PRODUCTIVITY AND SICK LEAVE INTEGRATED INTO BUILDING PERFORMANCE SIMULATION

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ABSTRACT

Indoor climate has a distinct influence on productivity and sick leave of employees. Rehva guidebook 6 "Indoor Climate and Productivity in Offices" (ISSO/Rehva, 2006) shows these effects.

Relations from this guidebook are integrated into the post-processing module of the Dutch Building Performance Simulation program VA114. Through this integration, effects of indoor climate measures are quantified, not only as change in comfort but also as change in productivity and as change in sick leave. The change in productivity and change in sick leave are than again translated into costs In this paper details about this integration are given.

The main goal of this paper is to show the possibilities of this integration, not the derivation of guidelines.

INTRODUCTION

The Rehva guidebook 6 shows that indoor air temperature, ventilation rate and indoor air quality have a clear influence on the productivity and sick leave of employees. In most cases, the increased profits, due to higher productivity, are large compared to the required investments in the equipment and compared to the possible rise in energy costs.

The guideline poses that there is a demand for models and tools, which are capable to assess health and productivity in terms of costs. These tools can than be used to perform cost benefit studies. Integration of these productivity relations into building simulation brings these capabilities within reach of a wide audience.

The guideline offers models and methods (state of the art at the end of 2005). Scientific data regarding measured productivity is available and can be used as a base for calculations. The authors of this paper are aware of other available sources for productivity relations. This paper is not about the validity of this research but about making this knowledge available and applicable for a larger audience. The software provided to our customers is based on either (international) standards or guidelines provided by branche organisations like ISSO or Rehva. The integration of the ISSO./Rehva guideline is according to the above policy.

Dutch publications by Stoelinga, 2007 and 't Hooft/Roelofsen, 2007 already show the interest by practitioners to integrate productivity in their building performance assessment.

Vabi Software BV has integrated this guideline in their Building Performance Simulation program VA114. As all BPS software, this program produces a huge amount of hourly data, which can be used to establish the influence on productivity. An integrated post-processing program uses this data together with the relations of the Rehva guidebook to determine the productivity. It shows the possibilities of integration productivity as a performance indicator besides energy, CO_2-emissions and thermal comfort. The approach is more widely applicable to other Building Performance Simulation programs and to other productivity relations.

BUILDING PERFORMANCE SIMULATION AND PRODUCTIVITY

As most other Building Performance Simulation programs VA114 dumps hourly data to an output file. These data are used to assess the energy balance, thermal comfort and overheating risk. The empirical relations from Rehva guidebook 6 for the assessment of productivity and sick leave can be applied on the same data.

Regular hourly output for building performance simulation programs contain data like: the indoor air temperature, the ventilation rate, the heating and cooling load, energy consumption by fans and pumps.

The empirical relations from the Rehva guidebook, which are used, are:

- short sick leave versus ventilation rate
- productivity versus ventilation rate
- productivity versus indoor air quality
- productivity versus indoor air temperature (see figure 1)

The hourly-calculated productivity is defined by the loss in productivity with respect to 'ideal' circumstances:

- indoor air temperature 22 °C
- ventilation rate is 'infinite'
- indoor air quality level corresponds with 0 percent people dissatisfied

These 'ideal' circumstances are used as a reference 100% productivity level. The real productivity will always be lower.

By assessing the productivity and sick leave with respect to this reference, it is always clear what is achievable with regard to an ideal situation. In addition, a comparison of different measures is very easy. For instance: measure A gives 3.1% loss in productivity and measure B gives 1.5% loss in productivity; this means with measure B a productivity increase of 1.6% with respect to measure A can be obtained.

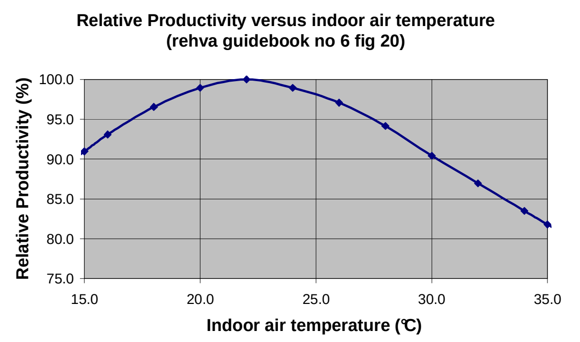

Figure 1: Productivity versus indoor air temperature

The productivity is determined hourly and per office module. The indoor air temperature, ventilation rate and number of persons can be different per module. The productivity is only assessed during office hours.

