

## Thermal performance improvements in low-income dwelling structures

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## I. Sources

This methodology also refers to the latest approved versions of the following tools (please delete those not applicable):

- Tool to calculate project emissions from electricity consumption;
- Tool for the demonstration and assessment of additionality v7;
- Guidelines on the consideration of suppressed demand in CDM methodologies EB 62;
- Standard for sampling and surveys for CDM project activities and programme of activities;
- ACM0005, ACM0006, AM0091, CDM Project #0079

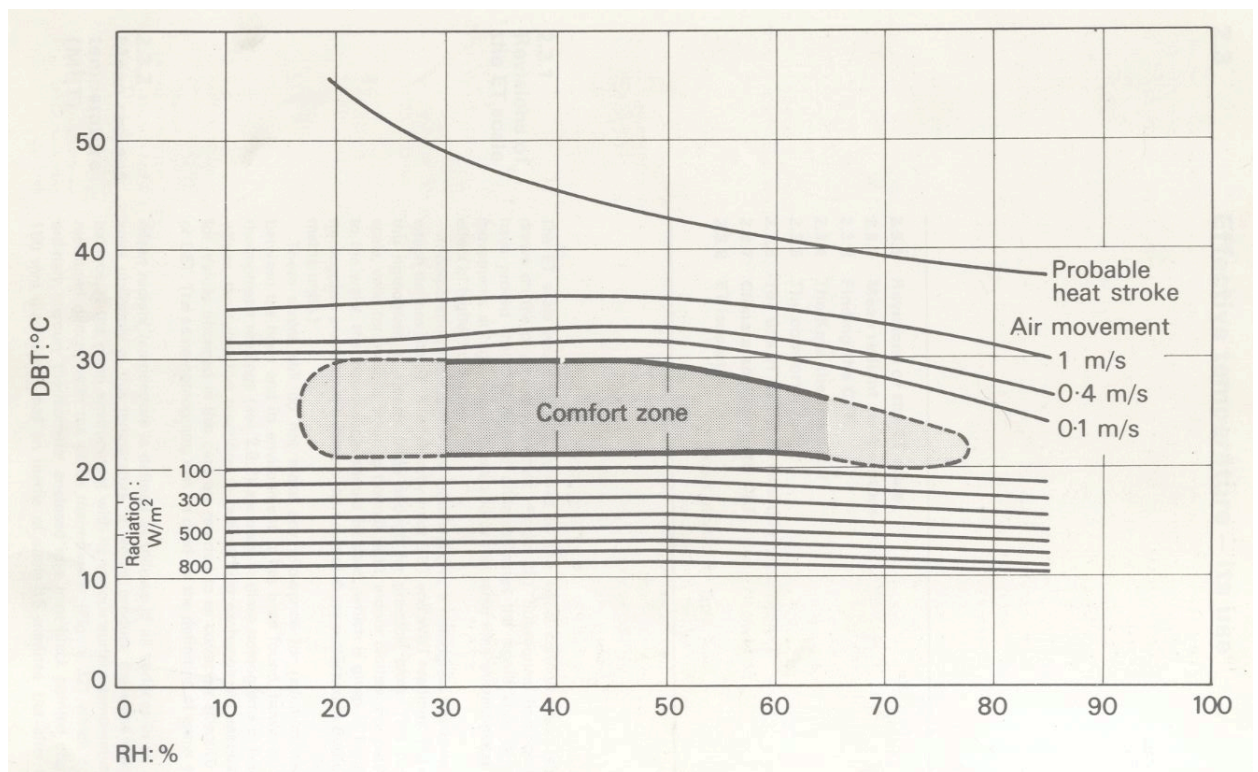
For more information regarding the proposed new methodologies and the tools as well as their consideration by the Executive Board please refer to <http://cdm.unfccc.int/goto/MPappmeth>.

## II. Definitions

For the purpose of this methodology, the following definitions apply:

1. **Project service:** The project service is the capped thermal comfort in dwelling structures during the non-sleeping occupancy periods of the day, in periods of the year when space heating is required.
2. **Capped thermal comfort:** The minimum bounds defined by the bioclimatic chart for the project.
3. **Minimum thermal comfort:** The minimum temperature considered to be in the comfort zone for the local conditions, taking into account among others the local humidity.
  1. **Thermal Performance:** The thermal performance of buildings is defined as the total energy expenditure - per unit of the indoor floor area - needed to heat and/or cool the interior of a building to a minimum level of "thermal comfort".
  2. **Thermal performance interventions:** Project interventions that improve the thermal performance of existing or new dwelling structures by reducing the amount of heating or cooling energy required to reach thermal comfort. Interventions could include:
    - The fabric of the structure;
    - Orientation towards the source of solar radiation;
    - Insulation materials in walls, ceiling/roof and under the base slab;
    - Finishes (plastering and paint);

- Apertures and their screening; and
  - Vertical and horizontal attachments of structures.
4. **Thermal Performance Building Standards:** Thermal Performance Building Standards are regulations, which mandate for new and/or existing buildings to achieve a certain level of thermal performance (e.g. building regulation SANS 10400:1990 in South Africa). Thermal performance building standards can be applied at country, state, provinces or city level. In case of overlapping standards, the most stringent of them shall be considered.
  5. **Thermal performance upgrades:** The modification or installation of material and design elements, which improve a building's thermal performance.
  6. **Thermal comfort:** In this methodology thermal comfort refers to a range of temperatures and humidity conditions under which a "satisfaction with the thermal environment" is achieved in buildings. This range of conditions is called the "comfort zone". This "comfort zone" shall be derived from bioclimatic charts for various climate zones around the world. (The sub-method to describe how to locate thermal comfort is described in more detail below (see Annex 2).



Ref: Manual of tropical housing and building: Part 1 – Climatic design

Authors: Koenigsberger, O. H., Ingersoll, T. G. and Szokolay, S. V.

Date: 1973

Publisher: Longman, London

7. **Empirical Thermal Comfort Level:** The Empirical Thermal Comfort level is determined from monitored data as the temperatures at which the house is typically kept in the space heated zone during the cold months of the year (see Annex 2).
8. **Non-sleeping Occupancy:** Non-sleeping occupancy is the occupation of a heated room or zone in the building, by a member of the household, during which that member is awake and during which thermal comfort is desired.
9. **Typical Space Heating Intervals:** The typical space heating intervals include a period of time in the morning (for example from 3am to 8am), and a period of time in the evening (for example 3pm to 10pm), during which there is non-sleeping occupancy in the space heated structure/heated zone, and during which the monitored data provides evidence of space heating. The periods are determined by observations of loads on the electricity circuitry or indoor temperature monitoring to locate intervals when active space heating is in use (see Annex 1).
10. **Structure:** Arrangement of all integrated components that make up the dwelling structure that are considered in calculating energy required to achieve thermal comfort. The dwelling structure can be freestanding or part of an apartment block. Of particular importance in this document are the structural components that, when taking their fabric into account, have a significant effect on the thermal environment within the boundaries defined by the structure. Typically, building structural components will include floors, walls, doors, windows, ceilings, roofs and fixed shading.
11. **Fabric:** Fabric may be defined for any object as the homogenous material(s) constituting that object. The objects of interest in this document are the building structural components, because their fabrics have properties that affect the thermal environment. So the type and the thickness of the various fabrics of the structure need to be recorded.
12. **Predictive tool:** A predictive tool refers to any tool that can accurately predict certain (output) conditions, unambiguously and realistically, from certain (input) conditions. Predictive tools may be computer software or a set of equations that provide meaningful outcomes based on a range of hypothetical input scenarios. A maximum of 5% error (computed in standardised verification methodologies) in accuracy of indoor temperature can be tolerated for a predictive tool to be eligible for use.
13. **Space heating:** Space heating refers to the action of heating a space, or room, by the addition of thermal energy (from various fuel sources e.g. solar radiation, other renewable fuels, fossil fuels).
14. **Active space heating:** Active space heating is supplied to make up the difference between the passive heat in the structure including heating sources other than ambient heat and solar radiation (warm bodies, cooking, lighting etc.). Typically active heating is supplied through fuel and a heating appliance combination.
15. **Orientation:** The orientation of the apertures of structures towards the sun or away from it affects the level of solar gain and is a required input to the modelling process.

Structures can be designed so as to maximise passive solar heat (and light) gains internally when this is desired. For example, in the southern hemisphere this implies an orientation of windows towards the north to maximise passive heat gain in the part of the structure where this is desired the most.

16. **Attachments (horizontal/vertical):** An attachment is defined as one or more surfaces by which two adjacent dwelling structures are connected and are not exposed to outside elements. Among others, adjoining walls and slabs/floors vertically separating one flat from another are attachments. For example, flats are attached in an apartment block.
17. **Class of dwelling structure:** For the purposes of this methodology the class of structure are defined as include low-income (government subsidized) basic low-middle income “gap” stand-alone structures, (not or partially subsidised), stand-alone structures, flats or “walk-ups” in an apartment block. The definition of these classes of structures will be guided by national or subnational categorizations as provided by income levels, geographical location, or other nationally defined stratifications.
18. **Formal Structures:** Formal structures are structures that are planned and approved by city or regional planning authorities and are normally constructed using solid fabrics such as bricks, blocks, concrete, and rigid roofing materials etc. For the methodology these are limited to low to low-middle income formal dwelling structures.
19. **Sample:** A *sample* is a subset of a *population*. The population could be, for example, all households included in a CDM project activity; the sample is a subset of these households. A characteristic of the population, such as average number of hours of operating a biogas stove, or proportion of installed refrigerator units still in operation, will be referred to as a *parameter*. The population parameter is unknown unless the whole population is studied, which is often not feasible or possible. A population parameter can, however, be estimated using data collected from a sample. It is therefore important that the sample is *representative* of the population. The correct choice of sample design can help to achieve this.
20. **Climate Zone:** Climate Zones are geographical zones loosely divided according to prevailing temperature, rainfall, humidity and latitude. Climate zones will need to be defined by Meteorologists or Architectural Professional bodies at a national level for countries hosting projects using this methodology. Should the project fall between two climate zones the zone with the lower temperature level of thermal comfort will be utilised for the project design purposes.

### III. Applicability

This methodology applies to project activities that improve the thermal performance of low-income dwelling structures:

Project activities implemented under this methodology shall comply with the following applicability conditions:

Applicability conditions for buildings:

(a) The project activity applies one or more of a menu of thermal performance improvements to either new and/or existing buildings.

(b) The project activity only applies to low and low middle-income formal dwelling structures.

(c) The project activity only applies to new or existing formal dwelling structures regardless of whether these structures have been constructed in or out of compliance with local and/or national standards and/or regulations. Informal structures built by land squatters or “back-yard shacks” which are irregular in size and fabric are specifically excluded.

(d) In accordance with E+ and E- rules, this methodology is only applicable if the procedure to identify the baseline scenario results in basic standard dwelling structures (minimum or less than attainment of planning and building standards at the time of building is the most plausible baseline scenario).

(e) The heated indoor spaces of dwelling structures can be determined. This can be the entire indoor structure or part thereof if there are multiple indoor divisions.

(f) Every dwelling structure included in the project can be identified in an unambiguous manner and the climate zone of each dwelling structure is determined.

(g) The methodology is only applicable where inhabitants of structures voluntarily opt-in. In new structures the PP will liaise with housing developers to ensure that the transfer of credits to the necessary destination/s are included in deeds of transfer/leases of structures. In retrofitted structures occupants will be asked to transfer credits to cover the costs of project additions prior to the project.

(h) The methodology applies to space heating but could in the future be adapted to include space cooling using an analogous approach to that for space heating.

Types of thermal performance improvements:

(a) The project activity consists of thermal performance upgrades. The upgrades may include any structural, fabric, or design changes to the structures that reduces the active space heating required in achieving thermal comfort for occupants of the structures when heating is required.

(b) The methodology does not explicitly address designed changes in electricity consumption, fuel switches or improvements in heating appliances. However, if these changes in space heating fuels/appliances/behaviour happen during the project cycle, they will be included in emissions calculations.

(c) The project activity does not include thermal performance improvement technology removed from existing and occupied structures.

(d) The energy that is used/required for or contributes to space heating (cooling is not included in this method) in the dwelling structures in the project can be determined and monitored.

This methodology is only applicable where households' livelihoods are shown to be improving over time. Improvements in livelihoods can be approximated by local, national or international measures such as improved real household income, Living Standards Measures, Human Development Indices, or any similarly recognised indicator/s of livelihoods.

Only internationally recognised tools for the accurate or conservative estimation of energy required for space heating in structures are to be used in the simulation of the thermal performance of structures in applying this methodology. Tools that have been verified to be accurate (within 5%) or conservative in calculating energy requirements may be utilised (see Annex 4, Internationally recognised predictive tool). It is essential to establish the credibility of the predictive tool that is used in applying this methodology is sufficiently robust for application in this methodology. PPs will provide evidence of the credibility of the tool/s they select and this will require validation by DOE, which will require the necessary expertise to evaluate selection and population of the calibrated tool. To achieve that, international peer review is a requirement to establish the integrity of the software. Positive review by bodies such as ASHRAE and their equivalents elsewhere would be one such review that would need to be positive in its assessment. The use of equivalent standard test for the review would also be a requirement, for example "ANSI/ASHRAE Standard 140-2007 - Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs."

The applicability conditions included in the tools referred to above apply in this methodology.

Application of Suppressed Demand in this methodology is determined by the shortfall in thermal comfort (in °C as defined in the bioclimatic chart) for the specific climatic zone during non-sleeping occupancy periods of the day during the season when space heating is required. The emissions from the energy required to achieve the minimum thermal comfort during non-sleeping occupancy periods with and without thermal performance improvements as defined by the projects using this methodology determines the emissions that can be claimed through this methodology.

#### IV. Boundary

The **spatial extent** of the project boundary encompasses all low to low-middle income dwelling structures within rural or urban areas within a defined climatic zone inside one or more existing or new housing development physical project boundaries where occupants have opted in to the project. Only structures whose occupants have opted-in shall be included within the project boundary. The boundary includes the heating systems and upstream emissions from the production and transportation/transmissions of heating fuels including electricity. In the specific case of electricity from the national or regional grid, all power plants supplying the grid shall be included within the project boundaries.

The greenhouse gases included in or excluded from the project boundary are shown in Table 1.

Table 1: Emissions sources included in or excluded from the project boundary



Source		Gas	Included?	Justification / Explanation
Baseline	Active Space heating fuel 1	CO <sub>2</sub>	Yes	Only CO <sub>2</sub> needs to be included; other GHG gasses are negligible
		CH <sub>4</sub>	No	This is conservative
		N <sub>2</sub> O	No	This is conservative
	Active Space heating fuel j	CO <sub>2</sub>	Yes	Only CO <sub>2</sub> needs to be included; other GHG gasses are negligible
		CH <sub>4</sub>	No	This is conservative
		N <sub>2</sub> O	No	This is conservative
Project activity	Active Space heating fuel 1	CO <sub>2</sub>	Yes	Only CO <sub>2</sub> needs to be included; other GHG gasses are negligible
		CH <sub>4</sub>	No	Only CO <sub>2</sub> needs to be included; other GHG gasses are negligible
		N <sub>2</sub> O	No	Only CO <sub>2</sub> needs to be included; other GHG gasses are negligible
	Active Space heating fuel j	CO <sub>2</sub>	Yes	Only CO <sub>2</sub> needs to be included; other GHG gasses are negligible
		CH <sub>4</sub>	No	Only CO <sub>2</sub> needs to be included; other GHG gasses are negligible
		N <sub>2</sub> O	No	Only CO <sub>2</sub> needs to be included; other GHG gasses are negligible

## V. Baseline

Project participants shall apply the following steps to identify the baseline scenario:

The identification of the baseline is to determine the single most plausible scenario in the absence of the project.

The baseline scenario is defined by the (A) structural and design elements (listed below) in conjunction to which (B) appliances and fuels types used for the provision of indoor space heating are applied to reach (C) a level of thermal comfort in dwelling structures during the months of the year when it is required. The baseline scenario needs therefore to be determined for (A) and (B).

### A) Determination of the baseline structural and design elements:

Among others, the following elements shall be taken into account when determining the baseline structural and design elements:

- Dwelling structural elements,
  - type;
  - fabrics;
  - dimensions and thermal conductivity of fabrics;
  - finishes (plastering and paint);

- orientation of structure; and
- attachments.
- Climate zone and climate data

The methodology undertakes to identify the most economically efficient course of action of housing developers (new structures) or dwelling structure owners (in the case of existing structures) in the provision of an empirically established level of thermal comfort during periods of non-sleeping occupancy in the dwelling structures.

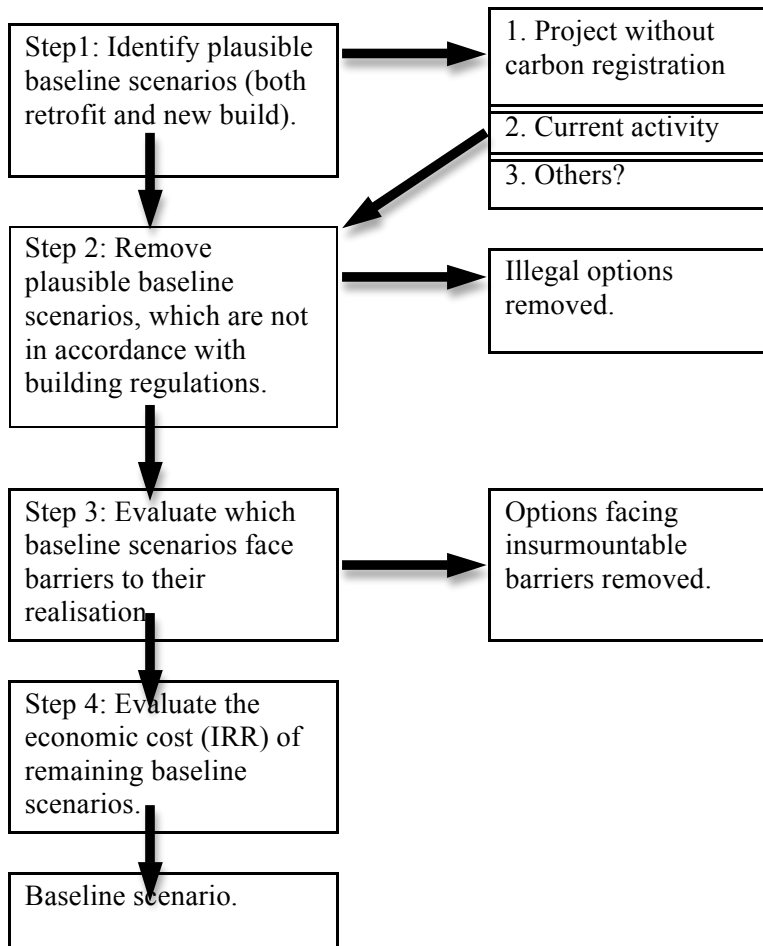
Project participants shall apply the following steps to identify the baseline structural and design elements:

Step 1: Identify plausible baseline scenarios.

Step 2: Remove plausible baseline scenarios that are not in accordance with building regulations.

Step 3: Appraise which baseline scenarios face barriers to their realisation.

Step 4: Determine the most economically efficient of the remaining plausible scenarios by comparing IRRs.



