search.proquest.com/docview/1904921523?accountid=14511

Mojic, I., Luzzatto, M., Haller, M., Lehmann, M., Benz, M., & van Velsen, S. (2018). ImmoGap: Einfluss der Kombination aus Nutzerverhalten und Gebäudetechnik auf den Performance Gap bei Mehrfamilienhäuser (Issue August). i.A. Bundesamt für Energie BFE.

Morris, M.D. (1991). Factorial Sampling Plans for Preliminary Computational Experiments. Technometrics. 33 (2): 161–174. doi:10.2307/1269043

Müller, J. & Jakob, M. (2021). IEA EBC Annex 70 – Building Energy Epidemiology. Resultate zur Erhebung Energie- und Gebäudedaten (in press). Zürich.

Müller J., Meyer M., Reiter U., Jakob M. (2019a). Simulation of Pre-cooling Strategies in Office Buildings: Deriving Demand Side Management Potentials. Paper submitted to and accepted by 16th International Building Performance Simulation Association (IBPSA) Conference, Rome, 2nd of September 2019.

Müller J., Meyer M., Reiter U., Jakob M. (2019b). Simulation of Pre-cooling Strategies in Office Buildings: Deriving Demand Side Management Potentials. Presentation at the 16th International Building Performance Simulation Association (IBPSA) Conference, Rome, 2nd of September 2019.

Nägeli, C., Camarasa, C., Delghust, M., Fennell, P., Hamilton, I., Jakob, M., Langevin, J., Laverge, J., Reyna, J.L., Sandberg, N.H., Webster, J. (2021). Best practice reporting guideline for building stock energy models (Preprint submitted to Energy and Buildings).

Ravetz, J. (2008). State of the stock-What do we know about existing buildings and their future prospects? Energy Policy, 36(12), 4462–4470. https://doi.org/10.1016/j.enpol.2008.09.026

Reimann, W., Bühlmann, E., Lehmann, M., Bade, S., Krämer, S., Ott, W., Montanari, D., & Ménard, M. (2016). Erfolgskontrolle Gebäudeenergiestandards 2014-2015. Demo SCOPE , econcept und Lemon Consult i.A. Bundesamt für Energie BFE.

Reiter U., Sunarjo B., Jakob M. (2018). The Role of Gas and the Gas Infrastructure within the future Energy System – a Techno-Economic Assessment – Work Package 2: Determination of Energy Demand and Renewable Potential. BFE EWG Project, Zurich/Bern, November.

Roost, M., Ménard, M., Lehmann, M., Ott, W., & Sitzmann, B. (2018). WP-GAP: Performance Gap bei Mehrfamilienhäusern mit Wärmepumpe – die Rolle der Betreiber. Lemon Consult AG und econcept AG und Energie Zukunkf Schweiz i.A. BFE.

Stamm N., Kost M. (2019). Energieverbrauch in der Schweiz 2011 – 2019 nach NOGA Stufe 2 (Abteilungen) - Auswertung der Erhebung: Energieverbrauch in der Industrie und im Dienstleistungssektor. Swiss Federal Office of Energy (Ed.), Bern, December.

van Dronkelaar, C., Dowson, M., Burman, E., Spataru, C., & Mumovic, D. (2016). A Review of the Regulatory Energy Performance Gap and Its Underlying Causes in Non-domestic

Buildings. Frontiers in Mechanical Engineering, 1(January), 1–14. https://doi.org/10.3389/fmech.2015.00017

Vetsch, B., Gschwend, A., & Bertsch, S. (2013). Warmwasserbereitstellung mittels Wärmepumpen in Mehrfamilienhäusern, Kurzfassung für Installateure und Planer (Issue Tabelle 2). Interstaatliche Hochschule für Technik Buchs, Institut für Energiesysteme i.A. BFE, EKZ.

Warmuth H., Knotzer A., Kranzl L., Forthuber S., Pfefferer B. (2021). IEA Energie in Gebäuden und Kommunen (EBC) Annex 70: Energie-Epidemiologie.

Wyss, S., & Hässig, W. (2016). UFELD: Feldmessungen von U-Werten zur Überprüfung der im Gebäudeenergieausweis (GEAK) hinterlegten U-Werte. hässig sustech gmbh i.A. BFE.