The building average productivity follows from the productivity per office module and the number of persons per module.

The loss in productivity per 'source' (indoor air temperature, ventilation rate, indoor air quality) is kept separate in the results. This is done because these 'sources' influence each other. The Rehva guidebook provides guidelines for these situations, which can be applied afterwards. By keeping these effects separate, insight is obtained about which source has the largest influence.

REHVA GUIDEBOOK AND GUIDELINES FOR COMBINING PRODUCTIVITY EFFECTS

As mentioned before the loss in productivity per source (indoor air temperature, ventilation rate and indoor air quality) can not be superimposed. For instance: a higher ventilation rate gives a better indoor air quality and can influence the indoor air temperature. In the applied empirical relations from the Rehva guidebook, the effects are not given separately. For the combination of these effects only some rule of thumb guidelines are given.

Rule of thumb guidelines for combination of productivity effects.

The Rehva guidebook gives rule of thumb guidelines. The main rules are:

- Short sick leave is only applicable for situations where mutual transfer of infections is possible; i.e. for office gardens, for situations with a substantial recirculation of return air
- The influence of the indoor air quality can only be calculated in case the indoor air quality is measured (Percentage People Dissatisfied). In other cases the influence is 0%
- Increase of the amount of fresh air gives an increase of the productivity according to the relation 'Productivity versus ventilation rate', but also according to the relation 'Productivity versus indoor air quality'. In this case the magnitude of the combined effect is taken as the maximum of the single effects. The effect of the other parameter is put to 0%
- Increase of the amount of fresh air gives an increase of the productivity according to the relation 'Productivity versus ventilation rate', but probably also according to the relation 'Productivity versus indoor air temperature'. The truth is somewhere in between the maximum of these two effects and the sum of these two effects.

The guideline does not give guidelines about how indoor air quality improves (decrease of Percentage People Dissatisfied) when the amount of fresh air is increased. Doubling the ventilation rate will globally decrease the concentration of 'harmful' substances with 50% (in the case 'pollution source in the space'); does the Percentage People Dissatisfied (for instance 40%) decrease with 50% too (to 20%)? Is Percentage People Dissatisfied inversely proportional to the amount of fresh air?

The decrease in short sick leave as function of ventilation rate is one of the given relations. The relation gives the decrease with respect to a fresh air amount of 0 liter/s per person (see figure 2). However this short sick leave at 0 l/s p.p. is not known and have to be given as an input (2%, 4%, 5%?) by the user of the program.

Remark: short sick leave is defined as sick leave (short – a few days to a week) caused by transfer of infections by the air. This is only a part of the total sick leave.

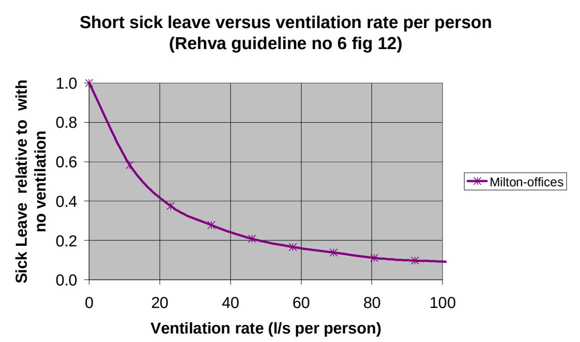

Figure 2: Short sick leave versus amount of fresh air per person

POST-PROCESSING DATA FROM BUILDING PERFORMANCE SIMULATION PROGRAMS

Post processing requires the following additional data:

- Number of office modules
- Number of persons per office module at 100% occupation
- Average occupation rate of the building
- Short sick leave at a ventilation rate of 0 l/s per person
- Indoor air quality expressed in Percentage People Dissatisfied.
- Type of office work

The average occupation rate of the building is important, because a lower occupation rate increases the ventilation rate per person.

