

ISSUE 684 **BULLETIN**



THERMAL MODELLING TOOLS FOR HOUSES

May 2023

- Thermal modelling software tools evaluate the impacts of design decisions on the likely thermal performance of a building.
- Modelling is the best way to assess what it would be like to live or work in a building that is not yet built or renovated.
- This bulletin covers thermal modelling tools for commercial and residential applications but has a focus on residential.

1 INTRODUCTION

1.0.1 There is growing pressure on the building industry to deliver higher-performing buildings. Operational carbon, energy efficiency, comfort, health and modest running costs (especially for those on lower incomes) are all driving demand for better residential buildings.

1.0.2 Global environmental issues such as climate change and the depletion of non-renewable energy sources are also impacting building design.

1.0.3 Thermal modelling and other building simulation tools used during the design process can be used to improve or optimise:

- comfort
- space conditioning costs
- occupant health and resulting productivity
- the building's environmental impact, including reducing operational carbon
- resource efficiency by enabling fast comparison of different design options
- service life and durability.

1.0.4 Whatever the state of the building (whether a new build or a retrofit) or type (such as office, mixed use, residential, hospital or school), almost all buildings can be thermally modelled to help with design decisions. Some modelling tools are designed for specific types of building.

1.0.5 Currently, it seems that few New Zealand design professionals use thermal modelling tools for anything more than meeting the compliance minimums of New Zealand Building Code clause H1 *Energy efficiency*. As a result, the majority of new buildings perform below their optimum level in terms of thermal comfort, cost, health and impact on the environment. This can adversely affect occupants and the environment for many decades to come.

1.0.6 The term 'thermal modelling' is often used interchangeably with the terms 'thermal simulation', 'energy simulation' and 'energy modelling'.

1.0.7 Different frequency of input data can be used to understand aspects of a building's performance characteristics. Dynamic simulation can provide more detail in terms of understanding daily effects, while monthly methods can provide quick feedback on aspects that operate on longer timescales.

1.0.8 This bulletin is an introduction to thermal modelling tools and focuses on thermal modelling for residential applications.

2 TYPES OF THERMAL MODELLING TOOLS

2.0.1 Thermal modelling tools differ in their complexity and the scope of their calculation abilities (Figure 1 and Table 1). Three ways to characterise tools are:

- whole-building versus component tools
- multi-zone versus single-zone tools
- defined by boundary conditions – steady-state, monthly or dynamic (step size of an hour or less).

2.1 WHOLE-BUILDING VERSUS COMPONENT TOOLS

2.1.1 Thermal modelling tools are available for the whole building and components of a building.

2.1.2 Among other uses, approved whole-building tools are used for compliance with Building Code Verification Methods H1/VM1 and H1/VM2. They assess the performance of the building as a whole and not just component parts of the building.

2.1.3 Component tools are used for specific components such as thermal bridging, moisture (hygrothermal modelling) or mould risk. These component results may feed into whole-building modelling or other analyses. Among other uses, component thermal modelling tools are commonly used for:

- determining the R-values of slab-on-ground floors as per H1/VM1 Appendix F and H1/VM2 Appendix F
- determining the R-values of windows, doors, skylights and curtain walling as per Building Code Acceptable Solution H1/AS2, H1/VM1 Appendix E and H1/VM2 Appendix E.

2.2 MULTI-ZONE VERSUS SINGLE-ZONE TOOLS

2.2.1 Multi-zone tools can assess different zones within a building. They are considerably more effective than single-zone tools at predicting more-complex situations such as overheating within individual rooms on different faces of a building, apartments and so on. Multi-zone tools do have a learning curve but are maturing quickly. With the right training, they can be used by non-energy-modelling professionals.

2.2.2 Single-zone tools can assess a building's energy needs as a single zone or entity only but are usually simpler to use by non-energy modelling professionals.

2.2.3 H1/VM1 requires the use of multi-zone tools for buildings with multi-unit dwellings such as apartment buildings.

2.2.4 For other buildings within the scope of H1/VM1, single-zone tools are permitted.

2.2.5 H1/VM2 requires the use of multi-zone tools for all buildings within its scope.

2.3 BOUNDARY CONDITIONS

2.3.1 Boundary conditions define the inputs of the thermal simulation model. They fall into three classifications:

- Steady-state tools provide analyses usually aimed at the component level – for example, simplified thermal bridging calculations. As the name suggests, steady-state tools assume fixed parameters – for example, constant temperatures on either side of an element. They also don't allow for any dynamic changes to thermal properties such as the impact of temperature and moisture content on the thermal resistance of materials.
- Monthly tools typically use monthly average climate data to calculate the energy flows in and out of a building or component. They are limited in their ability to assess daily effects like overheating, which is compounded by most monthly method tools also being single zone.