**Step 1: Identify plausible baseline scenarios for baseline structural and design elements.**

Key drivers of the determination of the baseline structural and design elements are: (i) the costs of the thermal performance measures (for step 4), (ii) the energy and therefore financial savings they provide to households (in the retrofit case)<sup>1</sup> (for step 4); (iii) the availability of public and/or private capital to improve structures (for step 3); and (iv) the interests of investors in thermal performance improvements (households and housing developers)(for step 3).

Among others the following alternatives to the project activity shall be considered:

1. **The proposed project activity not undertaken as a CDM project:** The application of one or more of a menu of thermal performance technology interventions offered by the project applied to new and/or existing dwelling structures in the project area. Space heating is achieved using the most common fuel and appliance combination/s (used in the project) to reach an empirically determined level of thermal comfort during non-sleeping occupancy periods of the day during cold periods of the day each year.
2. **The continuation of current activity:** Minimum (or no) application of thermal performance building standards (taking E+ and E- into account) applied to new (and existing dwelling structures where appropriate) in the project area. Space heating is achieved using the most common practice fuel and appliance combination/s (used in the project) to reach an empirically determined level of thermal comfort during non-sleeping occupancy periods of the day for the year.

### **Step 2: Remove plausible baseline scenarios, which are not in accordance with building regulations.**

Enforced national, regional, city and/or sectoral level regulations/policies that have impact on the thermal performance improvements must be evaluated to determine whether any of the baseline are in conflict (where compliance is universally achieved) with the plausible baseline scenario. Any plausible alternatives in conflict should be removed from the plausible baseline scenario list.

### **Step 3: Appraise which baseline scenarios face barriers to their realisation.**

The remaining plausible scenarios will be evaluated to determine whether they have realistic barriers to their implementation. This step will primarily consider the investment of the housing developers (for new build) or households (for retrofits), the availability of public or private finance to achieve this.

- Investment barriers may include:
  - Housing developer investment barriers: the lack of capital of the housing

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<sup>1</sup> Housing developers do not have interest in the energy savings of those who occupy structures they build; their motive is to sell structures at the maximum profit margin.

developer (received from public finance sources for new build subsidized dwelling structures) or potential user of the technologies either personally or passed on in their entirety to low-income households; or

- Dwelling structure owner/occupant's investment barrier: the lack of availability of loan finance for retrofitting either because of country conditions or specific project area conditions, such as bank exclusion on the basis of insecurity of collateral.
- Technical barriers refer to the understanding of the technology in the country and project area and the degree to which the technology has penetrated the potential market sector. Thermal performance improvement technology below 20% penetration in the same market sector will face technical barriers. The technology barrier in this methodology uses the 20% penetration of the technologies in low-income dwelling structures as a proxy for the level of local learning about the technology and those that will install and maintain them. If there is less than 20% penetration, a technological barrier exists.
- Prevailing practice refers to a situation where the project is not first of a kind in the specific climate zone or geographical/housing sub-sector and there are no barriers to its implementation.

**Step 4: Determine the most economically efficient of the remaining plausible scenarios using IRRs.**

If only one plausible baseline scenario remains, this step can be left out. Otherwise, determine the IRR of the remaining plausible baseline scenarios. A commercial discounting rate would be considered for the housing developers. For households, micro-lender rates or equivalent shall be considered. The most economically efficient of the remaining scenarios is the baseline scenario.

**B) Appliances and fuels types used for the provision of indoor space heating:**

The fuels and appliances used for active space heating in baseline scenario are determined by monitoring and recording the space heating fuels and appliances used in the project activity. The baseline scenario would be an arithmetic average of appliances and fuels combination used for space heating in the project. The monitoring of fuels and appliances will be undertaken during the project monitoring using sample 2.

The dwelling structures that have incorporated project thermal performance improvement measures are unlikely to have replaced the total requirements for active space heating. However, the project will have reduced the requirements for active heating to reach thermal comfort. The reduction of active heating will come from the

most common space heating fuel and appliance combinations. Options are, not limited to one or more of the following combinations:

H1. Electricity with conduction, convection or radiant heaters.

H2. Electricity with heat pumps.

H3. Liquid Petroleum Gas (LPG) or Natural Gas with conduction, convection or radiant heaters.

H4. Coal in stove or brazier.

H5. Biomass in stove or brazier.

H6. Kerosene cooker/heater.

H7. District heating.

## VI. Additionality

Additionality is determined using the latest version of the tool for the demonstration and assessment of additionality considering barriers and undertaking a barrier and investment analysis (as required for GS methodologies) using discount rates representative of those faced by the occupants of structures (for retrofits) and housing developers (for new built) in the project activity.

In applying the tool, the methodology requires both the investment and barrier analysis.

Project participants shall apply the following four steps:

- Step 1. Identification of alternative scenarios to the project scenario
- Step 2. Investment analysis (if applicable)
- Step 3. Barrier analysis
- Step 4. Common practice analysis

### **Step 1. Identification of alternative scenarios**

The baseline scenario is identified above and is the only alternative to a project defined as the introduction of a menu of thermal performance improvements in dwelling structures. From here on the demonstration and assessment of additionality compares the baseline scenario to the project activity.

### **Step 2. Investment analysis**

This step serves to determine which of the alternative scenarios in the short list remaining after step 2 is the most economically or financially attractive to the housing developer. For this purpose, an investment comparison analysis is conducted for the remaining alternative

scenarios after step 2. If the investment analysis is conclusive, the economically or financially most attractive alternative scenario is considered as the baseline scenario.

***Sub-step 2a: Determine appropriate analysis method.***

Identify the financial indicator, such as IRR, NPV, cost benefit ratio, or unit cost of service (e.g., levelized cost of electricity production in \$/kWh or levelized cost of delivered heat in \$/GJ which may be appropriate for project participants that build, own and/or use the structures) most suitable for the project type and decision-making context. In this methodology an IRR analysis will be used making use of the discount rates ( $dr$ ) included in Option I below.

***Sub-step 2b: Option I. Apply simple cost analysis.***

Document the costs associated with the project and the baseline scenario identified in Step 1 and compare the costs of the baseline with the project activity.

In this methodology the use of an IRR is recommended as a useful financial indicator of the costs of the thermal performance measures and the active energy savings (for households, possibly landlords but not housing developers who do not heat the structures after they are built).

In undertaking a simple financial analysis the following must be applied:

- In undertaking this analysis it is important to consider the perspective of the housing developer, who will have little interest in the life-cycle cost of the structure.
- If the owner of the dwelling structure is retrofitting the dwelling structure, the discount rates ( $dr$ ) that would be experienced by the purchaser of the technologies are used as a proxy for the interest rate.
- Where the  $dr$  cannot be substantiated, the commercial bank lending rate for the project area is used as a conservative default.
- In instances where the recipients of the technology are poor, a commercial lending rate may not apply and a  $dr$  specific to the time value of money (e.g. the lowest rate offered by commercial micro-lenders) in the project area, if known, is to be utilized.
- In specific areas where commercial micro-lending applies and it is regulated, that rate is applied as the  $dr$ .

Calculate the IRR for all alternative scenarios remaining after step 2. Include all relevant costs (including, for example, the investment cost, the costs of maintenance and the cost of energy savings). Also to be included if relevant are costs associated with increased local infrastructure (e.g. the increased local reticulation requirements) and revenues (including subsidies/fiscal

incentives, ODA, etc. where applicable), and, as appropriate, externalities in the case of public investors.

***If it is concluded that the proposed project activity is more costly than at least one alternative then proceed to Step 4 (Common practice analysis).***

***Sub-step 2b: Option II. Apply investment comparison analysis***

Sub-steps dealing with Options II and III are not applicable.

***Sub-step 2d: Sensitivity analysis:***

This step will be followed as per the tool only if the project proponent selects option III.

**Step 3. Barrier analysis**

***Sub-step 3a. Identify barriers that would prevent the implementation of alternative scenarios:***

Barriers that can be considered in the assessment of the barrier analysis include investment, technical, normative, institutional and policy, common practice etc.

***Sub-step 3b. Eliminate alternative scenarios, which are prevented by the identified barriers:***

Any alternative that would be prevented by the barriers identified in Sub-step 3a is not a viable alternative, and shall be eliminated from consideration.

Plausible alternatives to the project scenario in the identification of the baseline scenario have been excluded because:

- they do not occur in practice;
- access to capital is impossible;
- the interest rates for households are too high (for poor households); and/or
- households (in the retrofit scenario) do not consider thermal improvements a priority.

Common practice analysis

***Sub-step 4a: Analyze other activities similar to the proposed project activity***

The methodology considers technologies that are not new and are likely to be used in high to middle income dwelling structures and commercial structures in the region as standard practice<sup>2</sup>. So they are not new, to the region, but they will not be common practice to the low and low-middle income structures where public development, private capital (and access to capital) and incomes are low and when available prioritized elsewhere.

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<sup>2</sup> Where energy costs are low or affordable for active space heating, this standard practice is neglected.

The methodology is a way to achieve access to improved thermal performance in lower income dwelling structures through gaining access to carbon income to assist technology transfer between the common building practices for the higher and the lower income groups.

To assess whether common prevails, the project proponent must provide an analysis of any other activities that are operational and that are similar to the proposed project activity. Projects are considered similar if they are in the same country/region and/or rely on a broadly similar technology, are of a similar scale, and take place in a comparable environment with respect to regulatory framework, investment climate, access to technology, access to financing, etc. Other CDM project activities (registered project activities and project activities which have been published on the UNFCCC website for global stakeholder consultation as part of the validation process) are not to be included in this analysis. Project proponents must provide documented evidence and, where relevant, quantitative information. On the basis of that analysis, they should describe whether and to which extent similar activities have already diffused in the relevant region.

***Sub-step 4b: Discuss any similar Options that are occurring:***

If similar activities are widely observed and commonly carried out, it is necessary to demonstrate why the existence of these activities does not contradict the claim that the proposed project activity is financially/economically unattractive or subject to barriers. The project participant must demonstrate how the project differs from similar projects and/or how the environment in which the project is planned has changed. The tool provides guidance on how this can be achieved.

***If Sub-steps 4a and 4b are satisfied, i.e. (i) similar activities cannot be observed or (ii) similar activities are observed, but essential distinctions between the project activity and similar activities can reasonably be explained, then the proposed project activity is additional). If Sub-steps 4a and 4b are not satisfied, i.e. similar activities can be observed and essential distinctions between the project activity and similar activities cannot reasonably be explained, the proposed project activity is not additional.***

If the steps show that the baseline scenario is the more economically efficient course of action than the project activity, doesn't face barriers and is common practice, then the project activity is additional. If the project activity is more economically efficient, faces barriers or is common practice, the project is not additional.

## VII. Emission reductions

### Calculation of baseline emissions

Step 1:



Establish if the project is in a climate zone where space-heating requirements have been modelled using an internationally validated calibrated tool (described below). Establish if the dwelling structures in the climate zone are of the same materials in the building envelope (walls, roof and floor) to previously modelled structures. If the model has not been calibrated for dwelling structures of the same materials, the model must be recalibrated or populated from the beginning. If this has not been calibrated, proceed to step 2 otherwise proceed to step 5.

#### Step 2:

Select a sample of 10 structures<sup>3</sup> randomly in the climate zone that the project is in and in similar class of housing or structure type (e.g. publicly subsidised, “Gap”, multiple-family hostels 2 and 3 story walk-ups (rental and privately owned) etc.<sup>4</sup>) with the same building envelope materials.

Inventorise the building specifications (i.e. building layouts, indoor floor areas and orientation, fabrics, fabric thickness, R-values) ( $I_{bs}$ ) that characterize dwelling structures of a similar class. Obtain local historical weather data from the closest meteorological station within the climate zone ( $I_m$ ).

#### Step 3:

Select dwelling structures with the same materials in the building envelope to monitor as the baseline study sample in the climatic zone of the project for the calibration of the predictive tool (if this has not already been undertaken by a previous project developer with dwelling structures with the same materials in the building envelope and same climate zone). Monitor internal heat loads (stoves, heaters etc.) through data logging and/or other fuel monitoring ( $I_{hi}$ ) including typical internal occupancy ( $I_o$ ) temperatures inside and outside the dwelling structure ( $I_t$ ), for a sustained period (at least the coldest months or the heating season) of the year, for each dwelling structure in the baseline sample.

#### Step 4:

Select an internationally recognised accurate or conservative predictive tool that can predict the energy required to heat a structure to a predetermined indoor temperature within a conservative range. Calibrate the predictive tool using data gathered in steps 2 and 3 to account for heat gains and losses that are not monitored (e.g. from air changes per hour between internal and external air). Calculate the active space heating required in the baseline scenario to reach the defined level of thermal comfort. The heat required per year per square metre of indoor heated space is the baseline heating energy intensity for the dwelling structures built with the same materials in the same climatic zone. (TJ or kWh/m<sup>2</sup>/climate house/year (See equation 1 below)).

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<sup>3</sup> The number of structures in the sample must be proven to be adequately representative by the PP.

<sup>4</sup> These are well-defined classes of housing categories of housing in South Africa. In other countries where mass public and low-income housing programmes are implemented, equivalent classes of structures will exist and can be characterised and used to replace the South African specific classes.

**Step 5:**

Multiply the baseline heating intensity per the square metre of the structure by the total heated measured (see step2) square meterage of the heated area in the structures in the project to reach the minimum/sufficiency service level (thermal comfort) to obtain total space heating requirement for the year. (In TJ or kWh/climate house/year see equation 1 below.)

**Step 6:**

Calculate emissions in the baseline for all dwelling structures in the project  $n$  using the energy required to reach minimum/sufficiency level of thermal comfort in the project activity. Subtract the project emissions from the baseline structures (corrected for indoor heated area, and operational heating systems) multiplied by the emissions factors of the fuel and efficiency of the appliance combinations  $j$  or  $elec$ .

**2) Determination of the Non-Sleeping Occupancy (Heating Interval)**

A key input parameters that needs to be determined is the Non-Sleeping Occupancy ( $I_{nso}$ ) of heating intervals when heating is required and people are not asleep in all or parts of the dwelling structures in cold periods which shall be determined using the procedure explained in Annex 1.

The non-sleeping occupancy prescribes the heating interval when thermal comfort is required and is used in the calculation of heat required to reach that service level. The period of non-sleeping interval is an input to the predictive tool for the calculation of space heating requirements.

**3) Determination of the thermal comfort level**

Another input that needs to be determined is the Thermal Comfort Level ( $I_{tc}$ ). This can be determined empirically or through the use of a default. The Empirical Thermal Comfort level is determined using the following monitored (hourly) data: the internal temperatures (in the heated space) and the electrical circuits (during initial monitoring in sample 1 where electricity is being utilised in the sample dwellings for energy monitoring simplicity<sup>5</sup>) providing energy to the space-heating appliance (for electrified space heating). The time and temperature when the electrical space-heating appliance is switched off indicates when the empirical thermal comfort has been achieved. (refer to annex 2 for empirical thermal comfort procedure.)

If the empirical temperature data falls below the thermal comfort bounds illustrated in the relevant bioclimatic chart, the lowest temperature level at 50% humidity for that climatic zone as defined by the bioclimatic chart can be used as a conservative estimation of minimum/sufficiency thermal comfort. This can also be used as a default

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<sup>5</sup> During the monitoring of the small sample of dwelling structures to gather data to calibrate the predictive tool, any space heating fuels can be used but electricity is the easiest to monitor through data loggers. So if there is structures are grid electrified, occupants can be encouraged to use electricity for space heating for the duration of the monitoring for the sake of simplicity and accuracy.

level of thermal comfort, excluding the requirement to identify thermal comfort empirically. However, if empirical thermal temperature is within the thermal comfort bounds, the empirical thermal comfort temperature is used for calculating heat loads and emissions in both baseline and project scenarios.

Once the Predictive Tool is recalibrated/calibrated using real data measured from the small sample of typical classes of dwelling units in a specific climate zone, it is then able predict the amount of heat energy  $HG_{BL,i,y}$  required in the heated area of the dwelling in structure to take it to thermal comfort during non-sleeping occupancy periods of the day for the year.

A register or library of the energy required to heat the structures to the desired level of thermal comfort for housing types and climate zones during the year is developed and updated each time the predictive tool is calibrated for each project, climate-house<sup>6</sup>, the predictive tool is run to establish heating requirements in the baseline and project activity scenarios to build a library of scenarios (see Table 2 below). The heat required (per square metre of heated space) can then be drawn on and utilised by other project participants using heating data per square metre for projects in dwelling structures of the same materials in the same climatic zone. Table 2 provides an example of the library of scenarios.

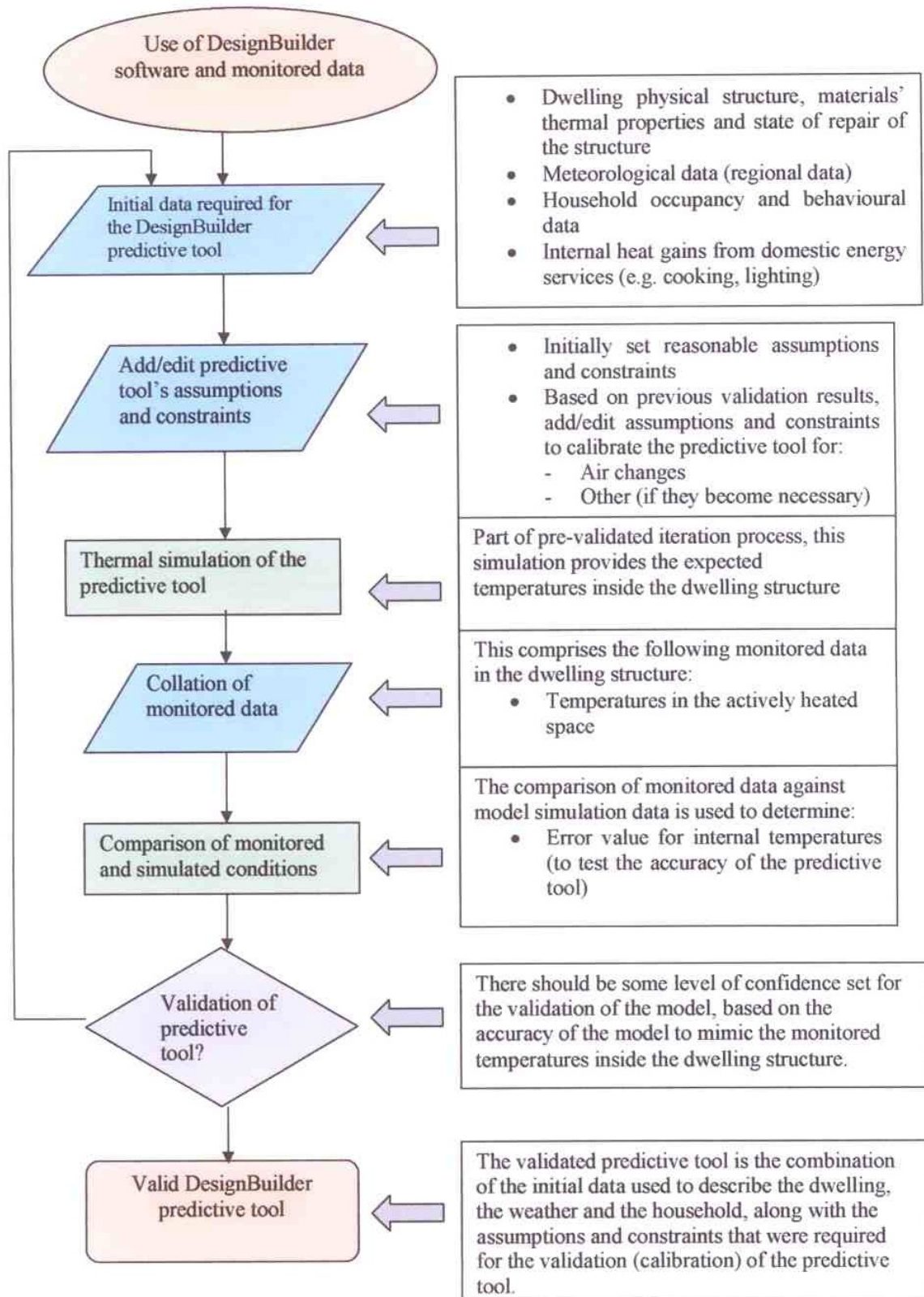
Table 2: Library of climate-house scenarios:

Climate Zone	Housing type	Housing elements (material and thickness)	$HG_{i,y} / A_i$ (TJ or kWh/m <sup>2</sup> /year) calculated using the predictive tool
1	Subsidy	Roof material, wall material, slab, ceiling, insulation, orientation etc	X TJ or kWh/m <sup>2</sup> /year
2	Gap		
3	Gap		
4	Subsidy		
Climate zone n			

The method for calibrating the predictive tool is described in the algorithm below and further elaborated in the Annex 3. The input to the predictive tool, numbers of structures in sample 1, the predictive tool chosen and the calibration of the tool must be checked by the

<sup>6</sup> Climate-house refers to each dwelling structure of the same materials in the same climate zone. The dwelling structures can in different projects.

validator. This will require the necessary expertise to evaluate selection and population of the calibrated tool.