The effect of the ventilation rate on the short sick leave can only be applied for cases where the people are working in the same space or for cases with a high recirculation rate of the return air. In other cases the effect is 0%. In the case that nothing is known about the indoor air quality the effect is also 0%.

Two types of office work are distinguished: general office work (typing work, counting, reading) or typing work only

Output parameters of the program

Output parameters of the post processing module are on hourly basis per office module, on annual basis per office module and for the entire building. Results are shown per effect (indoor air temperature, ventilation rate, indoor air quality, …). The least performing modules can be distinguished.

Assessment of improving measures can be done. Besides productivity loss with respect to the ‘ideal’ situation the energy consumption for heating, cooling, fans and pumps are given. These numbers are also expressed in costs.

RESULTS OF A SHORT SENSITIVITY STUDY

As an example, a short sensitivity study was done on the influence of two measures:

- Doubling of the amount of fresh air
- Applying local cooling

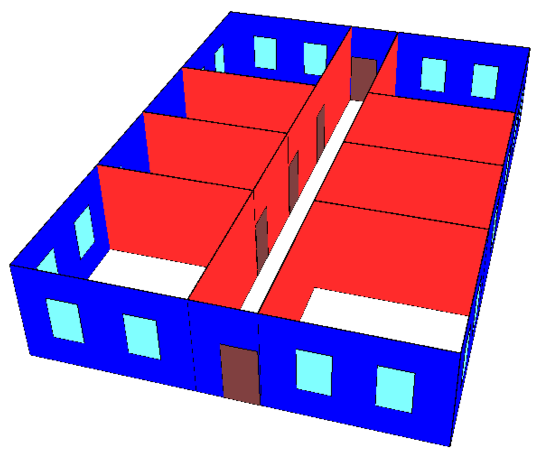

Figure 3: Office building used for the sensitivity study

The study was done for a simple office building consisting of 8 office rooms, which are connected by a corridor (see figure 3). Typical dimensions of the building block are 18m x 12.8m x 3.5m, corridor width 2m and office space dimensions 5.4m x 5.4m for the corner spaces and 5.4m x 3.6m for the smaller office spaces. The corner offices are used by 2 employees, the other offices by 1 employee. The offices have fresh air supply by a duct system. In the offices there is local heating and local cooling; both units are controlled on comfort temperature. The set points of these units are not fixed like traditionally is done, but change with ambient temperature (according to the 80% ATG-heating line and the 80% ATG-cooling line). This ‘untraditional’ way of control leads to a better thermal comfort and lower energy consumption (Wijsman, 2009).

The ‘Adaptieve Temperatuur Grenswaarde’ (ATG-) method produces a graph, which gives an adequate insight into the thermal comfort inside a building. With this method, the thermal comfort can be assessed and communicated in a simple way. The ATG-plot (see for instance figure 4) gives for each hour of the considered period the comfort temperature Ti as a function of a weighted ambient temperature. A weighting is applied on the daily mean ambient temperature ($(T_{maximum}+T_{minimum})/2$) of the considered day and the 3 days before (so ‘history’ is included).

In the ATG-plot the different coloured areas express a different percentage of satisfied people. The subsequent boundaries between two grades of colour indicate (going from outside to inside) 65%, 80% and 90% Satisfied People. Red is too warm, blue is too cold.

The number of hours a boundary is exceeded is determined and is an indication for the thermal comfort.

This ATG-plot shows for instance that at higher ambient temperatures higher indoor temperatures are still give an acceptable thermal comfort. The method is described in ISSO 74 “thermische behaaglijkheid” (ISSO 2004)and is based on research of Brager and De Dear (De Dear 1997)

In figure 4 an ATG-plot is given for this reference case. All comfort points are within the 80% -region. Figure 5 shows the same plot, but now for the case with a double amount of fresh air. Because the installed heating capacity is the same as in the reference case a number of comfort points is far outside the required 80%-comfort region in winter time.

Figure 6 gives the ATG-plot for the case with a normal ventilation rate but without local cooling. During summer time, comfort points are far outside the required 80%-comfort region.

The influence on energy consumption and on productivity and sick leave has been calculated.