- Dynamic tools usually use hourly or sub-hourly climate data to provide a clearer picture of daily effects. This allows the user to understand issues such as overheating bedrooms on a recurring basis in the summer months. This cannot be done by monthly methods. The climate data can be historical or predicted future data. Dynamic tools also provide the ability to test sensitivity of a building to different usage patterns and heating schedules. They are considered dynamic because they incorporate more physical parameters and processes than monthly methods.

3 USING THERMAL MODELLING TOOLS

3.1 HOW TO USE THERMAL MODELLING TOOLS

3.1.1 Thermal modelling tools can be thought of as having two parts – the simulation interface and the simulation engine.

3.1.2 A building modeller uses the simulation interface to create a virtual representation of the building’s thermal and/or moisture characteristics. They do this by entering information about the building’s form, construction systems and building occupant behaviour. These are commonly referred to as simulation inputs or variables and will differ according to the tool being used. Depending on the tool, this information can be entered through a graphic representation of the building such as 2D or 3D building model interface [Figure 2] or a numeric input form.

3.1.3 In the case of a dynamic tool, the simulation engine computes the impacts that these variables have on the indoor environment, usually over 1 year – 8,760 hours. Most tools will allow part of a year to be examined, but this provides less confidence. To understand the longer-term trends, simulation can be done over multiple years to minimise the effect of season fluctuations.

3.1.4 In the case of a monthly tool, the simulation engine computes the impacts that these variables have on the indoor environment, usually over 1 year – 12 months.

3.1.5 An approved whole-building energy simulation tool must be used to demonstrate compliance with the modelling methods in H1/VM1 and H1/VM2. This is

usually a tool that has undergone testing following ANSI/ASHRAE Standard 140 or Building Energy Simulation Test (BESTEST). See D.1.3.1 in both H1/VM1 and H1/VM2. EN ISO 52016-1 is the successor to the well-known EN ISO 13790 and sits inside the wider ISO EPB suite. The standard describes the calculation procedures for heating and cooling load calculations for both monthly and hourly methods – recognising that the hourly method removes the need for various correction factors. EN ISO 52016-1 also contains a set of verification cases that stem from ASHRAE 140.

3.1.6 The outputs of whole-building energy simulation are performance measures such as internal temperature profiles, relative humidity profiles, space conditioning demand and/or load and energy use.

3.1.7 Once the initial model has been created, the implications of altering the building’s physical layout, material properties, orientation or other aspects can then be easily explored.

3.2 WHY USE THERMAL MODELLING TOOLS?

3.2.1 Thermal modelling tools are used during the design process to:

- explore design options so that a better understanding of the implications of specification changes can be made to guide design priorities
- uncover and validate solutions for optimum or significantly improved indoor environments
- benchmark and compare a design against other simulation results from previous projects.
- meet voluntary building performance and energy efficiency/sustainability targets or ratings
- meet specific requirements of the design practice or client targets
- demonstrate compliance with the Building Code’s H1 *Energy efficiency* requirements using the modelling methods such as H1/VM1 or H1/VM2 as an alternative to the schedule/calculation methods of H1/AS1 and H1/AS2
- provide data to guide design decisions
- identify opportunities in the design that can help to bring down predicted energy use and improve cost-effectiveness of the design options
- meet the expected upcoming requirements for MBIE’s Building for Climate Change programme.