Note: 1. The use of the DesignBuilder/EnergyPlus Predictive Tool in the method is just an example of predictive software and is not specifically implying exclusive use of this software<sup>7</sup>.

The calibrated Predictive Tool then defines the amount of space heating energy (as given in the internal heat gain schedules, which were derived from the monitored/surveyed energy consumption) required in the non-sleeping occupancy zones to reach the identified level of thermal comfort.

Baseline emissions are the emissions from the quantity and type of energy used for active space heating in baseline dwelling structures in the baseline scenario to reach a level of thermal comfort for non-sleeping occupancy periods of the day (Space Heating Intervals) and year.

Baseline emissions are calculated as follows:

$$BE_y = \sum_i BE_{i,y} = \sum_i \left[ n_i * HG_{BL,i,y} * A_i * \left( \sum_j EF_j CO_2 / \eta_j + EF_{elec} CO_2 / \eta_{elec} \right) \right] \quad (1)$$

Where:

$n_i$	=	the cumulative number of dwelling structures of different types, $i$ that have been built or retrofitted in the project area (see correction of $n_i$ below).
$BE_y$	=	the baseline emissions from active space heating using fossil fuels or electricity during the year $y$ in each climate-housing type $i$ (tCO <sub>2</sub> e).
$EF_j CO_2$	=	the CO <sub>2</sub> emission factor per unit of energy of the fuel/electricity $j$ that would have been used in the baseline in (tCO <sub>2</sub> /TJ). If more than one heating fuel and/or appliance is utilized on a daily basis during the heating season, the lower/lowest emissions factor of the fuel and appliance combination will be used.
$EF_{elec} CO_2$	=	the CO <sub>2</sub> emission factor per unit of energy of the electricity that would have been used in the baseline in (tCO <sub>2</sub> /TJ). Emissions from grid-connected electricity will be calculated using tool to calculate emissions factor from an electricity system (including transmission and distribution losses).
$\eta_j$	=	the efficiency of the each class of space heater appliance and fuel $j$ that would have been used in the absence of the project activity.
$\eta_{elec}$	=	the efficiency of the each class of electrical space heater that would have been used in the absence of the project activity.
$HG_{BL,i,y}$	=	the net quantity of heat supplied in the baseline for each of the classes of

<sup>7</sup> The project design document using this methodology must provide references to independent review of the software that verifies that it predicts the energy requirements for structures with sufficient accuracy. The DOE must ensure the inputs to the tool are accurate and based on the correct empirical and other data.

		dwelling structure <i>i</i> to reach a predetermined level of thermal comfort level during the year <i>y</i> in TJ per square metre of indoor heated space. The quantity of energy is calculated using an internationally recognized predictive tool.
$A_i$	=	the heated square metres of indoor space in each climate-housing type <i>i</i>

The number of structures for which emissions reductions can be claimed is:

$$\sum_i n_i * (1 - d_i) \quad (2)$$

Where:

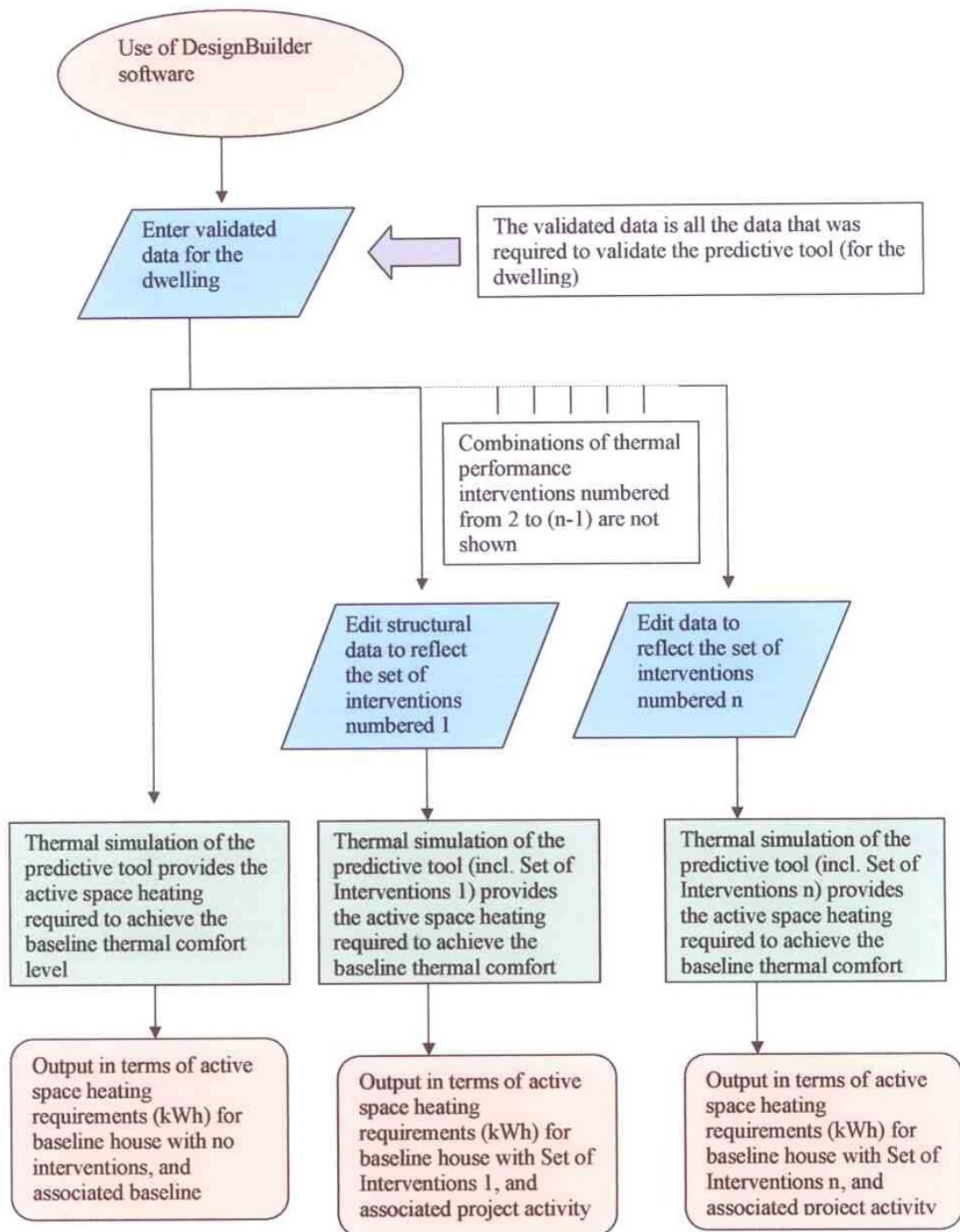
$d_i$	=	the monitored fraction of inadequate dwelling units of different classes <i>i</i> in a sample of project. Dwellings shall be considered inadequate for inclusion under this project activity if at least one of the following applies: (i) the dwellings no longer have the thermal performance interventions in place, and/or (ii) the dwellings are not used (inhabitants have vacated structure during inspection)
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### Calculation of Project Emissions

The project emissions are calculated using the same calibrated predictive tool used in the baseline calculation with the same external parameters but recalibrated including the project thermal performance improvements. The inputs to the predictive tool provide the heating requirements  $HG_{PA,i,y}$  that are required to take the project structures to the same level of thermal comfort as in the baseline scenario during the period of non-sleeping occupancy in the entire or identified heated areas in the dwelling structures. If more than one heating fuel and/or appliance is utilized on a daily basis during the heating season, the lower/lowest emissions factor of the fuel and appliance combination will be used.

To calculate the emissions from the project dwelling structures of each type *i* for the project circumstances in year *y* the active space heating energy is multiplied by the emissions factor for the space heating fuel and appliance combination.

Each of the projects and project interventions 1 to *n* are recorded and fed into the predictive tool to calculate the space heating energy. The algorithm below explains the process of calculating and cataloguing space heating requirements on a project-by-project basis.



Notes:

1. The use of the DesignBuild tool in the method is just an example of predictive software and is not specifically implying exclusive use of this software.
2. The sets of thermal performance interventions numbered 1 to n are made up by various permutations of k discrete interventions (where  $k < n$ ) into the baseline buildings' structure. (We can arbitrarily assume that the n-th set of interventions is defined by the incorporation of all k discrete interventions.)



All project interventions must be catalogued by the project participant (see below). Categories to be used to catalogue project interventions. Combinations of interventions 1 to k may include one or more of the following:

- Orientation towards the source of solar radiation;
- The fabric of the structure;
- Insulation materials in walls, ceiling/roof and under the base slab;
- Finishes (plastering and paint);
- Apertures and their screening; and
- Vertical and horizontal attachments of structures.

All project interventions and their relevant specifications must be catalogued by the project participant.

Table 3 is an example of a summary table of all installations in the project and includes the following data:

Table 3: Complete list of interventions in each house in the project or programme

<b>Erf number/GPS co-ordinates</b>	<b>Number using of occupants</b>	<b>Interventions<sup>8</sup> 1 to k</b>	<b>Heated indoor space m<sup>2</sup></b>	<b>Climatic Zone</b>	<b>Space Heating/square metre/year HG<sub>i,y</sub>/A<sub>i</sub> (TJ or kWh/m<sup>2</sup>/year)</b>
1. Erf 27910, Kuyasa, Cape Town	4	1, 4, 7, 8	30	1	X
2. Erf 27911, Kuyasa, Cape Town	5	1, 4, 7, 8	30	1	Y
...					
n. Erf 5119, Kuyasa Cape Town	2	1, 4, 6, 9	35	1	Z
Etc.					

Project emissions are the emissions from energy used for active space heating in households in the project to reach a level of thermal comfort for certain periods of the day and year.

Project emissions are calculated as follows

$$PE_y = \sum_i PE_{i,y} = \sum_i \left[ n_i * HG_{PA,i,y} * A_i * \left( \sum_j EF_j CO_2 / \eta_j + EF_{elec} CO_2 / \eta_{elec} \right) \right] \quad (3)$$

Where:

<sup>8</sup> Numbers refer to specific interventions including materials specifications.

$n_i$	=	the cumulative number of dwelling structures of different types, $i$ that have been built or retrofitted in the project area (see correction of $n_i$ below).
$PE_{i,y}$	=	the project emissions from active space heating using fossil fuels and electricity for each dwelling type $i$ during the year $y$ in $tCO_2e$ .
$EF_jCO_2$	=	the $CO_2$ emission factor per unit of energy of the fuel $j$ that are used in the baseline in ( $tCO_2/TJ$ ). Emissions from grid-connected electricity will be calculated using tool to calculate emissions factor from an electricity system. If more than one heating fuel and/or appliance is utilized on a daily basis during the heating season, the lower/lowest emissions factor of the fuel and appliance combination will be used.
$EF_{elec}CO_2$		the $CO_2$ emission factor per unit of electricity used in the baseline in ( $tCO_2/TJ$ ). Emissions from grid-connected electricity will be calculated using tool to calculate emissions factor from an electricity system.
$\eta_j$	=	the efficiency of the each class of space heater appliance and fuel combination $j$ that would have been used in the project activity. In most instances the efficiency will be 100% or 1 for delivered energy to indoor heating
$\eta_{elec}$	=	the efficiency of the each class of electrical space heater that would have been used in the project activity. In most instances the efficiency will be 100% or 1 for delivered energy to indoor heating
$HG_{PA,i,y}$	=	the net quantity of heat supplied in the project for each of the classes of dwelling structure $i$ to reach a predetermined level of thermal comfort level during the year $y$ in TJ per square metre of indoor heated space. The quantity of energy is calculated using an internationally recognized predictive tool, which provides a cumulative impact of any number of discrete interventions 1 to $k$ from a menu that may be deployed by housing developers
$A_i$	=	the cumulative square metres of indoor space in each housing type $i$

The number of systems for which emissions reductions can be claimed is

$$\sum_i n_i * (1 - d_i) \quad (4)$$

Where:

Parameter	Description
$d_i$	the monitored fraction of inadequate dwelling units of different classes $i$ in a sample of project . Dwellings shall be considered inadequate for inclusion under this project activity if at least one of the following applies: (i) the dwellings no longer have the thermal performance interventions in place; and/or (ii) the dwellings are not used (inhabitants have vacated structure during inspection).

## Leakage

No leakage is expected.

## Emission Reductions

Emission reductions are calculated as follows:

$$ER_y = BE_y - PE_y - LE_y \quad (5)$$

Where:

$ER_y$  = Emission reductions in year  $y$  (t CO<sub>2</sub>e/yr)

$BE_y$  = Baseline emissions in year  $y$  (t CO<sub>2</sub>e/yr)

$PE_y$  = Project emissions in year  $y$  (t CO<sub>2</sub>/yr)

$LE_y$  = Leakage emissions in year  $y$  (t CO<sub>2</sub>/yr)

## VII. Monitoring

In addition to the parameters listed in the tables below, the provisions on data and parameters not monitored in the tools referred to in this methodology apply.

The data and parameters not monitored but available prior to validation are relevant regulated building standards (enforced or not), household livelihoods indicators, emissions factors of heating fuels/electricity, and discount rates experienced by households/housing developers.

Parameters “I” that are used to populate and calibrate the predictive tool to calculate the space heating energy required to take the baseline and project structures to a predetermined level of thermal comfort (temperature) are monitored and available before validation. However, these monitored parameters or inventorised dwelling structure elements are included in the data and parameters monitored section.

The predetermined temperature conservatively estimated, will be used to determine space heating energy requirements. The level of thermal comfort and non-sleeping occupancy will be established through observations of indoor temperature, energy loads and real clock time prior to the commencement of the project and are used to recalibrate the predictive tool when this is required.

<b>Data / parameter:</b>	Building standards
Data unit:	-
Description:	The local (city), provincial/state, or National Building standards that are published applicable and enforced (or not) to domestic structures within the project boundary.
Source of data:	Promulgated standards that are aligned to a compliance regime.
Measurement procedures (if any):	
Any comment:	The minimum building standards if attached to a compliance regime are critical in identifying the baseline scenario with respect to E+ and E- applications.

<b>Data / parameter:</b>	$EF_fCO_2$
Data unit:	Tonnes $CO_2$ /TJ
Description:	The emissions factor of fuels used in the baseline.
Source of data:	IPCC, national data or international data.
Measurement procedures (if any):	-
Any comment:	-

<b>Data / parameter:</b>	$EF_{elec}CO_2$
Data unit:	Tonnes $CO_2$ /TJ
Description:	The emissions factor of electricity used in the baseline
Source of data:	Emissions factors for electricity will be calculated using the most recent version of the tool designed for this purpose.
Measurement procedures (if any):	-
Any comment:	-

<b>Data / parameter:</b>	Livelihoods trends
Data unit:	Positive or negative
Description:	A measure of livelihoods trends is required for households in project area to qualify for the application of the methodology.
Source of data:	Real income, living standards measures, or other relevant indicator
Measurement procedures (if any):	Income surveys, secondary data.
Any comment:	The livelihoods requirement is necessary to assess whether thermal comfort will be attained or not at some stage in the future. The reason that this is important is to ensure that lock-in to dirty technologies does not happen by applying the methodology and giving through it giving credit for a reducing suppressed demand for service that will be satisfied. Livelihoods improvements are an applicability criterion for the application of suppressed demand typology 3.

<b>Data / parameter:</b>	dr
Data unit:	%
Description:	The discount rate experienced by housing developers and poor households.
Source of data:	Local or National Commercial banks and local micro-lenders in the area of the project
Measurement procedures (if any):	-
Any comment:	These discount rates are used in the calculation of investment indicators such as IRRs in the identification of the baseline scenario and appraisal of additionality.

<b>Data / parameter:</b>	$I_{bs}$
<b>Data unit:</b>	Metres, $m^2$ , watts/ $m^{\circ}K$
<b>Description:</b>	Standard fabric and design characteristics of baseline dwelling structures for calibration monitoring and baseline identification of class <i>i</i> (building elements include floors, walls, ceiling, roof, doors, windows, curtains and major window obstructions) and orientation and square meterage of heated zones within the structure. Specifications of materials area, thickness, thermal conductivity, and other characteristics relevant to their thermal performance in structures.
<b>Source of data:</b>	Standardisation bodies, building specifications/plans/layouts, direct measurements, and internationally recognised sources of specifications.
<b>Measurement procedures (if any):</b>	The fabric and the dimensions of the fabrics the orientation of the building can be taken from building plans and housing layouts. These should be verified during the monitoring stage in sample 1 (in retrofit) or 2 (in either retrofit or newly built).
<b>Monitoring frequency:</b>	At the commencement of the project.
<b>QA/QC procedures:</b>	Sample confirmed during verification.
<b>Any comment:</b>	These are static parameters and refer to dwelling building specifications (bs). This is data required to calibrate the predictive tool to calculate active energy required to warm the dwelling structure to the predetermined temperature. Used in the calibration of the predictive tool at the commencement of the project and the commencement of subsequent crediting periods.

<b>Data unit:</b>	$I_{ac}$
<b>Description:</b>	Air changes/hour is the number of times in the hour the volume of the heated space is replaced. This affects the thermal temperature in the building by gaining thermal energy from the outside air if it is warmer outside than inside, or by losing thermal energy from inside if outside is colder than inside.
<b>Source of data:</b>	Deduced during calibration process.
<b>Measurement procedures (if any):</b>	Not monitored
<b>Monitoring frequency:</b>	
<b>QA/QC procedures:</b>	-
<b>Any comment:</b>	This parameter cannot be accurately measured, therefore it is used as a final calibration parameter to “squeeze” the calibrated tool into fitting the monitored data. Used in the calibration of the predictive tool.