Table 1 Occupancy assumptions

Information about Employees			
	Number of employees	12	
	Occupancy	100	%
	Hourly pay	30	€/hour

Hours work can be done			
			h
	Gross	52 Weeks	2080
	Holidays	8 % of time	166
	Long sick leave	2 % of time	42
			1872
	Short sick leave	5 % of time	

Table 2 gives the results for the case with a doubled amount of fresh air. The consumption for heating increases, for cooling decreases, the fan energy consumption increases and the pumping energy consumption increases (slightly). Expressed in costs: 83 € per person higher energy costs. The table shows also that by this measure the short sick leave and the productivity loss decreases. Expressed in costs: 1039 € per person less productivity loss. Increasing the ventilation rate seems to be very worthwhile. By increasing the local heating capacity these figures can be even better. If you look quickly at the differences between figure 4 and 5, it looks strange that a thermal discomfort during winter can still lead to a higher productivity. If you look in more detail the figure also shows that the indoor temperatures are lower during summertime and closer to 22°C, at which the productivity is maximal.

Table 2 Productivity effects double ventilation

Energy consumption		Old	New	New - Old		Price		Increase of Costs	
		kWh	kWh	**kWh**		€/kWh		€	€/pp
	Heating	10803	17213	6410	x	0.072	=	462	
	Cooling	1485	545	-940	x	0.081	=	-76	
	Electricity consumption - fans	3569	6895	3326	x	0.181	=	602	
	Electricity consumption - pumps	458	514	56	x	0.181	=	10	
	Total							998	83
Loss in Productivity [2])								Labour cost	
		%	%	**%**		hours		costs €/pph	gain €/pp
	Short sick leave at actual Ventilation Rate [3])	1.94	1.07	0.87					
	Loss in Productivity at actual Ventilation Rate [4])	1.48	0.50	0.98					
	Loss in Productivity at actual Indoor Air Quality [4])	0.00	0.00	0.00					
	Loss in Productivity at actual Indoor Air Temperature	1.37	1.27	0.10					
	Total [5]) Minimum			1.85	x	1872	x	30	1039
	Maximum			1.95					

Remarks:
[1]) At fresh air amount of 0,0 l/s per person
[2]) Loss in Productivity withrespect to 'ideal' (ventilation rate infinitive, indoor air temperature 22 °C; indoor air quality 0 PPD)
[3]) Short Sick Leave is only applicable for cases with office gardens or for cases with high a recirculation rate of the return air
[4]) The maximum of these two values is taken. The other value is taken 0,0
[5]) Minimum: PL-Short Time Sick Leave + PL-indoor air quality + Maximum (PL-ventilation,PL-temperature)
Maximum: PL-Short Time Sick Leave + PL-indoor air quality + PL-ventilation + PL-temperature
PL stands for Productivity Loss

Table 3 gives the results for the case with and without local cooling (figure 6) compared to the reference case with normal ventilation and local cooling (figure 4). The energy consumption for heating decreases slightly, for cooling it is zero, the fan energy consumption increases and the pumping energy consumption decreases. In costs: 12 € per person lower energy consumption. Table 3 also shows that this measure increases the productivity loss. In costs: 393 € per person higher productivity loss. Cut down on local cooling seems not to be worthwhile.

Table 3 Productivity effects with and without cooling

Energy consumption	Old kWh	New kWh	New - Old kWh		Price €/kWh		Increase of Costs €	Increase of Costs €/pp
Heating	10803	10794	-9	x	0.072	=	-1	
Cooling	1485	0	-1485	x	0.081	=	-120	
Electricity consumption - fans	3569	3634	65	x	0.181	=	12	
Electricity consumption - pumps	458	284	-174	x	0.181	=	-31	
Total							-141	-12
Loss in Productivity 2)	%	%	%		hours		Labour cost costs €/pph	Labour cost gain €/pp
Short sick leave at actual Ventilation Rate 3)	1.94	1.94	0.00					
Loss in Productivity at actual Ventilation Rate 4)	1.48	1.48	0.00					
Loss in Productivity at actual Indoor Air Quality 4)	0.00	0.00	0.00					
Loss in Productivity at actual Indoor Air Temperature	1.37	2.07	-0.70					
Total 5) Minimum			0.00	x	1872	x	30	-393
Maximum			-0.70					