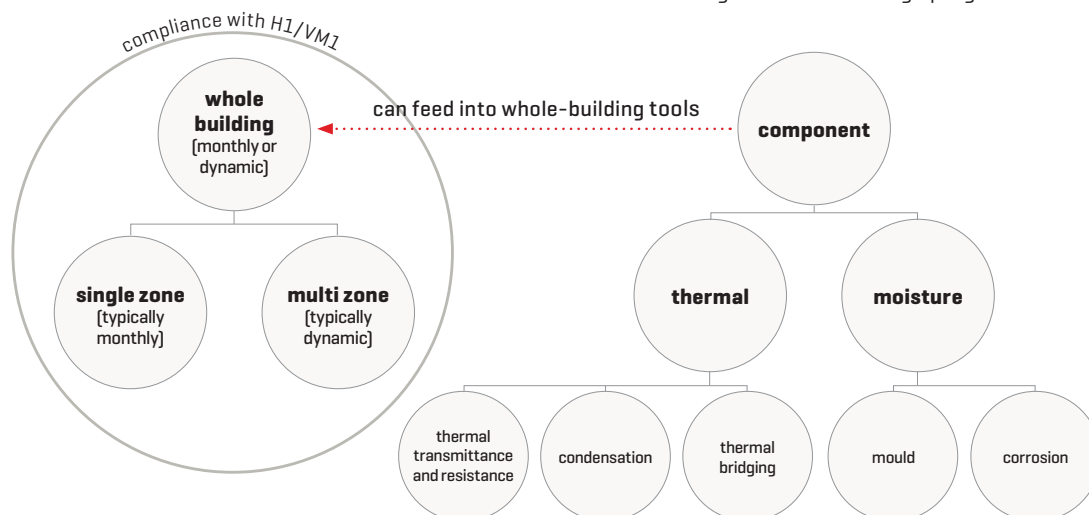


Figure 1. Thermal modelling tools differ in their complexity and functionality.

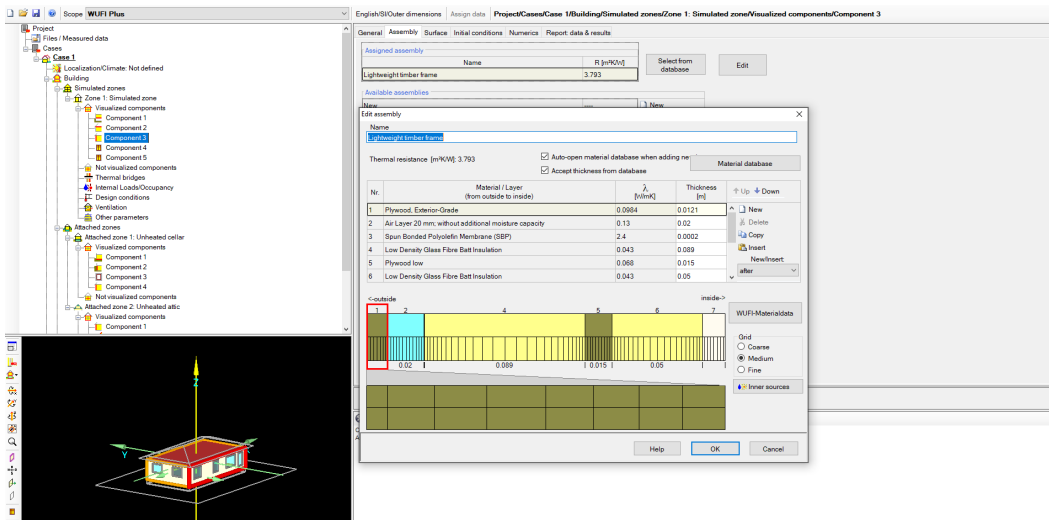


Figure 2. Example of a 3D thermal modelling interface.

3.2.2 For a residential dwelling, multi-zone thermal assessment tools can typically answer these questions:

- What is the impact on living room daytime comfort of altering the orientation/northern window size/exterior shading/insulation levels?
- How often does the house provide healthy indoor temperatures (around 18–25°C) without space conditioning?
- How often do the south-facing bedrooms become very cold in the winter [say <12°C] if left without supplementary heating [whether occupied or not]?
- What impact do window size, specification, orientation and shading have on the likelihood of a room exceeding thermal comfort limits?
- How much will an uncovered (no carpet or laminate flooring) concrete floor slab smooth the daily temperature fluctuations in the main living areas?

3.2.3 Single-zone tools assume the whole house is one zone so assessment of specific rooms is not possible. They are most useful when modelling compact designs.

3.3 WHO SHOULD USE THESE TOOLS?

3.3.1 Training is required to use building thermal modelling tools correctly. Experience is required to interpret the results to get the best out of them. A small mistake can have large and unforeseen consequences for the thermal performance of a building. Building professionals are encouraged to learn about thermal modelling tools, but unless they are using them on a regular basis, they are strongly advised to consult with specialists who are available nationally. The more familiarity building professionals have with these tools, the more possibilities there are for integration between practitioners.