<b>Data / parameter:</b>	$A_i$
Data unit:	Square metres $m^2$
Description:	The indoor space that is warmed using space heating appliances during cold periods for each class of structures within the project boundary.
Source of data:	From uniform simple developments (one room) from building plans. For irregular sized buildings in a development or simple buildings with additions either from building plans, or direct measurement or every structure. Interviews with occupants can determine space heating behaviour with respect to the heated space within the structure.
Measurement procedures (if any):	Building plans' specifications and/or using tape measures.
Monitoring frequency:	At the commencement of the project .
QA/QC procedures:	Sample confirmed during verification.
Any comment:	This parameter is only measured in multi-roomed structures is the heated area differs from the total area of the structure. For a single roomed house this is a matter of simply measuring dimensions of the heated space. For open plan multi-roomed structures ("gap") the concept of heated communal area (referred to as "lounge" is utilised). This is defined as an input to the simulation/predictive model and given a unique volume.

<b>Data / parameter:</b>	$I_o$
Data unit:	Number of persons in dwelling structure
Description:	Occupancy of structure. The number of persons occupying the structure overnight during the winter period. Occupants add to the heat load.
Source of data:	Interview with household
Measurement procedures (if any):	
Monitoring frequency:	At the commencement of the project in sample 1.
QA/QC procedures:	Spots check by PP when installing data loggers.
Any comment:	It is likely that in many communities that the overnight occupancy will be dynamic. Spot check at the commencement of monitoring of sample. Occupancy data is used in the calibration of the predictive tool as an additional heat load.

<b>Data / parameter:</b>	$I_{hl}$
Data unit:	TJ/year
Description:	Heat load that results in space heating within dwelling structure. Energy used and that results in space heating in structure. This will include cooking, passive heat gains, space heating and so on.
Source of data:	Data loggers
Measurement procedures (if any):	Electricity or other space heating fuel consumption.
Monitoring frequency:	Monitored at 30-minute intervals (or as specified by predictive tools). Energy usage demand is averaged and accumulated over the year. Or monitored/recorded cumulatively during the year when space heating is required. If non-electrical fuels are used for thermal loads inside the structure solid, liquid or gaseous fuel quantities that result in space heating inside the structure must be recorded continuously.
QA/QC procedures:	Data loggers are recalibrated at the commencement of new sample measurements. Data that show that there is temperature rises (at night) without electrical demand implies fuels other than electricity are being used for space heating. These data is considered contaminated and are then discarded. During the monitoring period households in the sample 1 are requested (or pre-paid) to use electricity only for space heating if they are not already doing so. Data loggers must be calibrated located according to the specifications of the predictive tools.
Any comment:	These data is required for the calibration of the predictive tool

<b>Data / parameter:</b>	$I_i$
Data unit:	Numbers, materials, orientation, dimensions
Description:	The thermal performance interventions introduced by the project.
Source of data:	Project participant log of interventions 1 to k. Recorded in tables 2 and 3 in the methodology.
Measurement procedures (if any):	-
Monitoring frequency:	Monitored to be in place when sample 2 is monitored each year or prior to verification (one month either side of the winter solstice).
QA/QC procedures:	The thermal performance interventions will be checked to be in place when sample two is monitored.
Any comment:	The projects and the menu of thermal performance intervention options included in each project are recorded by the project developer in the tables 1 and 2 provided as examples in the methodology.



<b>Data / parameter:</b>	$I_t$
Data unit:	°C
Description:	Indoor and Outdoor/External (dry-bulb) temperatures. Temperatures taken inside and outside of the house, and shielded from direct sunlight/rain/wind monitored at defined frequency over time.
Source of data:	Monitored temperatures from data loggers.
Measurement procedures (if any):	Temperature profiles are recorded continuously throughout the monitoring period of sample 1.
Monitoring frequency:	Measurement is on a 30 to 60 minute frequency in sample 1.
QA/QC procedures:	Verification of the placement and accuracy of the temperature probes and the accuracy of their recording
Any comment:	Temperature measurements required for the calibration of the predictive tool.

<b>Data / parameter:</b>	$I_m$
Data unit:	$W/m^2$ , $W/m^2$ , m/s, ° (bearing), °C, %, kPa, %
Description:	Meteorological data that influence the thermal performance of the structure. Climate data (including direct solar radiation, diffuse horizontal solar radiation, wind speed and direction, dew-point temperature, relative humidity, barometric pressure, and total and opaque sky cover).
Source of data:	Meteonorm software database values, measured or interpolated, for the project boundary.
Measurement procedures (if any):	Typical meteorological procedures. The data from the closest meteorological station to the project within the same climate zone.
Monitoring frequency:	Climate data can be downloaded from meteonorm as frequently as required.
QA/QC procedures:	Verification of the climate data available at Neteonorm by verifiers.
Any comment:	This is data required to calibrate the predictive tool to calculate energy required to warm the dwelling structure to the predetermined temperature.

<b>Data / parameter:</b>	$I_{nso}$
Data unit:	Real clock time and amperage.
Description:	Non-sleeping occupancy. The periods of time over a 24 hour period when heating is required. Conservatively this is a period of 2 to 3 hours in the morning and 4 to 5 in the evening (see annex 1).
Source of data:	The period is approximated by monitoring the electrical circuitry to check the cumulative frequency when heating, lighting and/or other appliances are turned “on” and “off”. The data is from sample 1.
Measurement procedures (if any):	Empirical non-sleeping occupancy is the period is established by monitoring the frequencies of “switch on” and “switch off” events throughout the day (weekdays only) and plotting these. The median of frequency peaks of the observations become the inner and outer bounds of the of the non-sleeping occupancy periods of the day. An empirical sub-method to establish the non-sleeping occupancy is included below (see Annex 1).
Monitoring frequency:	30 to 60 minute intervals continuously as per data logger settings.
QA/QC procedures:	Check data loggers are accurately calibrated for time and amperage.
Any comment:	The heating period is estimated using the periods in the sample 1 and using weekday data. Detail of the sub-meth is given in Annex 1. These data are used in the calibration of the predictive tool.

<b>Data / parameter:</b>	$I_{tc}$
Data unit:	°C
Description:	Empirical level of thermal comfort, as indicated by the temperature in the actively heated space.
Source of data:	Indoor temperature monitoring when “off” incidences occur.
Measurement procedures (if any):	Continuous monitoring of temperature and heating loads during the cold period in sample 1. If electricity is being used, the temperature at which a drop of 2Amps is recorded in the electricity load.
Monitoring frequency:	During the monitoring of sample 1, indoor temperature and heating loads are monitored at 30 to 60 minute intervals.
QA/QC procedures:	Check data loggers are accurately calibrated.
Any comment:	The tool requires a temperature around which to predict the heat required in the baseline and project to reach a level of comfort. It could be in a range depending upon the climate zone. As a default minimum/sufficiency service level the minimum temperature of the bioclimatic chart at 50% humidity for the climate zone can be utilised.

<b>Data / parameter:</b>	Currency
Data unit:	US\$
Description:	The price of the thermal performance interventions introduced by the project and the price of space heating fuels (in baseline and project).
Source of data:	Suppliers and installers of thermal performance interventions 1 to k. Recorded by the project participant in tables 2 and 3 in the methodology.
Measurement procedures (if any):	-
Any comment:	The projects and the menu of thermal performance intervention options included in each project are recorded by the project developer in the tables 2 and 3 provided as examples in the methodology. The price of fuels (in the baseline and project) and thermal performance interventions (in the project) are required to appraise additionality.

All data collected as part of monitoring should be archived electronically and be kept at least for 2 years after the end of the last crediting period. 100% of the data should be monitored if not indicated otherwise in the tables below. All measurements should be conducted with calibrated measurement equipment according to relevant industry standards.

In addition, the monitoring provisions in the tools referred to in this methodology apply.

The project proponent shall record each class of structure in the project activity.

The project proponent shall record indoor square meterage of all dwelling structures in the project activity by direct measurement or plans/layouts and all project activity thermal performance improvements in for each class of structure in the project activity at the commencement of projects. Extension of dwelling structures during the project's crediting period may increase the space heating requirements during the project. For the sake of conservatism the space heating requirements calculated at the commencement of the project will not be increased to accommodate dwelling structure extensions.

If no data exists for the class and climate zone of the dwelling structures, a small sample of the dwelling structures will be selected to provide detailed thermal performance data that will be used to calibrate a predictive tool to assess the energy required to reach thermal comfort in the dwelling structures. The sample can be small as it is about how the class of structure within the climate zone performs as a thermal envelope, which are similar (although while materials and dimensions may be similar variations in orientation, aperture placements and square meterage may exist) or identical by applicability definitions. The drawing of this sample shall be random and follow the relevant standards in the GS and/or CDM (ref: Sampling and surveys for CDM project activities and programme of activities. CDM-EB50, A30-STAN).

A second sample of all structures will be drawn that provides a 90% (small-scale application of the methodology) and 95% (large scale application of the methodology) confidence in the representivity of the sample to the entire project/programme for all thermal performance improvement technologies. Again the in the drawing of this sample the “Sampling and surveys for CDM project activities and programme of activities.” applies.

### **Monitoring methodological steps:**

Monitoring is required prior to validation of the project to calibrate predictive software model. After project implementation, monitoring is then required to assess whether the interventions are in place and the structure is occupied.

#### **Step 1:**

Establish the building standards that apply to the structures in the area of the project.

#### **Step 2:**

Establish the common practice thermal performance technologies applied to structures in project area and catalogue these.

#### **Step 3:**

Establish the emissions factors for common practice fuels for space heating. If electricity is used, the tool to calculate emissions factor from an electricity system must be applied to get an emissions factor. For all others, national or IPCC default figures can be used.

#### **Step 4:**

All classes of dwelling structures and indoor heated square meterage within the project boundaries must be catalogued for each class of structure  $i$  in each climate zone.

#### **Step 5:**

Non-sleeping occupancy and thermal comfort is determined. These sub-methods (see methodology above) and the monitoring required to establish them are described in detail below (see annex 3).

#### **Step 6:**

The heat that each class of structure requires to reach thermal comfort can be established via monitoring and populating an internationally recognized predictive tool for the purposes of calibration. There are several inputs ( $I$ ) to the predictive tool (described in detail in section 2 to Annex 3) that are required and these are grouped into:

- $I_{bs}$  static building structure parameters);
- $I_t$ : temperatures inside and outside the dwelling structure;
- $I_{hl}$ : heat loads within the dwelling structure;
- $I_m$ : meteorological data;
- $I_{tc}$ : data required to locate thermal comfort levels;
- $I_i$ : thermal performance interventions in the project activity;
- $I_o$ : occupancy levels within the structure;

- $I_{\text{NSO}}$ : data required to identify non-sleeping occupancy when heating is required on a diurnal basis; and
- $I_{\text{AC}}$ : information required to determine the number of air changes per hour.

Data loggers are installed on a small sample (sample 1) of the occupied structures that represent either the baseline or project conditions. The characteristics of the structures will be used to populate the predictive tool to calculate the changes in thermal performance of the structure. The loggers will record the indoor and outdoor temperatures on a continuous basis over the winter months at a frequency of one sample every 30 minutes. The heat gains from solar energy, occupancy and other internal heat sources (from thermal services within the structure) will be used to further populate the predictive tool to ensure that it predicts the indoor temperature with accuracy. Throughout conservative assumptions and predictions will be used.

#### Step 7:

At the commencement of each annual monitoring cycle a new representative sample (sample 2) of the structures within the project boundary defined by equivalent class 1 to k of the installed thermal performance interventions are monitored to check whether they are in place and the structure is occupied. If thermal performance interventions are not in place or the structure is not occupied, the total emissions reductions to be claimed will be reduced in proportion to the number of systems “not operational”  $d_i$  in the sample. The same sample will monitor which fuels and appliances are used for active space heating.

The energy required to warm structures to thermal comfort in each class of dwelling structure in the sample will be extrapolated from the sample to all occupied structures in the project area in which the thermal performance technologies are in place.

#### Step 8:

The project participant shall develop a monitoring plan, appoint and ensure the training of those tasked with the implementation of the plan. In domestic applications, this task will have to be undertaken by a municipality or newly appointed individual/facility. Data collected during monitoring and the calibrated predictive tool will be archived for up to 2 years after the end of the crediting period.

Internationally recognised QC/QA systems, and test procedures should be applied to the application, use, calibration and servicing of the data loggers where required.

### **Sampling**

Two samples are drawn for project making use of this methodology.

1. The first (sample 1) is to calibrate the predictive model that determines the amount of energy required to warm the interior of the structure to a desired level of

thermal comfort. This small sample of 10 occupied dwellings<sup>9</sup> of differing orientations is drawn within a single class of housing (same materials) in a specified climatic zone (same climate zone) and is used in the calculation of the thermal performance of the dwelling structure envelope pre- or post-project implementation. This sample is monitored for a period of four months or more during a season when space heating is required. The condition for the selection of the sample is that the energy that provides thermal energy to warm the structure can be recorded during that period using data loggers and/or manual recordings (of fuel used that results in the internal thermal load if this is not electricity.) Sample 1 is small as all structures in this sample are constructed of the same structure envelope fabrics and is not subject to sampling rules requiring representivity. The size of this sample will be supported by expert opinion supplied by the project participant and checked during validation.

2. The second (sample 2) is to ensure the thermal improvement measures are in place, the structure is occupied and to record the space heating fuel and appliance in use. The sample is also used to record occupancy and fuel and appliance mixes at the commencement of the project and subsequent crediting periods. This requires the selection of a representative sample within each class of structure in the project area that provides a 90% (small scale) or 95% (large scale) confidence level. The sample is drawn at the commencement of the project and is reselected at the commencement of subsequent crediting periods. The sample may have to be augmented should the number of structures within the project boundary be increasing (as is possible in the case of new build dwelling structures) during the crediting period. These dwelling structures are visited for monitoring once a year one month either side of the winter solstice for the duration of the project.

The drawing of the second sample is guided by the Standard for Sampling and Surveys for CDM projects and programmes of activities (EB65 annex 2).

All data collected as part of monitoring should be archived electronically and be kept at least for 2 years after the end of the last crediting period. 100% of the data should be monitored if not indicated otherwise in the tables below. All measurements should be conducted with calibrated measurement equipment according to relevant industry standards.

In addition, the monitoring provisions in the tools referred to in this methodology apply.

### **Data and parameters monitored**

The following data parameters are monitored to calibrate the predictive model and in asserting that the technologies that improve the thermal performance of the structures is working and being used.

---

<sup>9</sup> The number of structures in this sample will need to be relevant as described above. This will be subject to validation.

<b>Data / parameter:</b>	$n_i$
Data unit:	Cumulative number
Description:	Cumulative number of dwelling structures that have installed one or more thermal performance upgrades 1 to k. The number applies to structures in climate zones of class <i>i</i>
Source of data:	Initial inventory of upgrades included in dwelling units registered by project participant and checked at verification.
Measurement procedures (if any):	A catalogue (see tables 2 and 3) of the dwelling units in which thermal upgrades have been completed will be recorded and maintained by the project participant. The catalogue will include address, the list of interventions, number of inhabitants in the household and the date of commissioning. The orientation and size of the structure will be measured and recorded for each class of structure. Where this is irregular, each structure will be measured separately.
Monitoring frequency:	This is cumulative during the duration of the project implementation.
QA/QC procedures:	These figures can be corroborated using the structure developers' records and by direct examination of a sample of structures during verification.
Any comment:	

<b>Data / parameter:</b>	$A_i$
Data unit:	Square metres $m^2$
Description:	The indoor space that is warmed using space heating appliances during cold periods for each class of structures within the project boundary.
Source of data:	From uniform simple developments (one room) from building plans. For irregular sized buildings in a development or simple buildings with additions either from building plans, or direct measurement or every structure. Interviews with occupants can determine space heating behaviour with respect to the heated space within the structure.
Measurement procedures (if any):	Building plans' specifications and/or using tape measures.
Monitoring frequency:	At the commencement of the project.
QA/QC procedures:	Sample confirmed during verification.
Any comment:	This parameter is only measured in multi-roomed structures is the heated area differs from the total area of the structure. For a single roomed house this is a matter of simply measuring dimensions of the heated space. For open plan multi-roomed structures ("gap") the concept of heated communal area (referred to as "lounge" is utilised). This is defined as an input to the simulation/predictive model and given a unique volume.

<b>Data / parameter:</b>	j or elec
<b>Data unit:</b>	Space heating appliances and fuels/electricity
<b>Description:</b>	This parameter is required to determine the household's availability of space heating energy services. It is used together with "energy service demand profiles" (Data/parameter) to determine how the internal heat gains are generated and what are the fuels and appliances that are used to achieve these contributions to space heating in the baseline and project. If more than one heating fuel and/or appliance is utilized on a daily basis during the heating season, the lower/lowest emissions factor of the fuel and appliance combination will be used.
<b>Source of data:</b>	Survey of household fuel and appliances in during the monitoring of sample 2.
<b>Measurement procedures (if any):</b>	-
<b>Monitoring frequency:</b>	At the commencement of the project and updated in sample 2.
<b>QA/QC procedures:</b>	At verification of the accuracy (sample 2) of households of the range of space heating appliances and fuels/electricity.
<b>Any comment:</b>	Used in the calibration of the predictive tool for determining energy and hence emissions in the baseline and project.



<b>Data / parameter:</b>	$\eta_j$
Data unit:	% or fraction
Description:	Efficiency of providing heat from the fuel and appliance combination. The ratio is between useful energy (heat that contributes to space heating) divided by the delivered energy to the structure. The efficiency of the fuel appliance combination is used in both baseline and project emissions calculations. In the baseline default efficiencies can be applied where these are published in CDM methodologies or universal 100% efficiency can be applied unless there is a chimney for venting smoke (and heat).
Source of data:	During the monitoring of sample 2, the heating fuel and appliances are recorded. The likely combinations electricity, kerosene, LPG, coal, and/or biomass and corresponding space heating appliances.
Measurement procedures (if any):	Peer reviewed, specified and/or other published efficiencies using the highest levels for the baseline and lowest for the project activity.
Monitoring frequency:	-
QA/QC procedures:	Check data sources
Any comment:	Take into account the transmission/transportation losses from primary to delivered energy, where appropriate. These can be ignored on the basis of conservatism if project participant so decides. The efficiency can be assumed to be 100% unless the dwelling structure has a chimney/flue.

<b>Data / parameter:</b>	$d_i$
Data unit:	% or fraction
Description:	The monitored fraction of dwelling units of different types and sizes in a sample of project dwellings (sample 2) that no longer have the thermal performance interventions in place or the structure is not occupied.
Source of data:	Monitoring of project dwelling structures in sample 2. The number of dwelling structures in the sample in which the thermal performance technologies are not in place is divided by the total sample size to provide the fraction $d_i$ .
Measurement procedures (if any):	Checking
Monitoring frequency:	Annually.
QA/QC procedures:	Spot check during verification of a number of randomly selected dwelling structures recorded by project participant as having been monitored prior to or during validation.
Any comment:	Used to correct the number of structures $n_i$ for which emissions can be claimed

## Annex 1: Non-sleeping occupancy heating periods

### Definition:

The typical periods of time, during the day, in which there is a non-sleeping occupancy in the house, and which is determined from the monitored data by providing evidence of space heating.