Remarks:

1) At fresh air amount of 0,0 l/s per person

3) Loss in Productivity withrespect to 'ideal' (ventilation rate infinitive, indoor air temperature 22 °C; indoor air quality 0 PPD)

4) Short Sick Leave is only applicable for cases with office gardens or for cases with high a recirculation rate of the return air

5) The maximum of these two values is taken. The other value is taken 0,0

6) Minimum: PL-Short Time Sick Leave + PL-indoor air quality + Maximum (PL-ventilation,PL-temperature)
Maximum: PL-Short Time Sick Leave + PL-indoor air quality + PL-ventilation + PL-temperature
PL stands for Productivity Loss

More detailed economical calculations (i.e. including investments costs) should lead to definite answers.

MISSING INFORMATION IN THE REHVA GUIDEBOOK

The Rehva guidebook 6 "Indoor climate and productivity in Offices" provides a lot of information. For a number of issues the guidebook is somewhat unclear or additional information is needed in order to implement the information in a Building Performance Simulation program.

Missing information like:

- The guideline gives no information about a reference level. In the method described in this paper an 'ideal' situation was defined at which the productivity is maximal:
    - Indoor air temperature 22 °C
    - Ventilation rate is 'infinite'
    - Indoor air quality corresponds to 0 Percentage People Dissatisfied.

  These 'ideal' circumstances form the reference. The real productivity will always be lower.
- In the Rehva guidebook the terms sick leave and short sick leave are used mixed. A definition of short sick leave is not given. We made up from the reading of the guideline: short sick leave is defined as the sick leave (short – a few days to a week) caused by transfer of infections by the air. This is only a part of the total sick leave.
- Short sick leave is given relatively to the short sick leave at a fresh air amount of 0 l/s p.p. Numbers for the absolute short sick leave at 0 l/s p.p. are not provided.
- The loss of productivity is symmetrical around 22 °C. It is not specified whether this is the air temperature or the comfort temperature.
- The ventilation rate influences not only the indoor air quality but in many cases also the indoor air temperature (depending on the air conditioning system). The given relation between productivity and ventilation rate is a mix of both. It would be better if both relations were separated.
- The relation productivity versus indoor air quality can only be used in the case that the indoor air quality in the starting situation is empirically known (Percentage People Dissatisfied). If this is not the case, assessment is not possible.
- The guideline does not give relations between the PPD and the ventilation rate. Doubling of the ventilation rate will globally decrease the concentration of 'harmful' substances with 50% (in the case 'polution source in the space'); does the PPD (for instance 40%) also decrease with 50% (to 20%)? Is the PPD inversely proportional to the ventilation rate?
- The given empirical relations have been derived at building level. Implications regarding application of these relations at the level of office modules are not given.

The Rehva guideline takes besides productivity and energy consumption also the extra investment costs into account. With these investment costs a good balance between the users (employees) and the indoor climate (building and system) can be made. This is not incorporated in the post-processing program yet.

CONCLUSIONS

In this paper a coupling of indoor climate (simulated by the Dutch Building Performance Simulation program VA114) and productivity is discussed.

Information from Rehva guidebook 6 "Indoor Climate and Productivity in Offices" is used. In this paper it is discussed what aspects from this guide book leave some freedom during implementation. Important is to have a reference level defined in order to be able to compare different design scenarios.

The implementation is not specific for a particular Building Performance Simulation program or specific for the productivity relations from Rehva.

This paper demonstrates the possibilities of such a coupling. The goal was not the derivation of guidelines. Even this very limited study shows that in terms of costs productivity is far more important than energy consumption. Maybe this will eventually lead to a new performance indicator “productivity efficiency”, which could be defined as a quotient of productivity and energy consumption.