3.3.2 It takes time to learn to use even the most user-friendly simulation tools properly and many hours to become proficient.

3.4 WHEN IS IT BEST TO USE THESE TOOLS?

3.4.1 The rule is early and often. The earlier thermal models can be integrated into the design process (starting at sketch/concept design), the more likely positive, cost-effective performance changes can result. The largest opportunities for design alterations are found in the early design stages.

3.4.2 This does mean the early model may be relatively crude and therefore inaccurate so will need to be refined as the design progresses. The designer may have to revisit some of the earlier assumptions.

3.4.3 Sometimes, it may be a good idea to use more than one tool and compare the likely costs of the different solutions.

3.5 WHEN SHOULD THESE TOOLS NOT BE USED?

3.5.1 Thermal modelling tools should not be used in these situations:

- To predict actual energy use, energy costs or space conditioning energy use. Since the occupier can strongly influence the space conditioning demand, real-life modelling and comparisons need qualifiers. No matter how sophisticated the tool is and the model made, it is still a simplification of reality. It's important to note that climate data used for modelling tends to be idealised reference years and that, if a user wants to understand performance in more extreme situations, a sensitivity analysis is needed.
- The designer's intended design goal or the performance criteria are not well defined or do not align with the outputs or scope of the simulation tool.
- A building is situated in a micro-climate that the available weather files do not represent well unless additional work is undertaken to take this into account. Alternatively, if the impacts of climate change are being investigated, where a representative predictive future climate file cannot be sourced.
- The tool has not been independently validated by an accepted process such as BESTEST or ASHRAE 140.

3.5.2 Any simulation tool needs to be configured appropriately (units, weather data etc.). Many thermal modelling tools (and simulation tools in general) are not set up with relevant default values.

3.6 GETTING THE BEST RESULTS

3.6.1 The best results will be achieved by having a structured approach:

- Have a very clear idea from the start of the issues you want to explore/answer and how these relate to your

design goals – in other words, have a clear objective. This will affect how detailed your simulation must be and how long it will take to carry out.

- The energy modelling process is an iterative one. Don't expect a design to achieve the desired goals in the first run. Knowing what doesn't work and why is just as important as knowing what does.
- Anyone can use a simulation tool and produce results – it is understanding the 'why' behind the numbers that is important in ensuring the result is valid. It's important to look for errors in material data and boundary conditions when assessing if a result is plausible.
- Document the changes associated with each version of the model, the assumptions made and why.
- Document the sources of material data.
- Document the model thermal zoning process on the plans.
- Select the appropriate weather file.
- Have a consistent way of naming files so that variants (including default values and schedules) can be easily recognised from their file name. This is particularly important for demonstrating Building Code compliance or meeting the requirements of a voluntary scheme.
- Keep a record showing the progress of the model from variant to variant and how decisions are being made.
- Spend time to get the very first model as robust and correct as possible so that, when variations of it are performed, there is certainty around them. In simulation, this is referred to as quality assurance. Standards such as CIBSE Guide A: *Environmental design* 2015 provide details on how to manage this process.
- Use experts to learn from and review work whenever possible. They will have a much better understanding of modelling defaults, shortcomings and limitations.
- If in doubt, check the tool manual and help files carefully to ensure you understand tool inputs and settings correctly. For example, when entering shading for glazed areas, it is important to know whether the tool interprets an input of 0 as unshaded or fully shaded. In some tools, some inputs can be counterintuitive so it's best to double check.

4 SELECTING TOOLS

4.0.1 Many thermal modelling tools are available, each with its own benefits and drawbacks. Tools vary in areas such as complexity, the inputs they accept and the comprehensiveness of their outputs. Tool features are constantly improving. Some tools are free to use.

4.0.2 It is critical that a tool is selected based on being fit for purpose. For example, overheating assessments using CIBSE TM59 require the use of a multi-zone dynamic tool. Some tools may also be more conservative than others.

4.0.3 Remember that H1/VM1 requires the use of multi-zone tools for buildings with multi-unit dwellings such as apartment buildings. For other buildings within the scope of H1/VM1, single-zone tools are permitted.

4.0.4 H1/VM2 requires the use of multi-zone tools for all buildings within its scope.

4.0.5 It is important to complete due diligence to ensure the tool's capabilities match your requirements. This may involve working with a building modelling specialist. Tool developers often allow prospective users to trial

their tool for a short period, which may give a good indication of its characteristics and capabilities.