### Steps for determination of non-sleeping occupancy heating periods:

1. Collect monitored hourly data for house temperatures  $T_{in}$  and  $T_{out}$ , and current CT over the winter period. Use only weekday data.

### Notes:

The example to be used is monitored data from May to September, taken in GAP houses in Kuyasa.

2. Plot the frequency of occurrences of heating appliances being turned on, for each climate-house-month<sup>10</sup>.

### Notes:

See the next item for occurrences of heating appliances being turned on.

3. Plot the frequency of occurrences of heating appliances being turned off, for each climate-house-month.

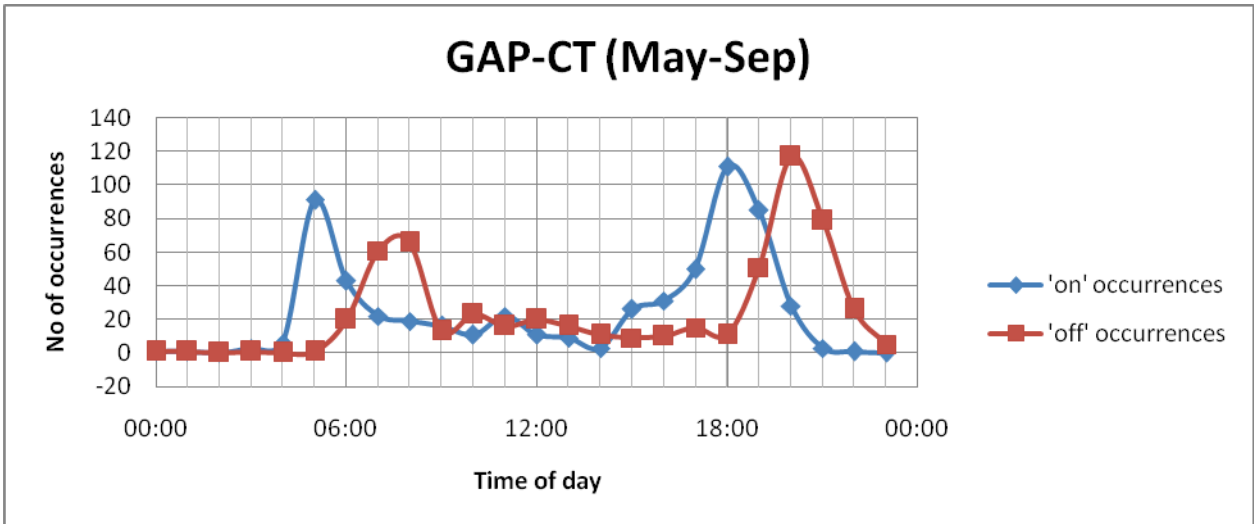
### Notes:

The occurrences of heating appliances being turned on and off are identified by a change in the average hourly electrical current demanded by the houses as changing by more than 2Amps. This could identify the use of a 1200W heater, or appliance of equivalent wattage, being on for 22 minutes before being turned off. This is also large enough to avoid mistakenly identifying a 60W light bulb being switched on ( $\max=0.27A$ ).

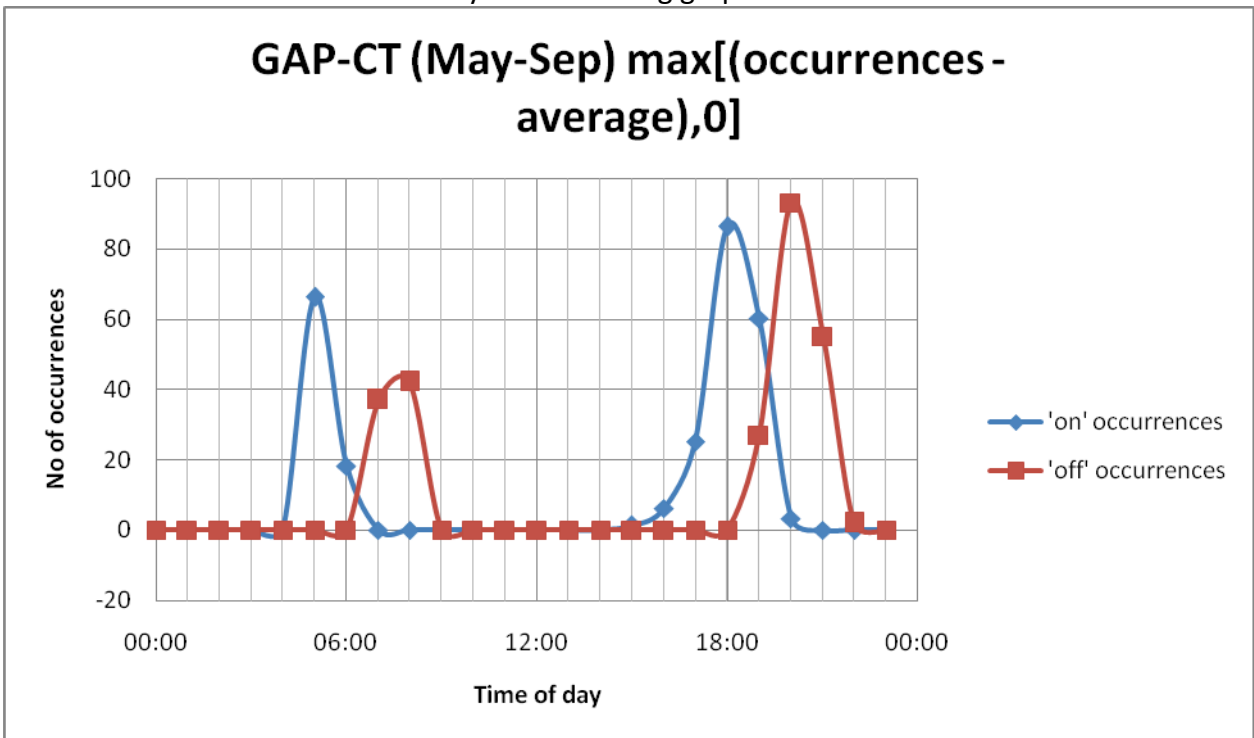
Initial results for Kuyasa “GAP” (months May to September) gives:

---

<sup>10</sup> Climate-house-month refers to data aggregated for a particular house type that shares particular climate zone, for a particular month



There is a lot of noise resulting from smaller peaks of 'on' and 'off' occurrences, and this can be removed by only considering the peaks that are larger than the average 'on' and 'off' occurrences for each hour of the day. The following graph results:



4. Consider the heating periods for each climate-house-month as the time periods between when heating appliances are typically turned on and off, so that the heating periods are the smallest periods that include 95% of these typical occurrences.

Notes:

The smallest heating periods that include 95% of the occurrences (in the graph above) are a heating period of 5am to 8am in the morning, and 5pm to 9pm in the evening.

## Annex 2: Empirical determination of thermal comfort levels

### Definition:

The Empirical Thermal Comfort level is determined from monitored data as the temperatures at which the house is typically kept in the space heated zone during the winter months of the year.

The Empirical Thermal Comfort level is determined from monitored data as the temperatures at which the house is typically kept in the space heated zone during the winter months of the year. The frequency of observations of temperatures at which heating appliances are turned off are bounded by the definitional temperatures that describe thermal comfort in the Bioclimatic Chart above. In this methodology the empirical thermal comfort level lies at the median of the temperature observations when heating appliances are turned off.

### Steps for the determination of empirical thermal comfort levels:

1. Use the data sets of occurrences of heating appliances being turned off in the heating periods (as determined above), but aggregated for winter months for each climate-house<sup>11</sup>.

### Notes:

To complete this step, the non-sleeping heating periods have been assumed to be from 5am until 8am, and from 6pm until 8pm.

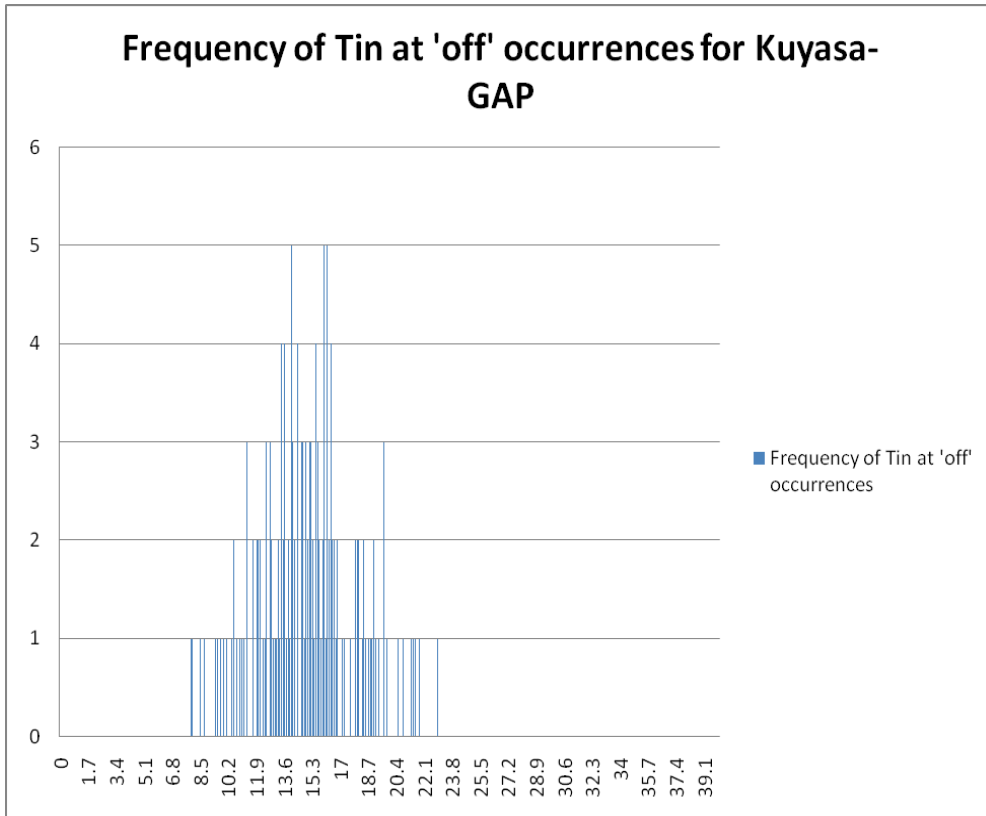
2. Plot the frequency of indoor temperatures  $T_{in}$  at which heating appliances are turned off.

### Notes:

Using these heating periods we get the following frequency distribution of  $T_{in}$ :

---

<sup>11</sup> Climate-house refers to a particular house type that shares particular climate zone



- 3: Using the bioclimatic chart bounds for thermal comfort bound the data within the temperature constraints.
- 4: Take the median of the temperature frequencies within the bound to be the empirical level of thermal comfort

### **Annex 3: Method for a thermal performance Predictive Tool**

#### **Use of EnergyPlus to model simple naturally ventilated buildings**

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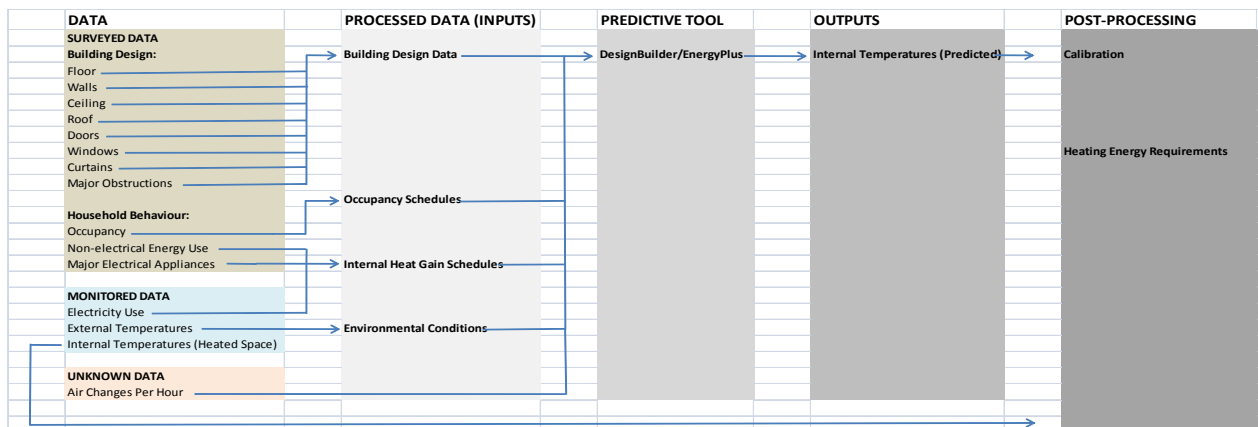


## 1. Introduction

This document is a compilation of detailed aspects of a method that has been developed for using the DesignBuilder/EnergyPlus ‘thermal performance’ simulation software as a Predictive Tool that can:

- a) Accurately describe the most significant thermal interactions that are likely to impact upon thermal comfort levels within a simple, naturally ventilated building, given adequate input parameters, and
- b) Can estimate the energy required to heat particular zones within the building to specified levels.

The figure below illustrates the flow of information that constitutes this method, and also shapes the layout of this document.



**Figure 1 Flow of data/information in the method**

This document provides some details of the required data collection, and extracts from pertinent publications, which can inform the reader of how to use the Predictive Tool, how some of the Predictive Tool’s input parameters have been generated, and how some of the Predictive Tool’s input parameters have been used to calculate its outputs. These issues, however, have not been documented exhaustively.

The document goes on to describe how the Predictive Tool outputs can be processed to give the results a) and b), as given above.

## **2. Data**

The information here gives details of what data needs to be collected to eventually inform the Predictive Tool, which delivers outputs that describe the thermal conditions in the building.

### **2.1 Surveyed Data**

This data was collected by:

- a) With regards to the building design, a visual inspection of the building was made and, where possible, further details were provided by the as-built architectural drawings and construction specifications for the building.
- b) With regards to the household behaviour, a senior household member was questioned about routines and behaviour that could have an effect on the thermal performance of the building.

#### **2.1.1 Building Design**

Details were collected about the size, shape, position and materials used in the construction of the building.

#### **Floor**

Details of floor construction were collected, including the typical building materials used. This information was used to model the floor's thermal properties, which include:

- U-values (in units of W/m-K)
- Specific Heat (in units of J/kg-K)
- Density (in units of kg/m<sup>3</sup>)
- Surface absorptance and emissivity (as a fraction of 1)
- Surface roughness (on a scale from very smooth to very rough)

Details of how these properties affect quantifiable thermal performance are given later in the section discussing the Predictive Tool and its calculations.

#### **Walls**

Details of wall construction were collected, including the typical building materials used for both the internal and external walls. This information was used to model the wall's thermal properties, which include:

- U-values (in units of W/m-K)
- Specific Heat (in units of J/kg-K)
- Density (in units of kg/m<sup>3</sup>)
- Surface absorptance and emissivity (as a fraction of 1)
- Surface roughness (on a scale from very smooth to very rough)

Details of how these properties affect quantifiable thermal performance are given later in the section discussing the Predictive Tool and its calculations.

### **Ceiling**

Details of ceiling construction were collected, including the typical materials used, if there was a ceiling present. This information was used to model the ceiling's thermal properties, which include:

- U-values (in units of W/m-K)
- Specific Heat (in units of J/kg-K)
- Density (in units of kg/m<sup>3</sup>)
- Surface absorptance and emissivity (as a fraction of 1)
- Surface roughness (on a scale from very smooth to very rough)

Details of how these properties affect quantifiable thermal performance are given later in the section discussing the Predictive Tool and its calculations.

### **Roof**

Details of roof construction were collected, including the typical materials used. This information was used to model the roof's thermal properties, which include:

- U-values (in units of W/m-K)
- Specific Heat (in units of J/kg-K)
- Density (in units of kg/m<sup>3</sup>)
- Surface absorptance and emissivity (as a fraction of 1)
- Surface roughness (on a scale from very smooth to very rough)

Details of how these properties affect quantifiable thermal performance are given later in the section discussing the Predictive Tool and its calculations.

In the cases where a roof space was created by the presence of a ceiling, it was assumed that the air changes per hour prevalent were 0.2. (The airchange regime determined, by the calibration process, for the rest of the building may not be used for the roof space, because there is little occupant discretion in this regard, and incorporating a second unknown input parameter would render the calibration process null)

### **Doors**

Details of door construction were collected, including the typical materials used in construction, for both internal and external doors. This information was used to model the doors' thermal properties, which include:

- U-values (in units of W/m-K)
- Specific Heat (in units of J/kg-K)

- Density (in units of kg/m<sup>3</sup>)
- Surface absorptance and emissivity (as a fraction of 1)
- Surface roughness (on a scale from very smooth to very rough)

Details of how these properties affect quantifiable thermal performance are given later in the section discussing the Predictive Tool and its calculations.

Some assumptions were made regarding the operation of the doors. External doors were assumed to be closed at all times, while internal doors were assumed to be half open a quarter of the time. This affects the internal circulation of air between the different zones in the building that experience different thermal conditions.

### **Windows**

Details of door construction were collected, including the typical materials used. This information was used to model the doors' thermal properties, which include:

- U-values (in units of W/m-K)
- Specific Heat (in units of J/kg-K)
- Density (in units of kg/m<sup>3</sup>)
- Surface absorptance and emissivity (as a fraction of 1)
- Surface roughness (on a scale from very smooth to very rough)

Details of how these properties affect quantifiable thermal performance are given later in the section discussing the Predictive Tool and its calculations.

### **Curtains**

The affect of the curtains on the thermal conditions was limited to a few options allowed by the Predictive Tool, namely:

- Drapes – semi open weave light
- Drapes – semi open weave medium
- Drapes – semi open weave dark
- None

These options were defined for the building as being in operation at all times.

### **Major Obstructions**

Due to the significant affect that large obstructions could have on the building's thermal performance, by obstructing solar radiation, all large obstacles found near the building were incorporated, and treated according to details provided in the Predictive Tool section.

### 2.1.2 Household Behaviour

Household occupant behaviour can potentially have a significant affect on the thermal conditions experienced in the building.

#### **Occupancy**

Building occupants provide a certain amount of localised heating due to their physiological metabolic activities (assumed to be 90Watts/person). Therefore, the number of occupants in the building during working hours, after hours, and on the weekends, and when the building occupants wake up in the morning and go to sleep in the evening are required.

The number of occupants present in the building can provided by a household survey, while details about the determination of household waking and sleeping times are given in the Monitored Data section, and this data is then compiled into Occupancy Schedules.

#### **2.1.1.1 Non-electrical Energy Use**

While electricity use in the building is monitored, the non-electrical use is estimated and manually incorporated into the Internal Heat Gain Schedules.

#### **Major Electrical Appliances**

To account for the location of the most significant internal heat sources in the building, in terms of the highest power rating and highest electrical energy demand, a survey was made of major electrical appliances.

This data is used to determine electrical contributions in the Internal Heat Gain Schedules for all thermal zones.

### **2.2 Monitored Data**

Data logging equipment, installed in each building, provides the necessary hourly data for internal temperatures, external temperatures and electrical heat sources in the building. The data is logged on the hour, every hour.

Occasionally, the data monitored by the data loggers is corrupted by technical failures, and some filters are required to ensure that the readings are within expected ranges and are valid. Invalid data is not used, but flagged so that the number of data errors can be accounted for at a later stage.

The placement of loggers for temperature and electrical current monitoring must follow specifications provided by the predictive tool.