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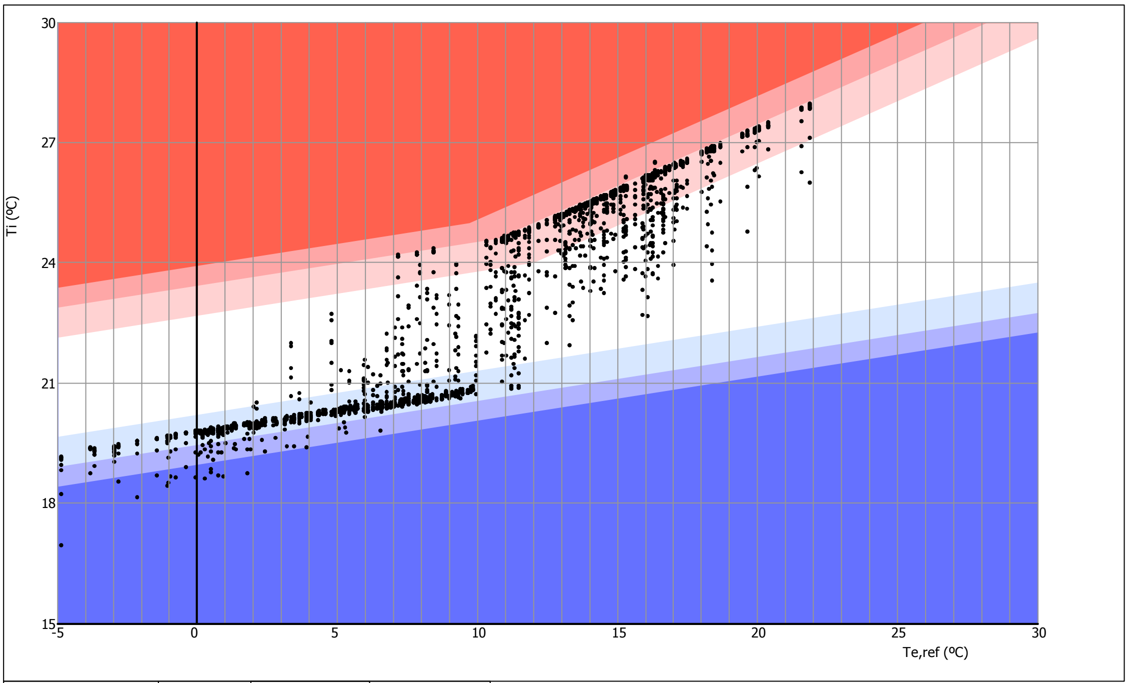
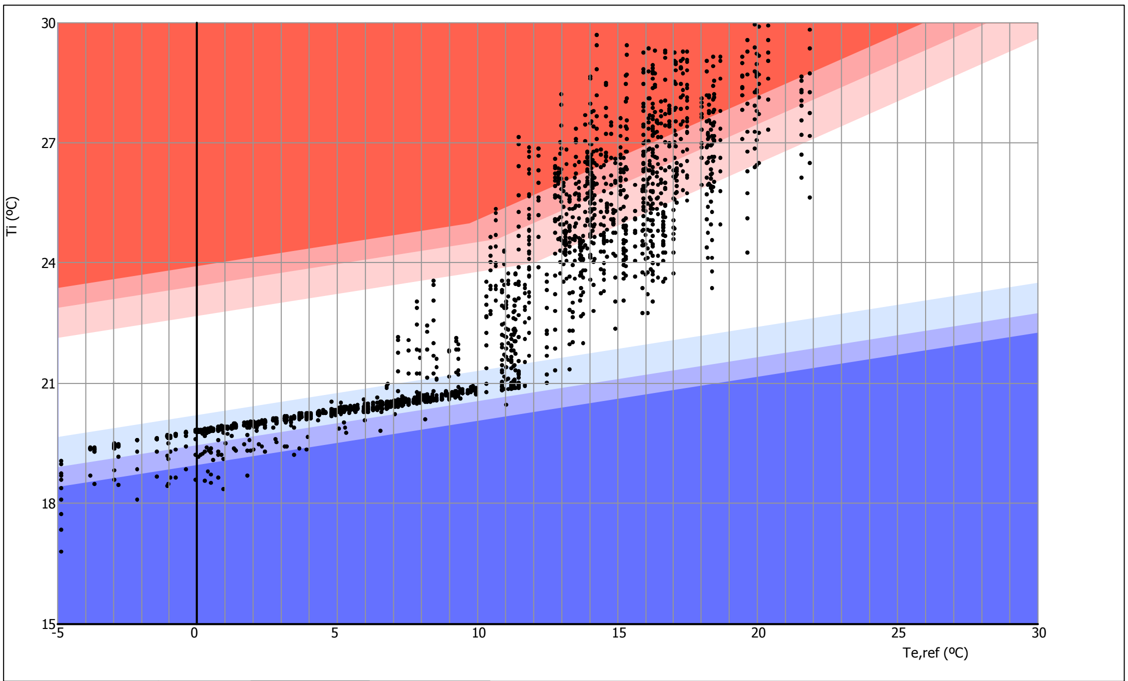