4.0.6 The tool should integrate well into your workflow.

4.0.7 When selecting a thermal modelling tool, first consider its simulation engine capabilities and then its interface. As a guide, the simulation interface should:

- be reasonably user-friendly
- provide the kind of reports that match the user's specific requirements.

4.0.8 The simulation engine should:

- provide input and output in SI [metric] units – many thermal tools developed in the United States do not have this as a default or do not have it as an option
- be capable of providing a sufficiently detailed representation of the actual systems in use or planned for the particular project
- model a full year using location-specific climate/weather data [including site shading, if known]
- allow for user-defined hourly variations in occupancy schedules, lighting and equipment power schedules and loads, thermostat set points and HVAC system operation
- take account of thermal mass effects, natural and mechanical ventilation, infiltration and thermal bridging
- use current standards
- be verified/validated to BESTEST or ASHRAE 140.

4.0.9 Some thermal tools are integrated with a diverse range of other environmental programs such as daylight, solar shading, computational fluid dynamics and whole-building life cycle assessment. However, these additional features must be reviewed to the same level of scrutiny as the thermal modelling functions. For example, many daylight simulation tools embedded in thermal modelling tools use the CIE uniform sky model and only calculate a space's daylight factor. However, a climate-based sky model calculates dynamic daylight performance metrics such as daylight autonomy and useful daylight illuminance and is current best practice.

4.0.10 The Building Energy Software Tools (BEST) Directory www.buildingenergysoftwaretools.com, formerly hosted by the US Department of Energy, provides an inventory of mostly whole-building tools with a description of the program, expertise required by the user, target/suitable user audience, major capabilities and strengths and whether or not it is free to download.

4.0.11 Simulation engines are included in some CAD programs. These should be used with considerable care as it is very easy to generate incorrect results, often due to apparently small errors. Users are advised to obtain full training in the use of these features and to trial their skills against calibrated models before applying them to their own designs:

- Autodesk's Green Building Studio – used by Revit, Insight and FormIt 360 interfaces. The simulation engine is based on the validated DOE-2.2.
- Graphisoft's ArchiCAD EcoDesigner STAR – used by ArchiCAD 17. The simulation engine has been validated.

4.0.12 Common modelling and thermal design tools and their characteristics are shown in Tables 1 and 2.

Table 1. Common whole-building thermal modelling and design tools.