### 2.2.1 Electricity Use

Circuit Transformers (CTs) have been installed on the supply cables at the Distribution Board to ensure that the data loggers read the average electrical current delivered to services in the building every hour.

This average current data can be converted to heat energy (in Watthours [Wh]) by assuming a resistive load (for the appliances), a supply voltage of 220V (a low estimate of the supply voltage), according to the following formula:

$$\text{Energy} = (220\text{V} \times \text{Current}) * 1\text{hour}$$

### 2.2.2 External Temperatures

A temperature sensor has been installed on a number of houses in each region where the buildings are monitored, externally to the building envelope and under either a radiation shield (to protect it from the sun, wind and rain) or in a sheltered location under a roof overhang.

This external temperature is effectively an hourly average dry-bulb temperature measurement. Each temperature sensor has been individually calibrated to give an accurate reading.

### 2.2.3 Internal Temperatures (Heated Space)

Either one or two temperature sensors have been installed in the heated space of the building, 10cm to 15cm below ceiling height (whether or not a ceiling is present). Because the buildings are naturally ventilated the internal air (thermal distribution) is assumed to be well mixed within the zone, therefore no vertical temperature profile has been used to adjust the measured temperatures to occupancy height temperatures (expected).

Each temperature sensor has been individually calibrated to give an accurate reading.

## **2.3 Unknown Data**

The only significant parameter that has not been assumed, modelled, approximated or measured is the infiltration of external air into the building due to either the non-airtightness of the building or intentional mixing through open windows.

### 2.3.1 Air Changes Per Hour

The two sources of air infiltration into the building, non-airtightness and intentional ventilation, are combined and used to calibrate the Predictive Tool, since this is the only significant parameter not accounted for. The air changes per hour are generated as a typical daily profile (with hourly values) for every day of a particular month, using the convergence of predicted and monitored internal temperatures. More details about this calibration of infiltration (in air changes per hour), and thereby the final model parameter, are given in the Calibration section.

### **3. Processed Data (Inputs)**

Often, the data that was provided for the buildings and environmental conditions have to be manipulated before they can be used as inputs to the Predictive Tool, which is what this section aims to describe.

#### **3.1 Building Design Data**

The Building Design Data has already been discussed in the previous section, with regards to what information is used and what assumptions are made.

#### **3.2 Occupancy Schedules**

By knowing the number of occupants in the building during working hours, after hours, and on the weekends, and when the building occupants wake up in the morning and go to sleep in the evening, the Predictive Tool accounts for occupancy by creating Occupancy Schedules for each zone based on the following rules:

- During sleeping times, all the occupants are shared between the non-heated thermal zones.
- During non-sleeping times, the occupants present in the building are evenly shared between all thermal zones.

#### **3.3 Internal Heat Gain Schedules**

The Internal Heat Gain Schedules have been created by using monitored electrical energy consumption, which can be accounted for by occupant use of the building's appliances, and any other fuel sources used by the occupants.

However, because these Schedules need to be created for each thermal zone in the building, some assumptions need to be made about:

- a) where the appliances are located in the building, noting that these appliances' locations may change from time to time, as well as
- b) how much energy is attributable to each of the appliances, since their energy inputs are not monitored individually.

This is dealt with by using researched information<sup>12</sup> on the typical energy service splits in low-income electrified houses. Typical domestic energy services include lighting, cooking, refrigeration, water heating, space heating and laundry. This researched information is in the form of proportional energy service splits as a fraction of the total energy demand. Since we know the total energy demand of the building from the monitored and surveyed data discussed in the previous section entitled 'Data', this energy use is split amongst the energy services, and

---

<sup>12</sup> The source of this researched information is the DA-Systemload survey of suburban houses in Hartebeespoort and Kuilsrivier by Eskom (Andries Gildenhuys) conducted in 2002.

appliances corresponding to that service are present, the corresponding heat gains are manually assigned to where the appliances are likely to be used.

### **3.4 Environmental Conditions**

The Environmental Conditions that are used in the Predictive Tool are made up of two sources. Firstly, the Dry-Bulb Temperatures are provided by monitored external temperature data. Secondly, the other required conditions, provided by a weather modelling software (Meteonorm v6.0), are:

- Direct Solar Radiation and Diffuse Horizontal Solar Radiation
- Relative Humidity, Dew Point Temperature and Barometric Pressure
- Wind Direction
- Wind Speed
- Total and Opaque Sky Cover
- Precipitation

Meteonorm uses a database of monthly weather data, for weather stations or interpolated for other locations, to calculate hourly values of all parameters using a stochastic model. Details of how Meteonorm calculates these values are given in the following excerpts from the application's documentation.

Meteonorm is described as:

METEONORM is primarily a method for the calculation of solar radiation on arbitrarily orientated surfaces at any desired location. The method is based on databases and algorithms coupled according to a predetermined scheme. It commences with the user specifying a particular location for which meteorological data are required, and terminates with the delivery of data of the desired structure and in the required format. (Meteotest 2008a:1)

Meteonorm software can be used when there is no measured data near the location for the simulation. Meteonorm extrapolates hourly data from statistical data for a location. Where statistical data aren't available, Meteonorm interpolates from other nearby sites. Generally a statistical approach is a last resort -- weather files generated from statistics will not demonstrate the normal hour-to-hour and day-to-day variability seen in measured data. Meteonorm version 6 will directly write EPW files. (EnergyPlus 2009:54)

The latter excerpt validates that Meteonorm can be used, in the absence of hourly data of the project, to approximate a specific location's weather data when using EnergyPlus as a Predictive Tool.

A description of Meteonorm base data is given as:



The METEONORM radiation database is based on 20-year measurement periods, the other parameters mainly on 1961-90 and 1996-2005 means. Comparisons with longer-term measurements show that the discrepancy in average total radiation due to choice of time period is less than 2% for all weather stations. (Meteotest 2008a:3)

A description of Meteonorm's reporting intervals are given as:

Hourly values are designated by the end time of the interval. Thus the value for 14.00 hours refers to the average value of the interval from 13.00 to 14.00 hours. The central value of this interval is 13.30 hours. The computer program contains an internal time reference in minutes, which defines the position of the center of the interval in relation to the end time. In the example given here it is -30 minutes. (Meteotest 2008b:29)

#### 3.4.1 Solar Radiation

A description of Meteonorm's calculation of global solar radiation is given as:

To meet present day needs, monthly average data is no longer sufficient, and many design codes call for hourly data. However, since the interpolation of hourly values at arbitrary locations is extremely time consuming (only feasible using satellite data), and necessitates extensive storage capacity, only interpolated monthly values at nodal points are stored. In order to generate hourly values at any desired location, stochastic models are used. The stochastic models generate intermediate data having the same statistical properties as the measured data, i.e. average value, variance, and characteristic sequence (autocorrelation). The generated data approximates the natural characteristics as far as possible. Recent research shows that data generated in this way can be used satisfactorily in place of long-term measured data (Gansler et al., 1994).

The following generation procedure is adopted. Starting with the monthly global radiation values, first the daily values, then the hourly values are generated stochastically. Further characteristic values, e.g. temperature, humidity, wind, longwave radiation, are derived from these as required. (Meteotest 2008b:41)

Some validation statistics for the determination of global solar radiation are given as:

Table 6.6.12: Measured autocorrelation (AC(1)) and standard deviation and factors of the generated values.

Site	AC(1) mes. []	AC(1) gen factor [%]	Std dev. mes. []	Std dev. mes. factor [%]
Uccle	0.428	58.1	0.100	43.3
Trier	0.474	103.5	0.109	84.0
Dresden	0.476	127.7	0.111	67.8
Hamburg	0.449	99.8	0.101	74.0
Braunschweig	0.461	113.1	0.107	71.2
Würzburg	0.475	55.2	0.110	34.6
Weihenstephan	0.445	127.4	0.116	77.8
Payerne	0.436	72.7	0.119	66.7
Alice Springs	0.335	70.8	0.124	102.5
Camborne	0.454	97.1	0.111	81.4
Bonville	0.370	70.2	0.116	90.8
Goodwin Creek	0.452	83.9	0.115	90.7
Penn State Univ.	0.433	88.5	0.113	87.8
Desert Rock	0.317	56.8	0.136	87.6
Sioux Falls	0.453	82.5	0.141	84.8
Table Mountain	0.436	87.7	0.157	94.8
Fort Peck	0.391	69.3	0.142	83.8
Mean value		86.1		77.7

(Source - Meteotest 2008b:51)

### 3.4.2 Other Environmental Parameters (other than Solar Radiation)

Environmental Conditions are calculated by Meteonorm, as:

The principal problem in simulating further parameters is to ensure their compatibility with the previously obtained parameters. The approximate formulae and methods are described below. The supplementary parameters are not of the same quality as the main parameters (global radiation and temperature) and were not validated in an equally comprehensive way. Most adaptations were made using data from 15 weather stations in the USA and Switzerland.

The following supplementary parameters are calculated in METEONORM: Dew point temperature, relative humidity, mixing ratio, wet-bulb temperature, cloud cover, global and diffuse brightness, longwave radiation (incoming, vertical plane, outgoing), wind speed, wind direction, precipitation, driving rain, atmospheric pressure and UV radiation (UVA, UVB, erythemal, global and diffuse). The computational algorithms for the supplementary parameters are described below. (Meteotest 2008b:74)

The following sections give some details about how these parameters are determined and validated, by providing excerpts from relevant documents.

#### **Relative Humidity, Dew Point Temperature and Barometric Pressure**

Details of the calculation of Barometric Pressure is given by:

The atmospheric pressure at a particular station is set to the same value the whole year round. The model used for average air pressure assumes a polytropic atmosphere with

constant temperature decrement (-6.5 °C/km) and constant temperature at sea level (15 °C) (7.2.33).

$$p_d = 1013 \cdot \left[ 1 - \frac{0.0065 \cdot z}{288.15} \right]^{5.264} + (Kt_d - KT_m) \cdot 20 \quad (7.2.33)$$

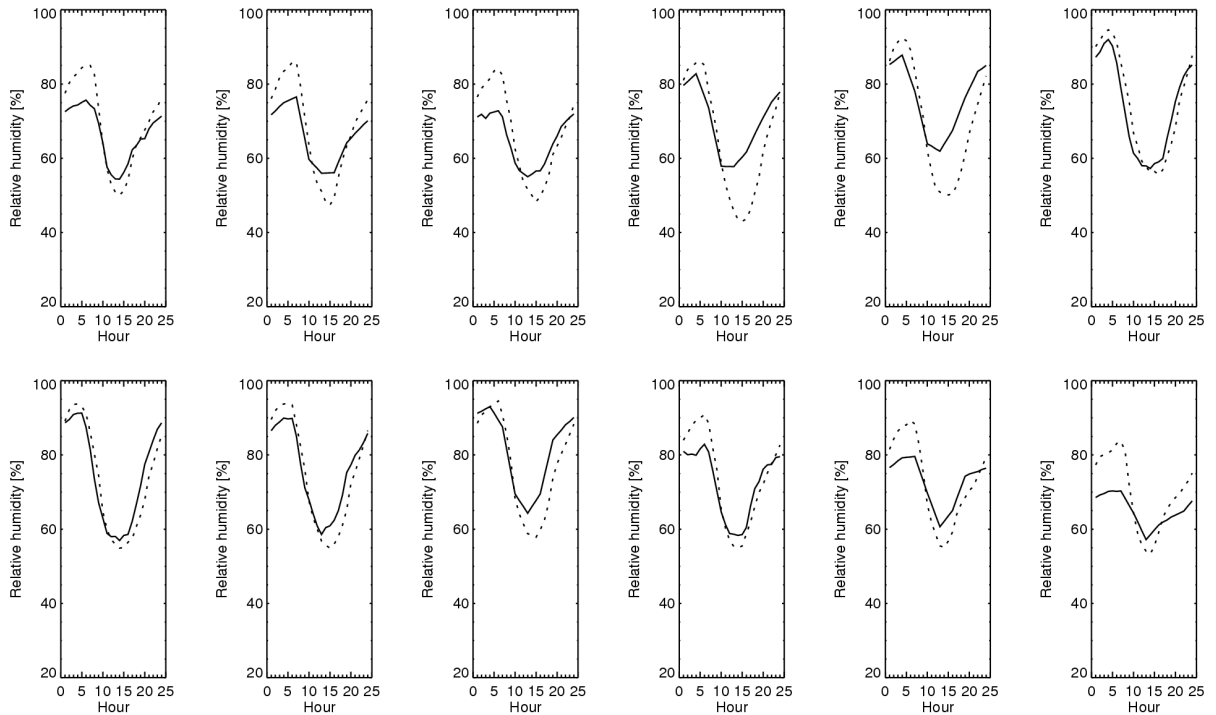
$p_d$ : Daily mean of atmosphere pressure [hPa]

$z$ : Height above sea level [m]

(Source - Meteotest 2008b:91)

Meteonorm (v6.0) bases its calculation of Relative Humidity on the relationship between air temperature, dew point temperature and relative humidity, with the results of validation testing as:

For both dry and wet climates the generated humidity values compare well with measured data. The differences between the climates can be distinguished clearly. Nevertheless we advise the user to check the outcomes of the humidity generation before using it for delicate simulation processes (like cooling).



[Example Figure] Fig. 7.2.4: Mean daily profile of relative humidity at Portland ME USA. Solid line = measured, broken line = generated values.

(Source - Meteotest 2008b:76)

### Wind Speed and Direction

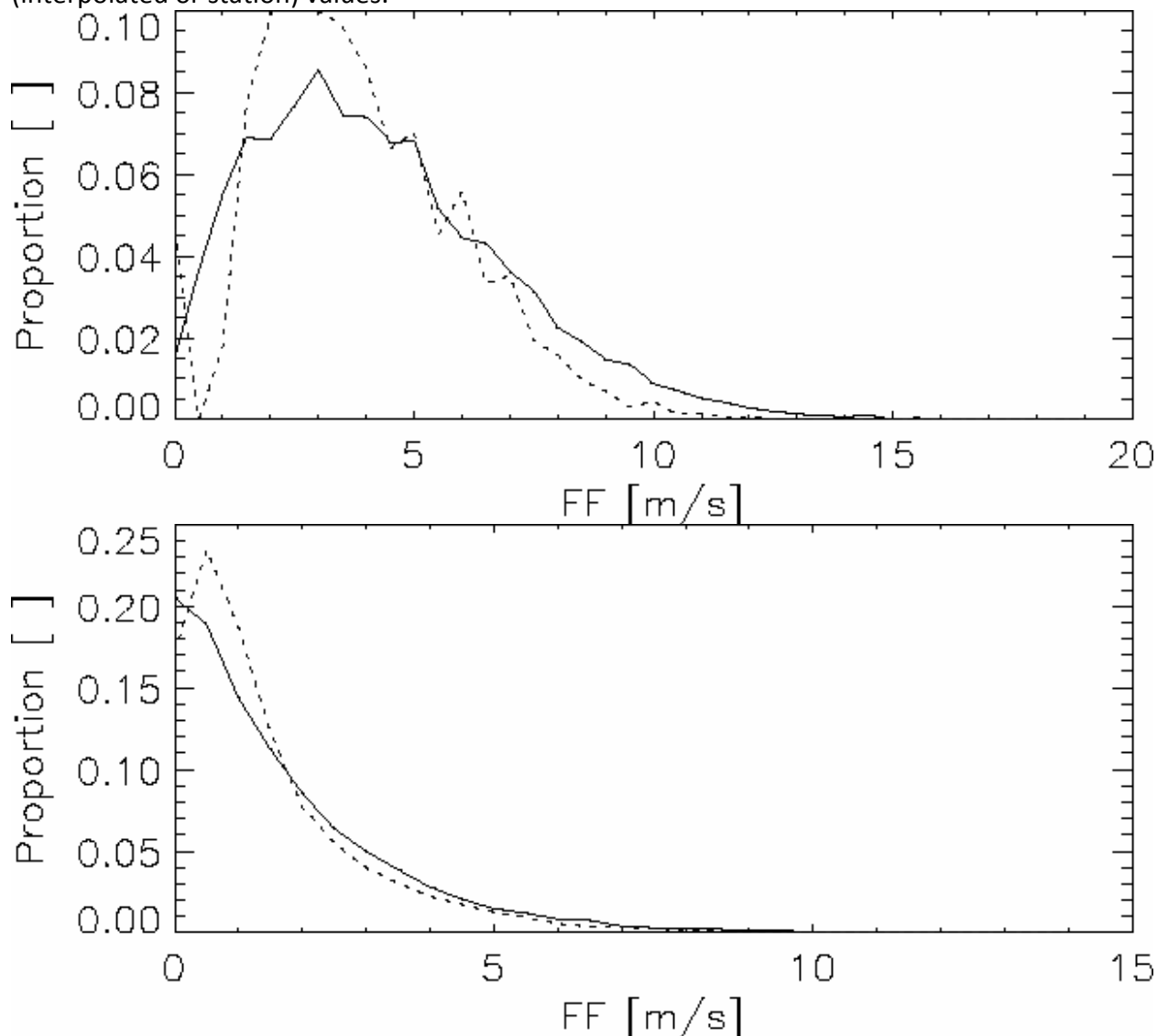
Meteonorm gives the following description for, and validation of, Wind Speed as:

The problem of wind simulation for any desired location is practically insoluble, since wind speed is greatly influenced by local features, and spatial variations are very large.

The average monthly value is very difficult to estimate without a detailed knowledge of local topography.

Despite the difficulties described above, hourly wind speed values were nevertheless generated. The model was adapted to 30 stations in the USA (Tab. 3.3.1) and 20 stations in Switzerland. It consists of a daily model based on average daily global radiation, and on an independent stochastic model.

The calculated hourly wind values were tested using data from 15 stations in the USA and Switzerland (Tab. 3.3.2). The validation was restricted to checking the distributions. The results showed good agreement between calculated and measured data (Fig. 7.2.11). The average monthly values of generated data come to the original (interpolated or station) values.



[Example Figure] Fig. 7.2.11: Comparison between distributions of calculated (full line) and measured (broken lines) wind speed, showing data from Portland (MN, USA) (above), and Bern-Liebfeld (CH) (below).

(Source - Meteotest 2008b:86-89)

Meteonorm gives the following description for the determination of Wind Direction as: The basis of the model is approximately 100 stations with stored wind direction distributions (45°) for the months of January and July. Mainly data from ISMCS (NCDC, 1995) are used. The nearest site is chosen as representative. The monthly distributions are calculated as a weighted average of the July and the January distributions. If monthly mean values of wind direction are available, the distribution is turned in order that the maximum value of the distributions matches the mean direction value. (Meteotest 2008b:89)

### **Total and Opaque Sky Cover**

Meteonorm gives the following description of its determination of cloudiness as: Here too, a new model is used in version 5.0. The knowledge of the cloud cover index is essential for estimating the long wave radiation emitted by the atmosphere and for temperature modelling during night. The Equation of Kasten and Czeplak (1979)<sup>13</sup> was used for calculating global radiation from clear sky radiation and the cloud cover index in two recent publications (Badescu, 1997; Gul et al., 1998)<sup>14</sup>.

Initial checks with this model showed that it could be used for Europe and other temperate zones, but changes were needed for other regions. Additionally, when the Kasten and Czeplak algorithm was used in reverse to estimate cloud cover, it generally produced results biased towards cloud cover values that were too high.