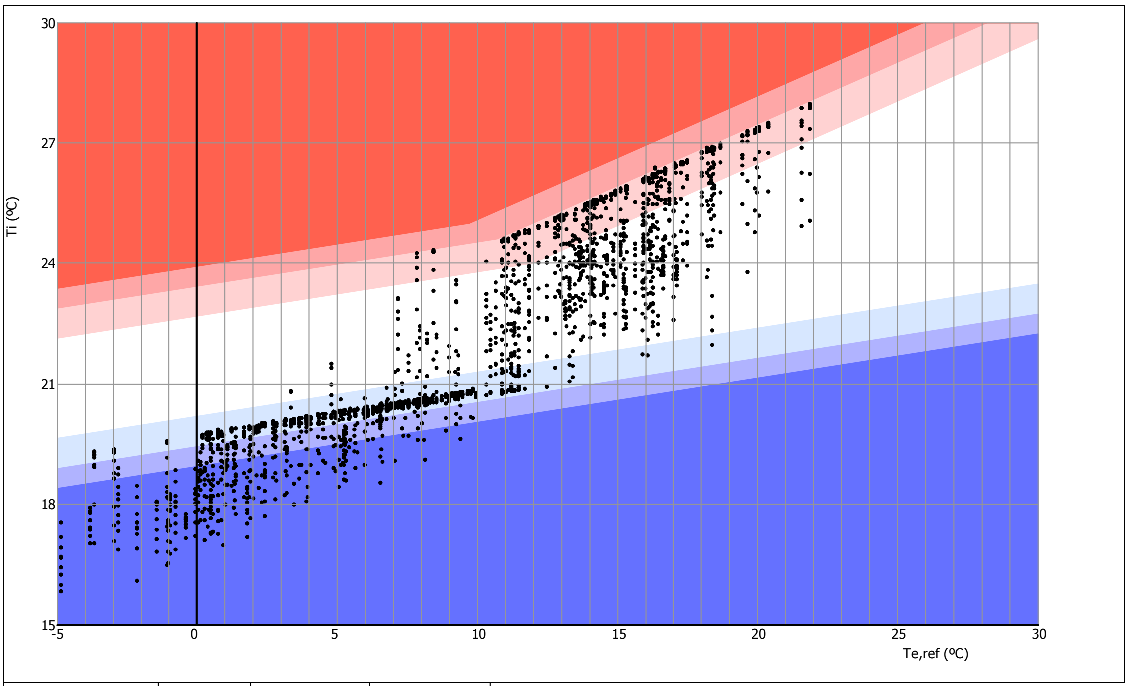
Period: Utilization period only		Too cold	Too warm
Temperature: Comfort temperature	Class A: 90%	1331	873
	Class B: 80%	59	4
Type of building: Alpha	Class C: 65%	20	0

Figure 4: ATG-graph for the reference case (normal amount of fresh air, local cooling present)



Period: Utilization period only		Too cold	Too warm
Temperature: Comfort temperature	Class A: 90%	1479	711
	Class B: 80%	82	470
Type of building: Alpha	Class C: 65%	27	295

Figure 5: ATG-graph for the case with double ventilation rate



Period: Utilization period only		Too cold	Too warm
Temperature: Comfort temperature	Class A: 90%	1461	510
	Class B: 80%	472	0
Type of building: Alpha	Class C: 65%	319	0

Figure 6: ATG-graph for the case without local cooling