	Description	Cost	Platform	Dynamic solution tool	Multi-zone or single zone	Overheating methodology	Energy estimation methodology	Moisture risk assessment	Geometry import	Can be used for H1/M1 compliance	Benchmarked
ALF airbranz.co.nz	Calculates building performance index (BPI). However, both H1/AS1 and H1/M1 state compliance with the BPI is not sufficient for demonstrating compliance with H1.3.1a 'adequate thermal resistance'. Therefore, while ALF can demonstrate compliance with H1.3.2E (BPI) and can be used as a design tool, it is no longer a complete H1 compliance tool.	Free	Online	No	Single zone	n/a	EN 13790 (modified)	No	No	No	No
designPH passivehouse.nz	Estimates a building's heating, cooling and primary energy demand. Does not estimate overheating. Can be used for new buildings and retrofits and is generally operated by a trained passive-house designer or consultant. Typically used in early-stage design but can also be part of the basic certification of a building as a passive house. Can be exported to PHPP for more detailed simulation.	Pay to use (purchase a licence)	Plugin for Trimble SketchUp, MS Windows and Mac	No	Single zone	n/a	EN 13790 (modified)	No	Yes	No	No
Passive House Planning Package (PHPP) passivehouse.nz	Estimates a building's heating, cooling and primary energy demand and tendency to overheat in the warmer months. Can be used for both new buildings and retrofits and is generally operated by a trained passive-house designer or consultant. Forms the basis for certification of a building as a passive house.	Pay to use (purchase a licence)	MS Excel tool for Mac and Windows		Single zone		EN 13790 (modified)	No	Yes (from SketchUp plugin designPH or from BIM software using IFC)	Yes	ASHRAE 140-2017
WUFI Plus (V3) wufi.de/en/software/wufi-plus	Comprehensive simulation tool for evaluating the dynamic hygrothermal behaviour of buildings. Calculates energy needs, indoor climate and comfort conditions, air quality and hygrothermal conditions for predicting moisture accumulation within building components. WUFI Plus includes the full functionality of WUFI Passive.	Pay to use (hygrothermal simulation) – free version with limited functionality available (only thermal simulation)	MS Windows only	Yes	Multi-zone	DIN 4108-2	Dynamic simulation; EN 13790 (modified; passive house calculation mode)	Yes (hygrothermal simulation comes with paid version)	Yes (geometry import comes with paid version)	Yes	ASHRAE 140; VDI 6020; DIN EN ISO 10211, field measurements
ECCH0 www.nzgbc.org.nz	New Zealand Green Building Council modelling tool for residential buildings. Developed to enable compliance with its Homestar rating tool. The energy performance aspect of ECCH0 is based on a simplification of PHPP V9.6.	Accessible only to registered Homestar assessors			Single zone					Yes	Online version ECCH0 28 April 2023; ASHRAE 140
WUFI Passive wufi.de/en/software/wufi-passive	WUFI Passive is closely related to WUFI Plus. The main difference is that the dynamic hygrothermal simulation is performed only after static passive house criteria are met. In addition, WUFI Passive employs a fast monthly balance approach that enables optimisation and then certification of passive house designs.	Pay to use (hygrothermal simulation for passive houses); free version with limited functionality available (only thermal simulation)	MS Windows only	Yes	Multi-zone	DIN 4108-2	EN 13790 (modified; passive house calculation model); dynamic simulation	Yes (hygrothermal simulation comes with paid version)	Yes (geometry import comes with the paid version)	Yes	
Energy Plus energyplus.net	Full-featured whole-building energy simulation engine that models 3D geometry, envelope heat and moisture transfer, airflow, daylighting and artificial lighting, component level HVAC, water heating and refrigeration and controls at sub-hourly intervals. Owned by US Department of Energy, Board of Trustees of University of Illinois, Regents of University of California.	Free (BSD-3 open-source licence), although typically used via graphical interfaces most are proprietary and have seat licence fees	MS Windows, Mac OS, Linux	Yes	Multi-zone		Heat, mass, moisture balance; quasi-static, load-based predictor-corrector approach, tested in accordance	Yes	Via graphical user interfaces		

Table 2. Common component thermal modelling and design tools.

	Description	Cost	Platform	Dynamic solution tool	Multi-zone or single zone	Moisture risk assessment	Geometry import	Benchmarked
WUFI Pro	WUFI Pro is the standard program for evaluating moisture conditions in building envelopes. Of all the programs in the WUFI Software Family, it is the easiest to use. WUFI Pro performs one-dimensional hygrothermal calculations on building component cross-sections, taking into account (where appropriate) built-in moisture, driving rain, solar radiation, long-wave radiation, capillary transport and summer condensation.		MS Windows	Yes	Single zone	Yes	No	
WUFI 2D	WUFI 2D expands the scope of WUFI Pro to two-dimensional analysis. A one-dimensional WUFI Pro analysis cannot be used when regions next to the cross-section of interest have different heat and moisture responses. In particular, two-dimensional analyses are necessary for complicated geometries, such as building corners, window locations and foundation connections, and when there are non-uniform sources/sinks of heat and moisture.		MS Windows	Yes	Single zone	Yes	Yes	
THERM windows.lbl.gov/therm/therm.html	THERM is used to model two-dimensional heat-transfer effects in building components such as windows, walls, foundations, roofs and doors, appliances and other products where thermal bridges are of concern. THERM 8 has the added capability of transient (time-based) moisture and thermal modelling.	Free, developed by the US Department of Energy	MS Windows	THERM 7 is steady state, THERM 8 is dynamic	Single zone	Yes for THERM 8	Yes	
Berkeley Lab WINDOW windows.lbl.gov/software/window	Berkeley Lab WINDOW provides a versatile heat transfer analysis method consistent with the updated rating procedure developed by the National Fenestration Rating Council (NFRC) that is consistent with the ISO 15099 standard. The program can be used to design and help new products, to assist educators in teaching heat transfer through windows and to help public officials in developing building energy codes.	Free, developed by the US Department of Energy		No; WINDOW 8 should be used with THERM 8	Single zone	No; WINDOW 8 should be used with THERM 8	No	
FLUXO www.fluxo.com	2D steady state thermal bridge analysis and reporting application.	€1,990 [excl. VAT] a year	MS Windows	No	Single zone	No	Yes	Validated according to EN ISO 10077-2 and EN ISO 10211



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