Therefore, another model was investigated based on the Perraudau's nebulosity index. With stochastically generated data the distribution of Perraudau's index is significantly different. The generated IP values are lower than the measured ones. Therefore, this distribution has to be adapted to get accurate and bias free cloud cover information.

The factor is calculated with the Index for elevation of the sun above 5°. For night hours the cloud cover is interpolated linearly between sunrise and sunset. (Meteotest 2008b:82-83)

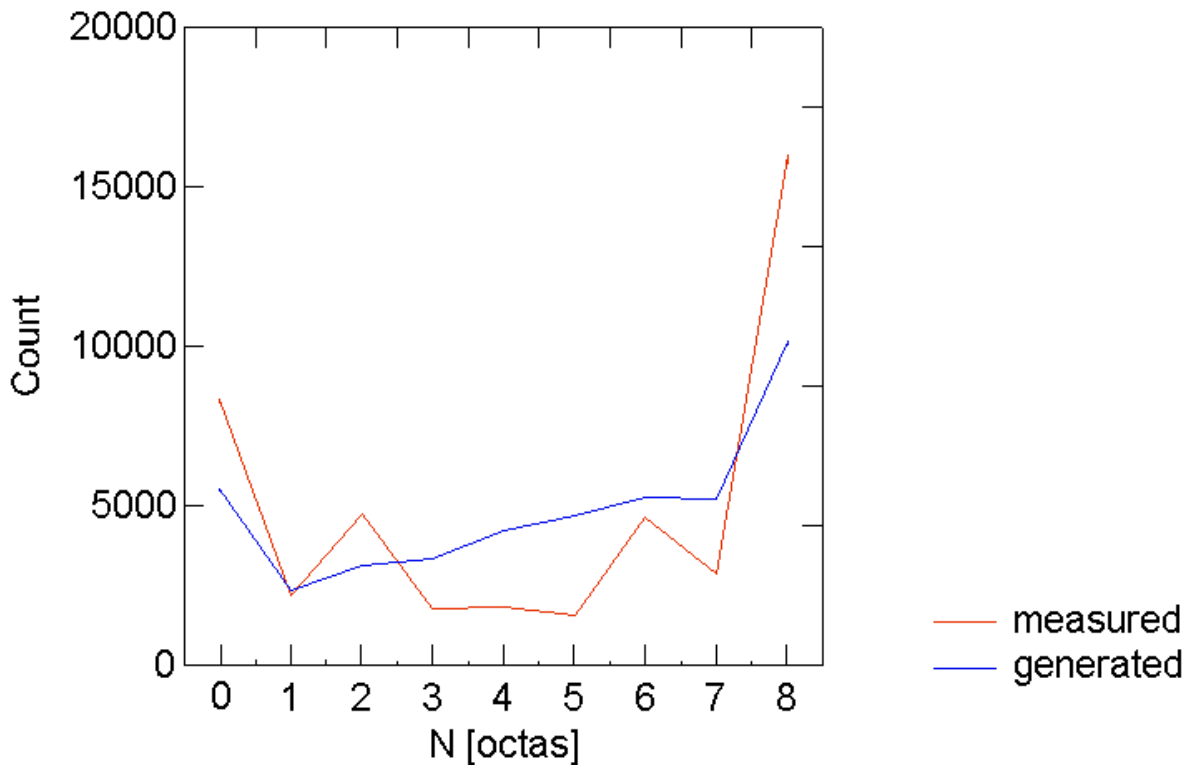
Test site validation of the determination of cloudiness is given as:

The distribution and the mean values of all 5 sites together are better reproduced with the new method. The mean values are both 4.7 octas for generated and measured values. The histograms are given in Fig. 7.2.10. Generally, too many intermediate values are generated compared with the observed cloud cover. (Meteotest 2008b:84)

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<sup>13</sup> No references provided for the document

<sup>14</sup> No references provided for the document



[Example Figure] Fig. 7.2.10: Histogram of measured and generated cloud cover. Data of Anchorage, Seattle, Salt Lake City, Raleigh and San Juan 1990 and generated values with mean radiation values of 1961–90. (Source - Meteotest 2008b:84)

### Precipitation

Meteonorm gives the description of the determination, and validation, of Precipitation as:

In former versions of METEONORM, precipitation was only available as monthly sums. A new generation process is introduced for version 5. It is based on the broad knowledge available from many publications of weather generation, which are mostly related with the WGEN generator (Richardson and Wright, 1984).

The reason for choosing new algorithm was that time series of precipitation are also needed in building simulation and that no existing method was based on solar radiation, which is available in this case. Generally the generation of the dry or wet days' time series is the first step. Additionally the existing generators are fitted to agricultural simulations, mostly provide only daily time series and are site dependent. The proposed method produces first daily precipitation series and then hourly values for every site worldwide.

Days with precipitation are reproduced well. Especially the lower thresholds (RRd>0mm, RRd>1mm) are given precisely. Monthly and yearly sums correspond to input values. Small differences in the table are induced by different time periods. The

maximum daily sum is calculated too low (-28%). The maximum hourly sum is calculated quite precisely. The amounts of wet and dry spells are calculated too low. This is mainly induced by the fact that the calculations are fitted to monthly means and not to yearly means. The number of hours with precipitation is also too low. Nevertheless, the deviations the different magnitudes of the precipitation for the different climates are clearly observable. (Metetotest 2008b:91-94)

#### 4. Predictive Tool

The Predictive Tool that is used in this project is made up of the DesignBuilder (v1.8) graphical interface tool as a front end (and back end) for the EnergyPlus (v3.0) simulation software. This means that all of the data inputs for the building are inputted into DesignBuilder, while the complete building model is simulated in EnergyPlus, and the results are then presented again in DesignBuilder.

Tests performed on earlier versions of DesignBuilder (v1.2) and EnergyPlus (v1.3) softwares (ASHRAE 2006) have shown that the DesignBuilder software (with EnergyPlus simulation) provides identical simulation results as for data entered directly into EnergyPlus.

Since EnergyPlus handles all of the simulation calculations, it is effectively the Predictive Tool mentioned previously.

EnergyPlus (v3.1) has been favourably validated through various testing procedures, including<sup>15</sup>:

- ANSI/ASHRAE Standard 140-2007 - *Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs*
- ASHRAE 1052-RP - *Development of an Analytical Verification Test Suite for Whole Building Energy Simulation Programs – Building Fabric*

##### 4.1 EnergyPlus Simulation

EnergyPlus is described as:

The EnergyPlus program is a collection of many program modules that work together to calculate the energy required for heating and cooling a building using a variety of systems and energy sources. It does this by simulating the building and associated energy systems when they are exposed to different environmental and operating conditions. The core of the simulation is a model of the building that is based on fundamental heat balance principles.

Since it is relatively meaningless to state: “based on fundamental heat balance principles”, the model will be described in greater detail in later sections of this document in concert with the FORTRAN code which is used to describe the model. It turns out that the model itself is relatively simple compared with the data organization and control that is needed to simulate the great many combinations of system types, primary energy plant arrangements, schedules, and environments. The next section shows this overall organization in schematic form. Later sections will expand on the details within the blocks of the schematic. (EnergyPlus 2009:1)

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<sup>15</sup> <http://apps1.eere.energy.gov/buildings/energyplus/testing.cfm> on the 17/08/2009



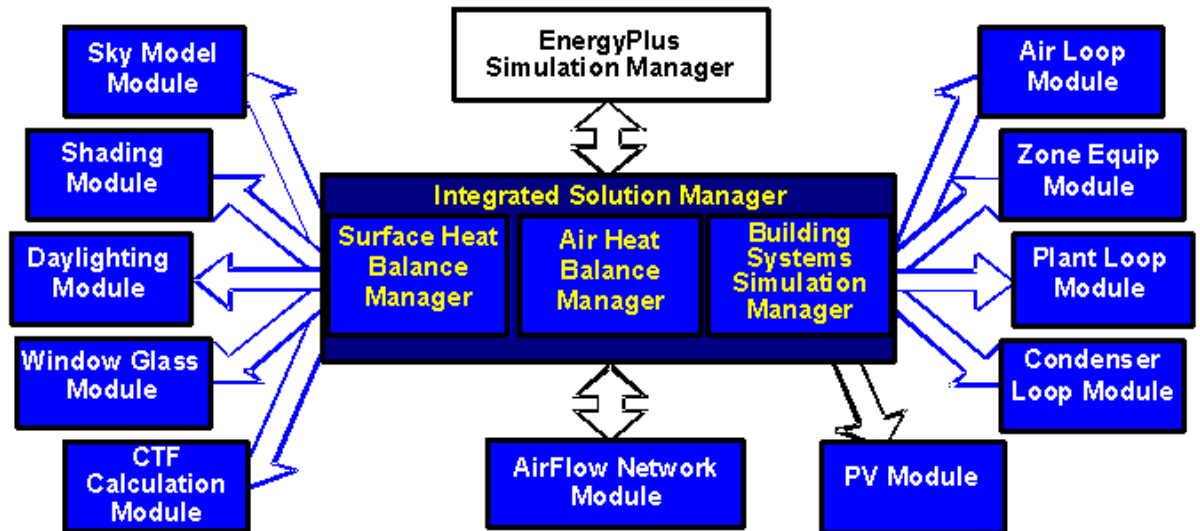


Figure 1. EnergyPlus Program Schematic  
(Source - EnergyPlus 2009:1)

Details of some of the major calculations, that regard naturally ventilated buildings, performed by EnergyPlus (v3.0), are provided in the following sections.

#### 4.1.1 Outside Surface Heat Balance

EnergyPlus documentation gives the outside surface heat balance as:

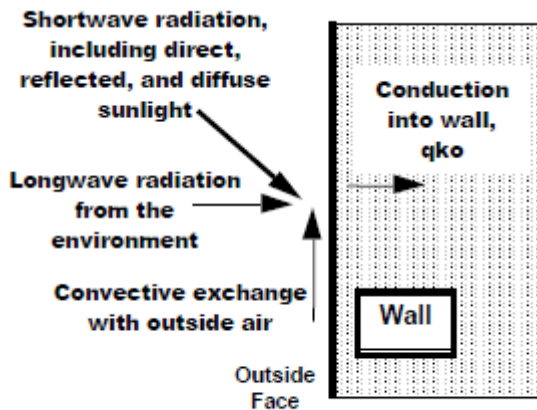


Figure 14. Outside Heat Balance Control Volume Diagram

The heat balance on the outside face is:

$$q''_{\alpha sol} + q''_{LWR} + q''_{conv} - q''_{ko} = 0 \quad (60)$$

where:

$q''_{\alpha sol}$  = Absorbed direct and diffuse solar (short wavelength) radiation heat flux.

$q''_{LWR}$  = Net long wavelength (thermal) radiation flux exchange with the air and surroundings.

$q''_{conv}$  = Convective flux exchange with outside air.

$q''_{ko}$  = Conduction heat flux ( $q/A$ ) into the wall.

All terms are positive for net flux to the face except the conduction term, which is traditionally taken to be positive in the direction from outside to inside of the wall. Simplified procedures generally combine the first three terms by using the concept of a sol-air temperature. Each of these heat balance components is introduced briefly below. (EnergyPlus 2009:37-38)

#### 4.1.2 Inside Heat Balance

EnergyPlus gives the inside heat balance as:

The heart of the heat balance method is the internal heat balance involving the inside faces of the zone surfaces. This heat balance is generally modelled with four coupled heat transfer components: 1) conduction through the building element, 2) convection to the air, 3) short wave radiation absorption and reflectance and 4) long wave radiant interchange. The incident short wave radiation is from the solar radiation entering the zone through windows and emittance from internal sources such as lights. The long wave radiation interchange includes the absorption and emittance of low temperature radiation sources, such as all other zone surfaces, equipment, and people.

The heat balance on the inside face can be written as follows:

$$q''_{LWX} + q''_{SW} + q''_{LWS} + q''_{ki} + q''_{sol} + q''_{conv} = 0 \quad (88)$$

where:

$q''_{LWX}$  = Net long wave radiant exchange flux between zone surfaces.

$q''_{SW}$  = Net short wave radiation flux to surface from lights.

$q''_{LWS}$  = Long wave radiation flux from equipment in zone.

$q''_{ki}$  = Conduction flux through the wall.

$q''_{sol}$  = Transmitted solar radiation flux absorbed at surface.

$q''_{conv}$  = Convective heat flux to zone air.

Each of these heat balance components is introduced briefly below.

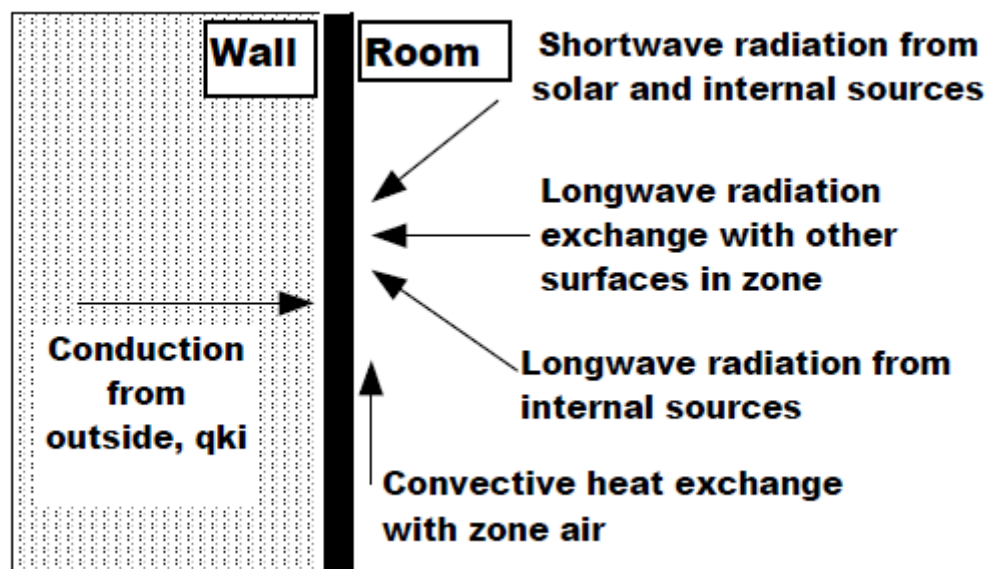


Figure 15. Inside Heat Balance Control Volume Diagram

(Source - EnergyPlus 2009:50)

4.1.3 The Glazing Heat Balance Equations

EnergyPlus gives the glazing heat balance equations as:

The window glass face temperatures are determined by solving the heat balance equations on each face every time step. For a window with N glass layers there are 2N faces and therefore 2N equations to solve. Figure 80 shows the variables used for double glazing (N=2).

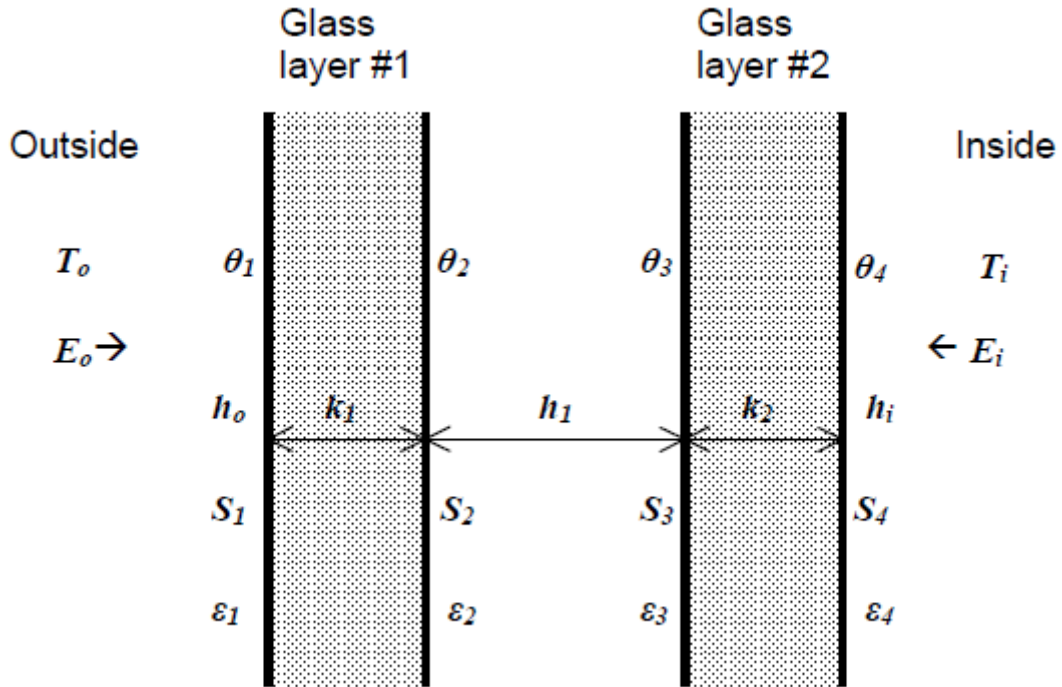


Figure 80. Glazing system with two glass layers showing variables used in heat balance equations.

The following assumptions are made in deriving the heat balance equations:

- 1) The glass layers are thin enough (a few millimeters) that heat storage in the glass can be neglected; therefore, there are no heat capacity terms in the equations.
- 2) The heat flow is perpendicular to the glass faces and is one dimensional. See "Edge of Glass Corrections," below, for adjustments to the gap conduction in multi-pane glazing to account for 2-D conduction effects across the pane separators at the boundaries of the glazing.
- 3) The glass layers are opaque to IR. This is true for most glass products. For thin plastic suspended films this is not a good assumption, so the heat balance equations would have to be modified to handle this case.
- 4) The glass faces are isothermal. This is generally a good assumption since glass conductivity is very high.
- 5) The short wave radiation absorbed in a glass layer can be apportioned equally to the two faces of the layer.

(Source - EnergyPlus 2009:213-214)

#### 4.1.4 Conduction Through The Walls

EnergyPlus gives the conduction through the walls as:

The most basic time series solution is the response factor equation which relates the flux at one surface of an element to an infinite series of temperature histories at both sides as shown by Equation (29):

$$q''_{ko}(t) = \sum_{j=0}^{\infty} X_j T_{o,t-j\delta} - \sum_{j=0}^{\infty} Y_j T_{i,t-j\delta} \quad (29)$$

where  $q''$  is heat flux,  $T$  is temperature,  $i$  signifies the inside of the building element,  $o$  signifies the outside of the building element,  $t$  represents the current time step, and  $X$  and  $Y$  are the response factors.

While in most cases the terms in the series decay fairly rapidly, the infinite number of terms needed for an exact response factor solution makes it less than desirable. Fortunately, the similarity of higher order terms can be used to replace them with flux history terms. The new solution contains elements that are called conduction transfer functions (CTFs). The basic form of a conduction transfer function solution is shown by the following equation:

$$q''_{ki}(t) = -Z_0 T_{i,t} - \sum_{j=1}^{nz} Z_j T_{i,t-j\delta} + Y_0 T_{o,t} + \sum_{j=1}^{nz} Y_j T_{o,t-j\delta} + \sum_{j=1}^{nq} \Phi_j q''_{ki,t-j\delta} \quad (30)$$

for the inside heat flux, and

$$q''_{ko}(t) = -Y_0 T_{i,t} - \sum_{j=1}^{nz} Y_j T_{i,t-j\delta} + X_0 T_{o,t} + \sum_{j=1}^{nz} X_j T_{o,t-j\delta} + \sum_{j=1}^{nq} \Phi_j q''_{ko,t-j\delta} \quad (31)$$

for the outside heat flux ( $q''=q/A$ )

where:

$X_j$  = Outside CTF coefficient,  $j = 0, 1, \dots, nz$ .

$Y_j$  = Cross CTF coefficient,  $j = 0, 1, \dots, nz$ .

$Z_j$  = Inside CTF coefficient,  $j = 0, 1, \dots, nz$ .

$\Phi_j$  = Flux CTF coefficient,  $j = 1, 2, \dots, nq$ .

$T_i$  = Inside face temperature

$T_o$  = Outside face temperature

$q''_{ko}$  = Conduction heat flux on outside face

$q''_{ki}$  = Conduction heat flux on inside face

The subscript following the comma indicates the time period for the quantity in terms of the time step  $\delta$ . Note that the first terms in the series (those with subscript 0) have been separated from the rest in order to facilitate solving for the current temperature in the solution scheme. These equations state that the heat flux at either face of the surface of any generic building element is linearly related to the current and some of the previous temperatures at both the interior and exterior surface as well as some of the previous flux values at the interior surface.

The final CTF solution form reveals why it is so elegant and powerful. With a single, relatively simple, linear equation with constant coefficients, the conduction heat transfer through an element can be calculated. The coefficients (CTFs) in the equation are constants that only need to be determined once for each construction type. The only storage of data required is the CTFs themselves and a limited number of temperature and flux terms. The formulation is valid for any surface type and does not require the calculation or storage of element interior temperatures.

(Source - EnergyPlus 2009:20-21)

#### 4.1.5 Outdoor/Exterior Convection

EnergyPlus gives the outdoor/exterior convection as:

Heat transfer due to exterior convection is modeled using the classical formulation:

$$Q_c = h_{c,ext} A (T_{surf} - T_{air}) \quad (77)$$

where

$Q_c$  = rate of exterior convective heat transfer

$h_{c,ext}$  = exterior convection coefficient

$A$  = surface area

$T_{surf}$  = surface temperature

$T_{air}$  = outdoor air temperature

Substantial research has gone into the formulation of models for estimating the exterior convection coefficient. Since the 1930's there have been many different methods published for calculating this coefficient, with much disparity between them (Cole and Sturrock 1977; Yazdanian and Klems 1994). EnergyPlus offers a choice of six algorithms: Simple, Detailed, BLAST, TARP, MoWITT, and DOE-2. See the SurfaceConvectionAlgorithm:Outside object in the Input Output Reference document.

(Source - EnergyPlus 2009:43)

#### 4.1.6 Air Exchange

EnergyPlus gives the air exchange as:

Air exchange and interchange between zones is treated as a convective gain.

(EnergyPlus 2009:255)

#### 4.1.7 Combined Heat and Moisture Transfer (HAMT) Model

EnergyPlus gives the combined heat and moisture transfer as:

The combined heat and moisture transfer finite (HAMT) solution algorithm is a completely coupled, one-dimensional, finite element, heat and moisture transfer model simulating the movement and storage of heat and moisture in surfaces simultaneously from and to both the internal and external environments. As well as simulating the effects of moisture buffering, HAMT is also be able to provide temperature and moisture profiles through composite building walls, and help to identify surfaces with high surface humidity. (EnergyPlus 2009:28)

#### 4.1.8 Node Temperature Calculations

EnergyPlus gives the node temperature calculations as:

A brief description of the air node temperature calculation is given below. A detailed description can be found in the work of Swami et al. (1992). The following equation is used to calculate temperature distribution across a duct element at the given airflow rate and inlet air temperature:

$$\dot{m} C_p \frac{dT}{dx} = UP(T_\infty - T)$$

where

$C_p$  = Specific heat of duct wall [J/kg.K]

$m$  = Airflow rate [kg/s]

$P$  = Perimeter of a duct element [m]

$T$  = Temperature as a field variable [°C]

$T_\infty$  = Temperature of air surrounding the duct element [°C]

$U$  = Overall heat transfer coefficient [W/m<sup>2</sup>.K]

$$U = \frac{1}{\frac{1}{h_i} + \frac{1}{h_o} + \sum \frac{t_j}{k_j}}$$

$h_i$  = Inside heat transfer coefficient [W/m<sup>2</sup>.K]

$h_o$  = Outside heat transfer coefficient [W/m<sup>2</sup>.K]

$t_j$  = Thickness at j-th layer [m]

$k_j$  = Thermal conductivity at j-th layer [W/m.K]

The outlet air temperature at the end of the duct ( $x=L$ ) is:

$$T_o = T_\infty + (T_i - T_\infty) * \exp\left(-\frac{UA}{\dot{m}C_p}\right)$$

where

$T_i$  = Inlet air temperature [°C]

$T_o$  = Outlet air temperature [°C]

$T_\infty$  = Temperature of air surrounding the duct element [°C]

$A$  = Surface area (Perimeter \* Length) [m<sup>2</sup>]

The heat transfer by convection to ambient,  $Q$ , is:

$$Q = \dot{m} C_p (T_\infty - T_i) \left[ 1 - \exp\left(-\frac{UA}{\dot{m}C_p}\right) \right]$$

The outlet air temperature can be calculated using the above equation at the given inlet air temperature. Since the inlet temperature at one linkage is the outlet temperature for the connected linkage, the outlet air temperatures at all nodes are solved simultaneously. A square linear system assembled by the AirflowNetwork model is expressed below:

$$\{M\}[T] = [B]$$

where

{M} = Airflow matrix

[T] = Temperature vector

[B] = Given boundary conditions

The zone air temperatures and primary air loop component (fan and coils) outlet conditions are used as prescribed conditions in the AirflowNetwork model. In addition, the temperature difference across zone loop components (terminal units) is held constant during the calculations. For example, thermal zone temperatures calculated during the previous system time step are used as prescribed temperatures when calculating all other node temperatures. The zone air temperature is assumed constant (prescribed) throughout the AirflowNetwork iterative solution. The fan and coil outlet air temperatures, and terminal unit temperature differences are assumed constant within an AirflowNetwork iteration. The sensible heat gains calculated during the AirflowNetwork solution are then used to predict a new zone air temperature.

(Source - EnergyPlus 2009:396-398)

#### 4.1.9 Calculation of Zone Air Temperature

EnergyPlus gives the calculation of zone air temperature as:

The zone air heat balance is the primary mechanism for linking the loads calculation to the system simulation. As such, the zone air temperature becomes the main interface variable. Its role in the integration process was described previously (“Basis for the Zone and System Integration”). (EnergyPlus 2009:256)

#### 4.1.10 Climate Calculations

EnergyPlus gives the climate calculations as:

The location of the facility under analysis is critical for the determination of energy consumption, heating/cooling loads, daylighting potential, and a host of other calculations. In EnergyPlus, both external (i.e., weather files supplied from others) and internal (i.e., solar position, design day temperature/humidity/solar profiles) data is used during simulations.

The “Site:Location” input object includes parameters (Latitude, Longitude, Elevation, Timezone) that allow EnergyPlus to calculate the solar position (using Latitude, Longitude and Timezone) for any day of the year as well as supply the standard barometric pressure (using elevation). Solar position modeling is discussed in more

detail in both the Sky Radiance and Shading Calculation sections that directly follow this section.

Weather files have hourly or sub-hourly data for each of the critical elements needed during the calculations (i.e., Dry-Bulb Temperature, Dew-Point Temperature, Relative Humidity, Barometric Pressure, Direct Normal Radiation, Diffuse Horizontal Radiation, Total & Opaque Sky Cover, Wind Direction, Wind Speed) as well as some auxiliary data such as Rain or Snow that assist in certain calculational aspects. Weather file excerpts such as might be used in sizing calculations also have this breadth of data. The input object “SizingPeriod:DesignDay” describes design days (meant to mimic ASHRAE design conditions but in a whole day profile) using certain characteristics for the day and then EnergyPlus supplies the remaining portions to complete outdoor conditions needed for program execution. SizingPeriod:DesignDay are perhaps the best objects for sizing equipment as the ASHRAE specified design conditions can be input AND weather files may or may not have the conditions necessary to size equipment properly.

(Source - EnergyPlus 2009:95)

#### 4.1.11 Shading Module

EnergyPlus gives the shading module as:

##### Shading and Sunlit Area Calculations

When assessing heat gains in buildings due to solar radiation, it is necessary to know how much of each part of the building is shaded and how much is in direct sunlight. As an example, the figure below shows a flat roofed, L-shaped structure with a window in each of the visible sides. The sun is to the right so that walls 1 and 3 and windows a and c are completely shaded, and wall 4 and window d are completely sunlit. Wall 2 and window b are partially shaded. The sunlit area of each surface changes as the position of the sun changes during the day. The purpose of the EnergyPlus shadow algorithm is to compute such sunlit areas. Predecessors to the EnergyPlus shadowing concepts include the BLAST and TARP shadowing algorithms.

The shadow algorithm is based on coordinate transformation methods similar to Groth and Lokmanhekim and the shadow overlap method of Walton.



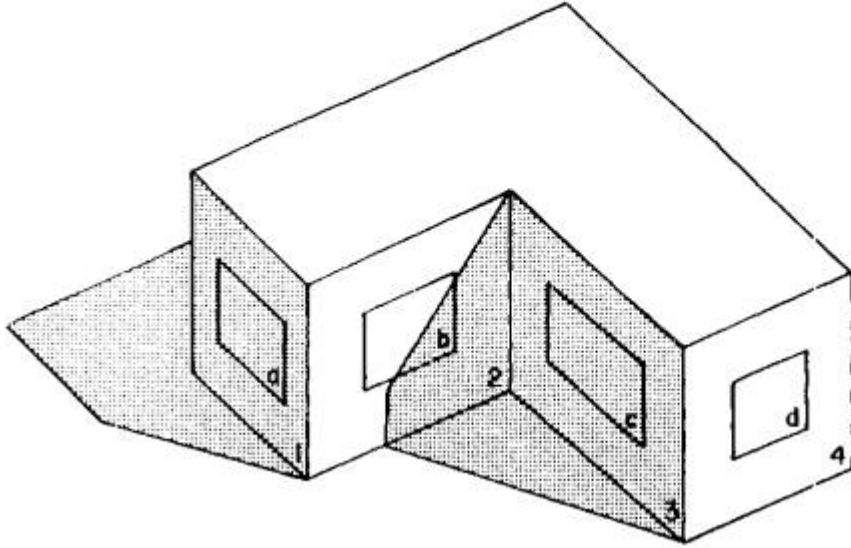
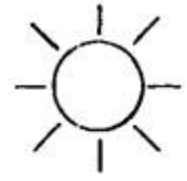


Figure 36. Overall Shading Scheme Depiction  
(Source - EnergyPlus 2009:103)

## **4.2 Outputs**

While the Predictive Tool (EnergyPlus) can provide a number of outputs, the most important output values are:

- a) Temperatures [°C] in the mechanically heated (thermal) zones of the building for calibrating the natural ventilation air change rates between the building and externally.
- b) Heating Energy [kWh] required to bring the heated space to thermal comfort levels.

Because these two types of outputs are related to different procedures, they will each be described in the next section.

## **5. Post-Processing**

The Predictive Tool is required to perform two separate procedures, as stated in the previous section.

### **5.1 Calibration of the Air Changes**

This procedure involves iterations whereby the hourly air changes experienced in the building, from externally to the building, are guessed for each month until the predicted (hourly) temperatures in the mechanically heated zone of the building correspond to the monitored (hourly) temperatures in the same heated space.

This procedure is a valid methodology because each guess of the air changes in the building (although it is a simplistic expression of how air is exchanged between inside and outside the building) represents a function of time, in units of air changes per hour, that gives an unambiguous prediction of what temperatures are expected in the mechanically heated zone.

The iterative guesses of the (hourly) air change function, as a Predictive Tool input, may be manipulated so that the Predictive Tool output of the temperature in the heated space converges on the monitored temperatures by:

- 1) Determining if the (monitored) space heated zone temperature is warmer or cooler than the (monitored) temperature outside the building.
- 2) Determining what Step1 implies for the temperature in the space heated zone, if the air changes are increased or decreased.
- 3) Determine if the Predictive Tool predicts a space heated zone temperature that is higher or lower than the monitored temperature in the space heated zone, and apply the correction to the next iteration's air change function.
- 4) Terminate iterations when the space heated zone temperatures predicted by the Predictive Tool and those monitored are similar (to a satisfactory level). This final guess of the air change function is then the parameter that calibrates the Predictive Tool for the building.

Once this air change function, which calibrates the Predictive Tool, has been determined, then the other parameters and this air change parameter together describe the building and its operation thermally.

If required, now, any number of inferences may be made as long as they are consistent with the building's thermal parameters.

### **5.2 Heating Energy Requirements**

These requirements may only be determined if the building, which is of interest, has been completely described in terms of its thermal parameters.

If, for example, it is the case that the building has complete thermal parameters to describe it, then the heating energy required to bring the mechanically heated zones in the building to thermal comfort levels may be determined by:

- 1) The method of heating should be described accurately, with regard to the heating system's capacity and efficiency, and the Predictive Tool must be able to reflect these specifications accurately.
- 2) The level of thermal comfort must be determined. For South Africa a reasonable level of comfort can be represented by (Holm D & Engelbrecht FA, 2005:13):

$$T_{nDBT} = 17,6 + 0,31 \times T_{oave}$$

$$\text{With } 17,8^{\circ}\text{C} < T_{nDBT} < 29,5^{\circ}\text{C}$$

Where  $T_{oave}$  = average outdoor DBT of the day, month or year  
DBT is calculated as the average of maxima and minima.

- 3) The Predictive Tool may now be used, in conjunction with the buildings thermal parameters, the heating system, and heating set point in the mechanically heated zone (which are all thermal parameters), to determine the energy required to reach the set point.

Once again, any number of inferences may be made as long as they are consistent with the building's thermal parameters.

## 6. References

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## Annex 4: Predictive Tool

The predictive tool used for the estimation of active space heating energy required in dwelling structures. An internationally recognised predictive tool/simulator and graphical interface were selected and populated with the data of existing occupied structures, either before or after the project intervention. The data collected includes a range of static (building fabric, colours, heated indoor area and design layout, average climate data etc.) and dynamic parameters (indoor and outdoor temperatures, heat loads, solar radiation, wind etc.) collected at pre-defined intervals over the monitoring period. The data is uploaded into the graphic interface and predictive tool and is used to determine parameters such as air-changes per hour in the heated area. The number of air-changes is the best fit in achieving correlation between predicted indoor temperatures and monitored indoor temperature in the small sample of dwelling structures. The monitoring is also used to determine heating period and temperatures at which heating is required and the indoor temperature at which affordable/minimum/sufficiency levels are achieved.

So at the heart of the methodology are the predictive tools, which need to be accepted as either accurate or conservative in determining emissions reductions. The DOE selected for validation and verifications of project activities must demonstrate the necessary expertise to evaluate selection and population of the calibrated tool.

The methodology is therefore dependent upon the acceptance of the models or predictive tools that are used to calculate the energy required to warm structures to the desired temperature of thermal comfort<sup>16</sup>. The model involves two elements: a Graphical User Interface (DesignBuilder) and a back-end calculator or simulator engine (EnergyPlus). These are respected tools used by designers and architects to understand and improve the passive thermal performance of the structures in warm and cool weather and to optimize active heating (and or cooling) through HVAC systems. The DesignBuilder and EnergyPlus combination is promoted internationally by the US Dept of Energy and has been validated by ASHRAE<sup>1718</sup>. In this instance version 3 of EnergyPlus has been utilized, its ASHRAE verification is available<sup>19</sup>.

Reviewing the accuracy/conservativeness of the instrument has revealed some recordings of the model in predicting heating and cooling requirements in “controlled” situations that point to accuracy within 2%. In structures such as those to which the methodology is applicable (low to middle income dwelling structures), requires approximately 5000kWh/year in the baseline and 4000kWh/year in the project, 2% of the baseline would be 100kWh and 80kWh/year in the project, leaving an immaterial difference of 20kWh/year (+/- 20kgs CO<sub>2</sub>e) by which the energy difference may be inflated/deflated.

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<sup>16</sup> There is a precedent for a multi-parameter model being used in the CDM in methodology AMS IJ. The model is used in the calculation of emissions reductions that can be claimed from the use of solar water heaters in small-scale methodologies.

<sup>17</sup> EnergyPlus has been validated under the comparative Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs BESTEST/ASHARE STD 140. BESTEST (Building Energy Simulation TEST) is a comparative set of tests which has become one of the industry’s most accepted methods to validate and test the simulation capabilities of the exterior envelope portions of building energy simulation programs. More information at <http://gundog.lbl.gov/dirpubs/rio4.pdf>

<sup>18</sup> [http://apps1.eere.energy.gov/buildings/energyplus/energyplus\\_testing.cfm](http://apps1.eere.energy.gov/buildings/energyplus/energyplus_testing.cfm)

<sup>19</sup> The report on the EnergyPlus version 3 EnergyPlus Testing with Building Thermal Envelope and Fabric Load Tests from ANSI/ASHRAE Standard 140-2007, EnergyPlus Version 3.1.0.027, April 2009 is available on request as a PDF file (web links no longer available).

The promoters of these tools are at pains to point out that: “A building is a complex thermodynamic object that accommodates constantly changing energy flows between the different thermal zones within the building and the outside. The two main components of the building energy simulation model are the building fabric and content (walls, floors, ceilings, occupants and equipment) and the plant components (HVAC equipment and other environmental control systems). Due to the complexity of a building model, computer simulations can analyze the effects of different ECMs (Energy Conservation Measures) and their complex interactions more efficiently, comprehensively and accurately than any other available method.”<sup>2021</sup>

It must be remembered that the model/tool is used for both baseline and project (with the additional thermal performance technologies included in the model simulation) energy estimates so even if 5% over estimates of both would result in a negligible or immaterial emissions reductions difference (as demonstrated in example above). More attention to the inputs to the model/tool during validation is likely to be of greater importance to the quality, wrt accuracy/conservativeness. The models are only as good as the underlying assumptions and the quality of the data that is uploaded.

The calibration of the predictive tool is specific to a dwelling structure type and climatic zone, and provides the amount of heat required to heat the same type of dwelling structures in the same climate zone to thermal comfort. For larger or smaller heated areas the heating intensity per unit of area calculated by the tool can be increased or decreased proportionate to the area. For different fabrics, colours, or layouts/designs the tool can be recalibrated changing the properties (e.g. thermal conductivity), or dimensions in new or existing dwelling structures, as changes to the existing calibrated tool. Similarly, for the project interventions, a recalibration is required with the project interventions and their technical specifications uploaded into the calibrated model. Alternatively, working from the project calibrated model (if this is when the tool was calibrated) “back” to the baseline dwelling structure project interventions can be removed or changed in the recalibrated tool.

Only in completely different dwelling structures, e.g. from freestanding dwelling to horizontally and vertically attached “flats” or from one climate zone to another, does the predictive tool require a complete new calibration (including primary data logging).

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<sup>20</sup> M Kaplan and P Caner, Guidelines for Energy Simulation of Commercial Buildings. Report for Bonneville Power Administration (DE-FC79-85BP26683). 1992.

<sup>21</sup> See: <http://www.gsd.harvard.edu/research/gsd-square/tutorials.html>